Forest Carbon Study: The Impact of Alternative Land-Use Scenarios on Terrestrial Carbon Storage and Sequestration in Massachusetts

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Prepared by:

For Massachusetts Executive Office of Energy and Environmental Affairs

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Glossary

Acronyms

DCR – Massachusetts Department of Conservation and Recreation.

DOER – Massachusetts Department of Energy Resources.

EEA – Massachusetts Executive Office of Energy and Environmental Affairs.

GHG – greenhouse gas such as carbon dioxide (CO_2) that trap heat and cause average global air temperature to rise and long-term weather patterns to change.

LSR – Land Sector Report, a technical report produced in 2020 as part of the Massachusetts 2050 Decarbonization Roadmap Study

NWL – Natural and working lands, including forests, croplands, grasslands, freshwater and coastal wetlands, and urban and parks, forests, other open space.

$MMTCO_2e$ – Million metric tons of carbon dioxide equivalent. This is a measure of how much greenhouse gas is emitted into or removed from the atmosphere. An emission of 1 $MMTCO_2e$ is equivalent to burning 112,523,911 gallons of gasoline.

Key Terms

Carbon pool – a particular reservoir of carbon; usually a component of an ecosystem (e.g., forest soil carbon, wetland dead organic matter).

Carbon sequestration – the process of removing CO_2 from the atmosphere and storing it in a carbon pool, i.e., the removal of CO_2 via photosynthesis and storage in NWL ecosystem carbon pools.

Carbon sink – a source of net carbon sequestration i.e. a system that removes and stores more atmospheric carbon than it emits.

Carbon stock or storage – the sum of all carbon pools in a defined area and time span. **GHG flux** – the rate of greenhouse gas release into (+) or removal from (-) the atmosphere from a particular source or sink per unit of land area (e.g., tons of CO_2e per hectare per year).

Greenfield (solar, building) development – construction of buildings, solar photovoltaic facilities, and/or other hard infrastructure on undeveloped natural and working lands (NWL).

Hectare – a unit of area equal to 10,000 square meters or 2.47 acres.

Land Sector – the GHG emissions sector that covers GHG emissions and removals from natural and working lands (NWL), also known as Land Use, Land Use Change, and Forestry.

Mass timber – a family of engineered wood products formed by layering and bonding pieces of wood together and that can be used as structural elements in large buildings as an alternative to materials like steel or concrete.

Net emissions – the sum of all GHG fluxes within a defined period and scope (e.g., net forest land emissions).

Silviculture – the art and science of controlling the establishment, growth, composition, health, and quality of forests to meet the diverse needs and values of landowners and society such as wildlife habitat, timber, water resources, restoration, and recreation on a sustainable basis. (Source: US Forest Service).

Wood utilization – how we produce and use wood, i.e. the process of turning in forest wood/timber into wood products for human consumption (e.g., lumber, paper, Mass timber) and following these products through its end of life (e.g., disposal in landfill).

1. Executive Summary

1.1 Overview and Key Findings

The Commonwealth's Global Warming Solutions Act (GWSA), as amended in 2021, requires Massachusetts to achieve net zero greenhouse gas emissions (GHG) in 2050. The net zero requirement allows for up to 15% of 1990-level emissions to be "offset" by GHG removals, which includes carbon sequestration from natural and working lands (i.e., the land sector; for the purposes of this report, references to the land sector excludes agriculture). In the U.S., the land sector is net sink for GHGs, removing 14.5% of gross emissions (EPA 2023). In Massachusetts, the land sector currently removes approximately 11% of Massachusetts' gross annual GHG emissions, with forested land being the primary carbon sink, but the magnitude of future carbon sequestration and emissions will be affected by many natural processes and human activities that could make the land sector a source or a sink of atmospheric carbon. The purpose of this report (hereafter, the Forest Carbon Study), commissioned by the Massachusetts Executive Office of Energy and Environmental Affairs (EEA), is to quantify the effects of forest growth, natural disturbances, deforestation, reforestation, and active forest management, such as timber harvesting, on the state's land sector carbon budget, as well as assess the potential influence of these factors on forest composition, structure, and adaptation and resilience to climate change. While the results inform the directionality of forest-related policies particularly for their role in helping the Commonwealth achieve net zero emissions in and beyond 2050, the study did not model specific policies under consideration by EEA.

