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TOPICAL REVIEW

Context and future directions for integrating forest carbon into sub-national climate mitigation planning in the RGGI region of the U.S.

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Abstract

International frameworks for climate mitigation that build from national actions have been developed under the United National Framework Convention on Climate Change and advanced most recently through the Paris Climate Agreement. In parallel, sub-national actors have set greenhouse gas (GHG) reduction goals and developed corresponding climate mitigation plans. Within the U.S., multi-state coalitions have formed to facilitate coordination of related science and policy. Here, utilizing the forum of the NASA Carbon Monitoring System's Multi-State Working Group, we collected and reviewed climate mitigation plans for 11 states in the Regional Greenhouse Gas Initiative region of the Eastern U.S. For each state we reviewed the (a) policy framework for climate mitigation, (b) GHG reduction goals, (c) inclusion of forest activities in the state's climate action plan, (d) existing science used to quantify forest carbon estimates, and (e) stated needs for forest carbon monitoring science. Across the region, we found important differences across all categories. While all states have GHG reduction goals and framework documents, nearly three-quarters of all states do not account for forest carbon when planning GHG reductions; those that do account for forest carbon use a variety of scientific methods with various levels of planning detail and guidance. We suggest that a common, efficient, standardized forest carbon monitoring system would provide important benefits to states and the geographic region as a whole. In addition, such a system would allow for more effective transparency and progress tracking to support state, national, and international efforts to increase ambition and implementation of climate goals.

1. Introduction

The Paris Climate Agreement represents the latest global effort to curb greenhouse gas (GHG) emissions with cross-sector planning and bottom-up leadership (Castro 2020). Since the Paris Agreement entered into force in 2016, more than 187 countries around the world have worked to detail their respective contributions towards limiting global warming to 1.5 °C and 2 °C by 2050 and 2100. For more than 100 countries, such pledges have included a range of mitigation options to reduce net emissions from the land use, land use change and forest (LULUCF) sector (Forsell *et al* 2016). Much of the methodological guidance for these estimates has come from the Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories (IPCC 2008, 2019).

In the United States, sub-national actors (states, cities, businesses, and others) are driving climate change mitigation through policies and actions that collectively generate significant contributions to GHG reductions at a more local scale (Hultman *et al* 2019, Hultman *et al* 2020). For nearly three decades, many state governments have not only implemented policies affecting their electricity, land, and transportation systems (to name a few), but have also set explicit GHG emissions reduction targets via legislation or gubernatorial directives. In doing this they have also charged state agencies and commissions to develop robust climate action plans to achieve these goals, and have developed monitoring strategies to quantify progress. To be most successful, a common scientific framework for estimating and comparing emissions reductions should be employed (Hsu *et al* 2019). This is particularly true for accurately measuring the contributions of land-based carbon to climate mitigation. Previous climate planning efforts have a mixed record of LULUCF inclusion due to the complexities of available techniques, a lack of available data, limited technical capacity, and budget constraints, among other issues (e.g. Ellison *et al* 2013, Krug 2018).

The first generation of climate action plans at the state and municipal levels across the eastern U.S. arose in the late 1990s in response to growing global climate awareness and action. These plans were largely focused on providing a review of the issue of climate change or targeting a more select set of GHG emissions (Wheeler 2008). In 2001, the New England Governors and Eastern Canadian Premiers began coordinating climate action planning through adoption of a Regional Climate Change Action Plan to reduce GHG emissions to 1990 levels by 2010 (NEGECP 2001, 2017). Jurisdictional level inventories of existing emissions have frequently served as the basis for subsequent climate planning, establishing a benchmark against which proposed GHG emissions reduction measures could be assessed (Kennedy *et al* 2010).

Many climate mitigation efforts in the U.S. have involved reducing emissions from sources tracked by the U.S. Environmental Protection Agency (USEPA) in fulfillment of national commitments under the United Nations Framework Convention on Climate Change. The USEPA assembles an annual, national GHG inventory by compiling information from various sectors that emit and sequester GHGs, including the electric power, transportation, industrial, residential, commercial, waste, agriculture, and forestry sectors (USEPA 2018). USEPA has also developed a State Inventory Tool (SIT) to provide a common method for states to calculate direct and indirect GHG emissions for state-specific GHG reduction accounting. Within the SIT, states have the option to utilize pre-loaded default data compiled by the USEPA in consultation with other federal agencies like the U.S. Department of Agriculture (USDA) Forest Service (USFS) or apply their own state-specific data (USEPA 2019a). Although the SIT does have a module for tracking emissions from LULUCF (USEPA 2020), many state governments opt not to use this module in their GHG inventories. Given the potentially large LULUCF contribution to state-level carbon budgets, many states have expressed an interest in better quantifying the role of forests within their GHG inventories and climate action plans. Specifically, there is interest in scientific approaches that go beyond the current form of the SIT and offer more consistent, accurate, and regularly updated geo-referenced data.

In 2017, a coalition of U.S. states formed the United States Climate Alliance (USCA) to accelerate and implement policies that advance the goals of the Paris Agreement (USCA 2020a). The 25 member states and territories of the USCA represent 55% of the U.S. population and collectively manage an economy larger than all other countries in the world except China and the United States (USCA 2019). The USCA has focused on a suite of GHG emissions sectors including ‘Natural and Working Lands’ (NWL) (USCA 2019). In 2018, 17 member states signed onto the ‘NWL Challenge,’ which commits states to improving their inventory methods for land-based carbon flux, undertaking actions to support a collective alliance-wide goal to maintain NWL as a net carbon sink, and integrating priority actions and pathways into state GHG mitigation plans by 2020 (USCA 2020b).

Regional coalitions have also paved the way for GHG reduction programs and trading schemes. Notably, ten USCA members are also part of the Regional Greenhouse Gas Initiative (RGGI), which includes eleven Northeastern and Mid-Atlantic states (figure 1). As the first mandated cap-and-trade program in the United States, RGGI has capped CO_2