The study uses state-of-the-art modeling of alternative land-use scenarios and **finds that limiting forest loss to development, ensuring post-disturbance forest recovery, and reducing the emissions from timber harvest are the actions with the greatest potential to protect forest carbon stocks and support ongoing long-term net carbon removal.** More specifically:

- **The state's forests are expected to continue serving as a long-term net sink of atmospheric carbon,** removing on the order of 200-300 MMTCO_2e from 2020 to 2100. This is the equivalent of forests removing 3 to 4.5 years of Massachusetts' current statewide gross GHG emissions over the next 80 years. **However, this forest carbon sink is vulnerable to natural and human disturbances.**
- **Hurricanes pose the largest single threat to forest carbon, with high disturbance scenarios resulting in periods of weaker sequestration rates (~1-2 MMTCO_2e per year) or even net emissions** to the atmosphere (up to ~5 MMTCO_2e per year). Net sequestration rates are projected to recover within ten years, **assuming impacted forests are not converted to other land uses.**
- Under scenarios **with minimal natural disturbances, forest carbon sequestration rates in Massachusetts should persist at current rates of approximately 5 to 6 MMTCO_2e per year through mid-century**, after which they are expected to decline to less than 1 MMTCO_2e per year by 2100 due to forest aging.
- **If recent trends in land use continue to 2050, the emissions from development and harvesting would reduce net sequestration by 20% (averaging 1.2 MMTCO_2e per year) relative to a hypothetical scenario with forest growth but no land conversion, harvesting, or major disturbances.** Permanent forest loss for building and solar development would account for approximately half of this difference. The

remaining half is attributable to timber harvesting (accounting for carbon storage in wood products and landfills).

- **Less land-consumptive building and solar development practices could reduce carbon emissions from land conversion by up to two-thirds by 2050, while still achieving the Commonwealth's projected solar capacity needs**. A continuation of recent trends in building development is expected to result in 14.0 $MMTCO_2e$ of emissions between 2020 and 2050 (0.5 $MMTCO_2e$ per year), while solar development that follows siting patterns from 2010-2020 and grows to meet anticipated needs is expected to result in up to 13.5 $MMTCO_2e$ (0.5 $MMTCO_2e$ per year) by 2050. **More sprawl-oriented building development patterns could increase these emissions by up to 50%.** These potential changes in emissions would be even greater if accounting for the impacts of development on soil carbon, which was not examined in this study.
- Reforestation and tree-planting **could modestly increase carbon sequestration rates in 2050 by a maximum of 0.6 $MMTCO_2e$ per year or a more achievable 0.1 to 0.3 $MMTCO_2e$ per year.** Total carbon removal potential from expanding forest and tree cover is relatively small due to limited suitable land, with an upper bound of 6 $MMTCO_2e$ by 2050 and 29 $MMTCO_2e$ by 2100.
- **Forest management presents complex tradeoffs between mid- and late-century cumulative carbon removal, sequestration rates, and other forest attributes and benefits, with effects contingent on disturbance levels.** Management emphasizing local wood production could reduce in-state carbon sequestration through 2050 relative to a continuation of recent management practices, up to ~30 $MMTCO_2e$ total through 2050 (averaging 1 $MMTCO_2e$ annually) while producing more than 52 $MMTCO_2e$ of additional wood products in the same time frame. The differences in annual sequestration become less significant by 2100, particularly with low disturbance levels.
- **Utilizing greater proportions of wood generated by harvesting, disturbances, and land clearing into durable products can reduce associated emissions, though these effects are only substantial with high levels of disturbance and salvage harvesting.** With minimal disturbances, these emissions reductions amount to ~5 $MMTCO_2e$ by 2050 and ~13 $MMTCO_2e$ by 2100. With high disturbance levels and salvage harvesting, these emissions could be reduced by 65 to 80 $MMTCO_2e$ by 2050 and 90 to 135 $MMTCO_2e$ by 2100.
- **Active forest management, including continuing conventional and climate-oriented silvicultural practices, can improve key indicators of forest resilience to climate change.** These practices, particularly the modeled climate-oriented prescriptions, help improve landscape-scale species and structural diversity values and increase regeneration opportunities for keystone tree species relative to reserves and untreated areas.

These key findings and the study approach are elaborated below (1.2 Summary of Methodology and 1.3 Summary of Results), including additional context and explanation of the rationale, nuances, and assumptions of the findings.

1.2 Summary of Methodology

The analyses presented here were conducted using a suite of spatially interactive ecosystem and land-use models. These models have been calibrated with and validated against empirical data and the results published previously in dozens of peer-reviewed articles. The model simulations are initialized using US Geological Survey land-cover maps and US Forest Service maps of forest tree species composition. Simulated ecosystem processes include species-specific tree establishment, growth, competition, senescence and disturbance-related mortality, and decomposition. Forest management is simulated using alternative silvicultural techniques, and the harvested carbon is tracked using a carbon allocation model. A cellular automata model simulates patterns of forest loss and gain. GHG fluxes from non-forest terrestrial carbon is estimated using a spatially explicit bookkeeping model, which utilizes static carbon density estimates for multiple land covers derived from an extensive literature review. Despite their important role as carbon stores, the study does not estimate stocks or fluxes of soil carbon; this is because of the high level of landscape heterogeneity in soil carbon and the scientific uncertainty regarding the belowground impacts of land use. In addition to investigating terrestrial carbon dynamics, this study also analyzes the outputs from the forest ecosystem model to assess outcomes for non-carbon forest attributes, including indicators of forests' adaptative capacity and resilience to climate change.

The study analyzes eight integrated land use and disturbance scenarios that bracket the upper and lower bounds of plausible forest management, ecological disturbances, and land cover changes. High levels of disturbance and high rates of development-driven land conversion were paired to represent a high-emission future while low levels of disturbance and rates of land conversion were paired to represent a low-emission future. The study also includes a counterfactual scenario—for comparative purposes only—that simulates continued forest growth without any major disturbances or future land use—i.e., no harvesting, reforestation, hurricanes, insect outbreaks, or building or solar development. All the scenarios are purely illustrative, intended for learning, and do not represent specific policies under consideration by the Commonwealth. Co-designed by the research team, staff at EEA, the Massachusetts Department of Conservation and Recreation (DCR), and a group of experts and stakeholders, the Integrated Scenarios envision four alternative future forest management regimes, each occurring under a high- and a low-emissions regime (Table E1). The scenarios explore forest management options that are frequently proposed to advance climate and conservation goals, including: improved "climate-oriented" silviculture practices, establishment of large forest reserves, and increased harvesting to meet more of Massachusetts' wood demand locally. These practices are overlaid onto dynamic landscapes with and without hurricanes, and differing levels of other ecological disturbances (such as insect outbreaks and blowdowns), deforestation for building and greenfield solar,[1] and reforestation and tree-planting. Simulations of forest dynamics and management scenarios span from 2020 to 2100, while simulations that include land cover change only span 2020 to 2050.

In addition to the eight Integrated Scenarios, the study includes a set of Focused Scenarios. These scenarios focus on specific drivers of forest land cover change and analyze their effects on future terrestrial carbon. These include scenarios depicting alternative rates and spatial distributions of new building and solar development, as well as alternative reforestation and tree planting scenarios. Similar to the Integrated Scenarios, we use counterfactual scenarios that omit key drivers to provide reference-cases against which land-use scenarios can be compared to isolate individual effects. For example, we simulated a counterfactual scenario that includes forest growth and minor natural disturbances but omits all land use (development or harvesting)

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[1] Greenfield Solar refers to solar installation built in previously undeveloped land cover (i.e, forest, croplands, or grass/shrub)

and major disturbances (hurricanes or insect outbreaks), allowing us to determine the impacts of these drivers on carbon storage and sequestration.

Table E1. *Eight Integrated disturbance and land-use scenarios codesigned with EEA, DCR, and a group of experts and informed stakeholders.*

		Forest Management Regimes			
		Recent Trends	*Reserves Emphasis*	*Local Wood Emphasis*	*Combined Emphasis*
Forest Harvest:		Current forestry practices and harvesting levels	Climate-oriented forestry, current harvest levels	Climate-oriented forestry, increased harvest levels to meet 20% of MA wood consumption	Climate-oriented forestry, increased harvest levels to meet 15% of MA wood consumption
Forest Reserves:		Current forest reserves	Expand forest reserves to 33% of forest land	Current forest reserves	Expand forest reserves to 20% of forest land
Land Cover Change & Ecological Disturbance Regimes	*High Ecological Disturbance* *Uncoordinated Land Cover Change*	**Recent Trends Harvest + High Disturbance/ Development Scenario**	**Reserves Emphasis + High Disturbance/ Development Scenario**	**Local Wood + High Disturbance/ Development Scenario**	**Combined Emphasis + High Disturbance/ Development Scenario**
	Low Ecological Disturbances *Coordinated Land Cover Change*	**Recent Trends Harvest + Low Disturbance/ Development Scenario**	**Reserve Emphasis + Low Disturbance/ Development Scenario**	**Local Wood + Low Disturbance / Development Scenario**	**Combined Emphasis + Low Disturbance/ Development Scenario**
Wood Utilization:		Two variants for all scenarios: (a) *Recent trends wood utilization* (b) *Improved wood utilization*			

1.3 Summary of Results

The counterfactual scenario with no harvesting, development, or major disturbances estimates that the theoretical biophysical potential for Massachusetts' existing forests to sequester and store additional carbon between 2020 and 2050 in the absence of land conversion, harvesting, and major disturbances is 177.0 MMTCO$_2$e (Figure E1). Since disturbances and land use will occur, this estimate is useful insofar as it defines the land system's theoretical maximum carbon uptake without major shifts in the system. When we include a continuation of recent trends in land use (i.e., development and timber harvesting) and non-hurricane disturbances, net carbon sequestration is 147.8 MMTCO$_2$e between 2020 and 2050 (not shown in Figure E1 and not including reforestation or tree-planting).[2] The difference between the counterfactual and the recent trends in land use is 29.2 MMTCO$_2$e by 2050—or an average of 1.0 MMTCO$_2$e per year—and represents the additional theoretical net carbon sequestration. This constitutes a relatively modest potential increase over the current level of NWL annual carbon sequestration,

[2] Due to the inherent uncertainty in human development patterns, we did not simulate land cover change beyond 2050 and therefore cannot estimate impacts of a continuation of recent land use trends to 2100.

not nearly enough to fully offset the 14 $MMTCO_2e$ of allowable residual emissions in 2050 under the Massachusetts Net Zero emissions limit (EEA 2022).

The counterfactual scenario estimates that, without any major disturbances or harvesting, the rate of forest carbon sequestration would begin to decline after ~2060 and eventually reach a dynamic equilibrium by 2100 (Figure E2). The decline reflects the forests' reduced rate of growth and increased rate of tree mortality associated with the aging of the forest—i.e., increasing ecosystem respiration relative to gross primary production—and the absence of any new tree planting (Figure E2). The timing of this inflection in carbon accrual is based on our best understanding of the relevant ecological and physiological processes; however, estimates of all ecological dynamics occurring further into the future and further outside of observed forest conditions should be interpreted with greater skepticism.

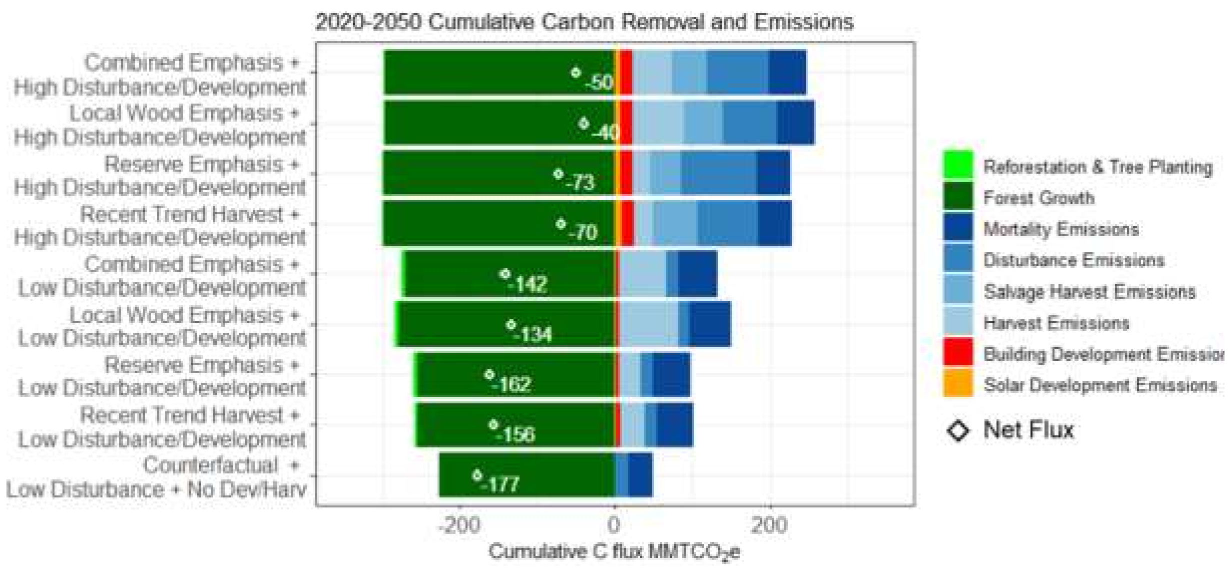

Figure E1. *Cumulative carbon removals and emissions from 2020 and 2050 for the eight Integrated Scenarios and a counterfactual scenario (no development or harvesting). Green bars to the left represent cumulative removals (i.e. sequestration), bars to the right represent cumulative emissions, and white diamonds show the cumulative net flux to the atmosphere. Carbon transfers between all simulated pools are accounted for, including in-forest live and dead wood and harvest residues, new forest and tree live wood, and out-of-forest wood products in use and in landfills. Note that the "High Disturbance" scenarios include a major hurricane in 2038 and much higher levels of building and solar development, which alter the trajectory of carbon accumulation.*

Of all the influences on land sector carbon that we examine, hurricanes are the single factor that poses the greatest risk (Figure E1). We use the simplifying assumption that the timing and storm track of future hurricanes would mirror the hurricanes observed during the 20th century. To account for anticipated effects of warming oceans on hurricane strength, we increased hurricane wind speeds by 8% above what was observed and applied them to the 21st century,100 years after they occurred—e.g., the Great Hurricane of 1938 was simulated to occur in 2038 and be 8% stronger (see year 2038 in Figure E2). Our analysis shows that these storms have the potential to flip the land sector from a sink to a source of atmospheric carbon in the short term (5-10 years post hurricane) (Figure E3). Salvage logging can mitigate some of the carbon losses associated with major disturbances, but salvage logging also can have ecological consequences and logistical challenges that should be considered. The hurricane-induced flip from carbon sink to source is temporary with recovery to a net carbon sink generally occurring within 10 years post hurricane so long as the forests are allowed to recover and continue to grow. However, the timing of future hurricanes has a large impact on the contribution of the land sector to the state's 2050 Net Zero emissions goal. For example, the impact of the modeled 2038 hurricane on net land sector emissions would shift if such a hurricane were to happen earlier or later.

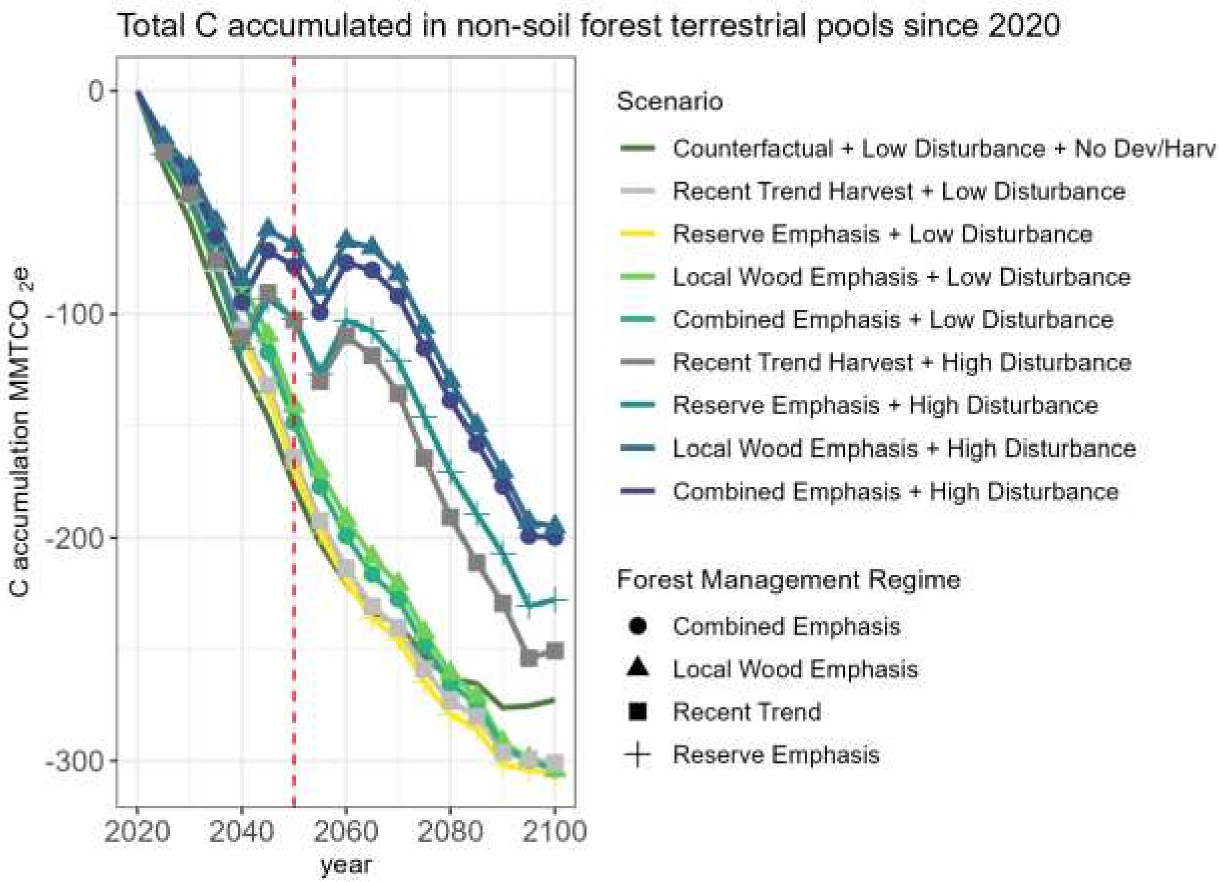

Figure E2. *Total accumulation of carbon from 2020 to 2100 in all non-soil carbon pools (including in-forest live and dead wood and harvest residues, new forest and tree live wood, and out-of-forest wood products in use and in landfills). Negative values indicate cumulative carbon removal from the atmosphere (i.e. cumulative negative emissions). For consistency across time, these results do not include the effects of development-driven land conversion because development was not simulated past 2050. Note that the "High Disturbance" scenarios include major hurricanes in 2038 and 2054. Red dash line indicates 2050, Massachusetts' net zero compliance year.*

Some of the Integrated Scenarios envision large increases in the area designated as forest reserves, characterized by passive management with no resource extraction or other vegetation manipulation. Currently, less than four percent of the state's forests are in a designated reserve. We explored the consequences of increasing reserve area to 20% and 33% of forest land. The location of new reserves was informed by the experts and stakeholders who weighed the importance of multiple environmental criteria, such as landscape connectivity, current carbon density, and species composition. The scenario with low disturbances and the largest increase in reserves resulted in the highest level of carbon stored among all scenarios considered (Figure E1); however, the -161.7 MMTCO_2e in carbon accumulation compared to the scenario portraying a continuation of recent trends resulted in a quite modest difference (5.51 MMTCO_2e; just 3.5% higher by 2050). The small differences are because the Reserve Scenarios include an influential assumption that statewide annual harvest volume would remain unchanged by the new reserves; only the locations of harvests would change to accommodate the reserve area. By maintaining statewide harvest volumes, the scenarios attempt to control for the potential that harvesting "leaks" out-of-state beyond the baseline level observed in recent trends. The effect of this assumption is that Reserve Scenarios increase carbon density (amount of carbon stored per unit area) inside newly reserved areas and decrease carbon densities outside of reserves, with small net increase of statewide terrestrial carbon stocks. Any increase in reserve area to increase forest carbon stocks would need to consider how new reserves will affect harvest behavior outside of the reserves, in and outside of the Commonwealth. If leakage of harvesting is less than 100% – i.e., if new reserves result in less total harvest volume with a concurrent decrease in wood product demand – then these scenarios would underestimate the potential for forest reserves to increase carbon stores.

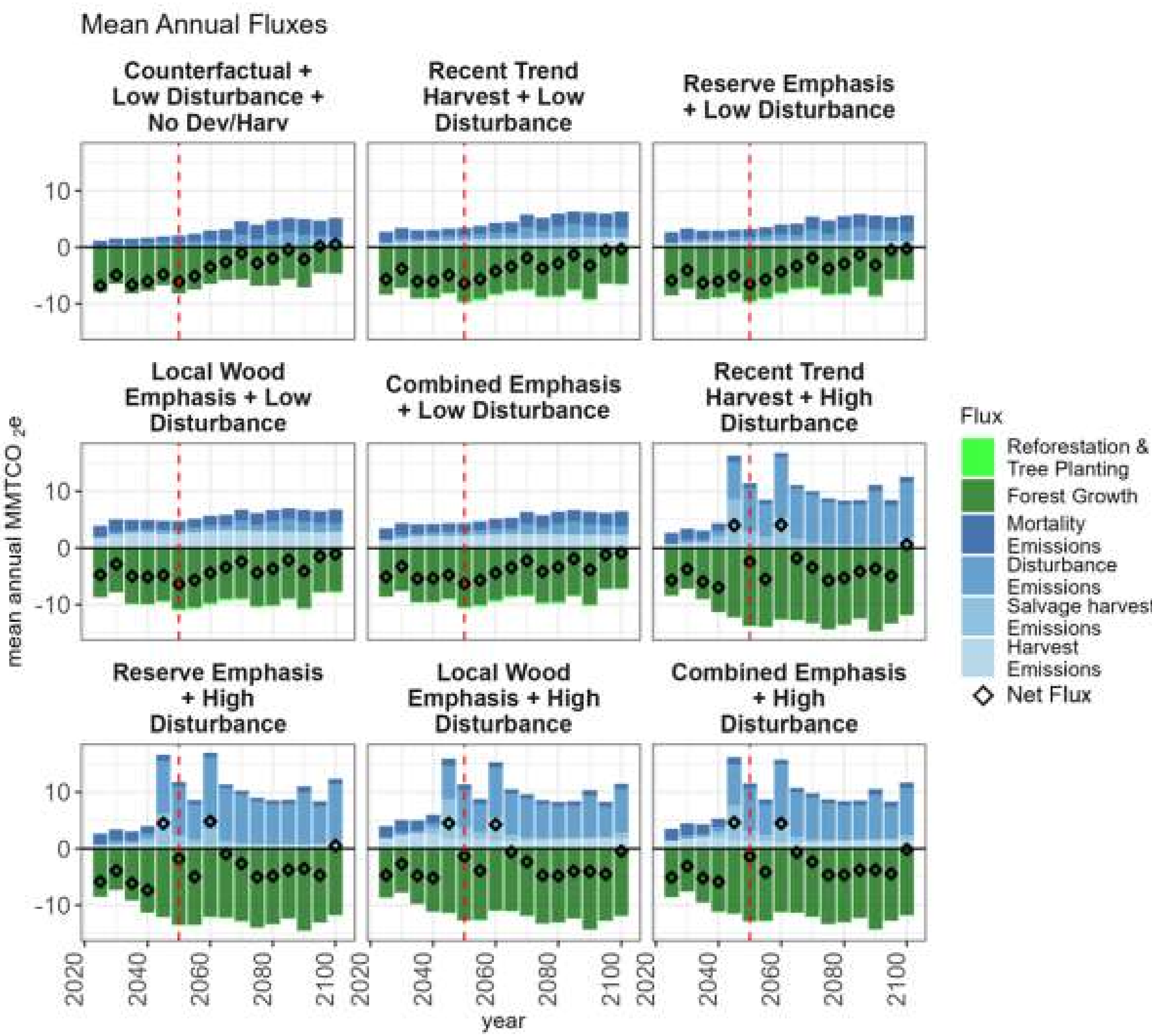

Figure E3. *Mean annual carbon fluxes to the atmosphere over 5-year timesteps from 2020 to 2100 for a counterfactual scenario (no development or harvesting) and the eight Integrated Scenarios. Green bars below zero represent carbon removals (i.e. sequestration), blue bars above zero represent emissions, and black diamonds show the net flux to the atmosphere (i.e. the annualized difference between sequestration and emissions in a timestep). For consistency across time, these results do not include the effects of development-driven land conversion because development was not simulated past 2050. Note that the "High Disturbance" scenarios include major hurricanes in 2038 and 2054. Red dash line indicates 2050, Massachusetts' net zero compliance year.*

While some stakeholders emphasized the need for more reserves, others suggested that Massachusetts' residents should take greater responsibility for their consumption of wood products by harvesting more wood locally, which could lower lifecycle emissions and create economic demand for commercial forestry in Massachusetts versus conversion of working forests to another land use. Currently, harvest volumes in the state account for approximately 7% of the volume of wood products it consumes annually, and only 5% of the lumber.[3] The Local Wood scenario increases annual harvest volume to ~20% of current consumption levels. Even at this higher rate of harvest, Massachusetts forest remain a net carbon sink throughout the century. In the near term (i.e. until at least 2050), increasing harvesting to this level would reduce cumulative carbon storage relative to a Recent Trends scenario by 22.2 to 30.2 $MMTCO_2e$, for low and high disturbance regimes respectively. This focus on timber production results in approximately 63.4 and 52.8 $MMTCO_2e$ of additional wood products by 2050, for low and high disturbance regimes respectively. After approximately 75 years, carbon accrual in the Local Wood scenario is similar to Recent Trends with low disturbances but lags behind with high disturbances through the end of the century. Our analyses also show that carbon emissions associated with commercial forestry can be reduced by improving wood utilization. We simulated improvements such as a shift to producing and using more long-term products (e.g., mass timber or wood insulation) and more efficient logging and milling practices. These practices have the potential to reduce harvesting emissions by 5%-14% by 2050 and 10%-12% by 2100.

Active forest management, where it was simulated, was found to have a strong influence on forest composition, structure, and successional trajectories. Well-planned and executed silviculture can help ensure the continuity of structural conditions across the landscape over time, including young and old forest habitat and facilitate the adaptability of natural communities to a changing climate. Modeling of practices designed to reflect a recent trends-based harvest regime resulted in a more even distribution of forest structural conditions and patch sizes, increased regeneration and recruitment of keystone tree species in natural communities and helped perpetuate those communities over time relative to untreated areas. Scenarios designed to reflect climate-oriented silvicultural practices included additional elements, such as stand improvement and other early interventions in stand development (not normally practiced in Massachusetts due to cost); adjustments to the patch size, intensity, and frequency of harvests; and ecologically informed, ecoregion-specific species removal and retention priorities. Modeling results from areas receiving climate-oriented silvicultural treatments tended to have enhanced species and structural richness and diversity, climate adaptability, and increased values of some indicators of resilience relative to areas treated with recent trends-based silviculture and areas reserved from harvest.

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[3] Note that these estimates refer to the equivalent wood and fiber volume, not the actual source of the wood used in-state.

In addition to the effects of natural disturbances and forest management, the study examines alternative scenarios of forest loss and other land cover changes due to new building and solar energy development. By 2050, more compact building development patterns could reduce emissions and foregone sequestration from 14.0 to 4.7 $MMTCO_2e$, assuming greenfield development at one third the rate observed from 2000-2020. In contrast, sprawl-oriented building development could lead to emissions of 28.0 $MMTCO_2e$, assuming greenfield development rates twice those observed from 2000-2020. Emissions and forgone sequestration associated with new greenfield solar development to achieve the Commonwealth's projected solar capacity needs in 2050 (i.e., approximately 27 GW_{AC}, depending on the availability of other sources of clean energy generation and the level of demand management that can be achieved) range from 3.4 to 13.6 $MMTCO_2e$, depending on whether siting patterns follow conservation-based criteria or those observed from 2010 to 2020, and on assumptions about the level of solar production capacity per unit land area.[4] Actual emissions and emissions reductions can be expected to be greater when the effects of development on soil carbon are included.

Reforestation and tree planting are frequently recommended natural climate solutions, but face several challenges, including land availability constraints, slow initial rates of carbon accrual, and ensuring tree survivorship in the face of climate change, herbivory, invasive species, and other stressors. We examined the biophysical potential for reforestation and tree planting but did not assess social or economic constraints on implementation. We focused on reforestation in riparian areas, marginal agricultural lands, and other open space, as well as tree planting in developed areas, including parks and rights-of-way. In sum, active reforestation and tree planting are expected to have relatively small total carbon removal benefits, of 1.3 to 6.4 $MMTCO_2e$ by 2050, and 5.3 to 29.5 $MMTCO_2e$ by 2100, with >90% of that derived from reforestation. Sequestration rates would initially increase only modestly, though could reach 0.1 to 0.6 $MMTCO_2e$ by 2050 before slowly declining later in the century. These ranges represent baseline and additional reforestation and tree planting occurring on 10% to 50% of suitable land by 2050.

Overall, the study estimates that the land sector will remain a significant carbon sink for many decades, irrespective of the land-use or disturbance scenario considered. However, the magnitude of the sink varies significantly among scenarios. Hurricanes are the largest single driver of variation—average net carbon sequestration in 2050 is approximately 58.0 $MMTCO_2e$ among the scenarios that include hurricanes and 148.4 $MMTCO_2e$ among scenarios without hurricanes (Figure E1). The impact of land use on the state's terrestrial carbon sink is smaller but also significant and, importantly, can be shaped by policies. Assuming similar natural disturbances and land cover change, the difference between the least and most impactful forest management scenarios spans more than 25 $MMTCO_2e$ by 2050, reflecting an increase harvesting to supply more of the state's wood demand locally, though this range shrinks to 5 $MMTCO_2e$ by 2100. The building development scenarios' impacts on carbon sequestration and storage span a range of 23.2 $MMTCO_2e$ by 2050, the solar development scenarios span a range of just over 10 $MMTCO_2e$, and reforestation scenarios span a range of 4.95 $MMTCO_2e$ by 2050 and 23.4 $MMTCO_2e$ by 2100. This study's detailed findings can help policymakers in the Commonwealth understand the potential role of the land sector in achieving the state's climate mitigation goals under alternative disturbance, land-use, and management scenarios.

[4] Energy production from solar photovoltaic sources in lieu of fossil fuel-based sources does contribute to emissions reduction in the power sector, which is not examined in this report.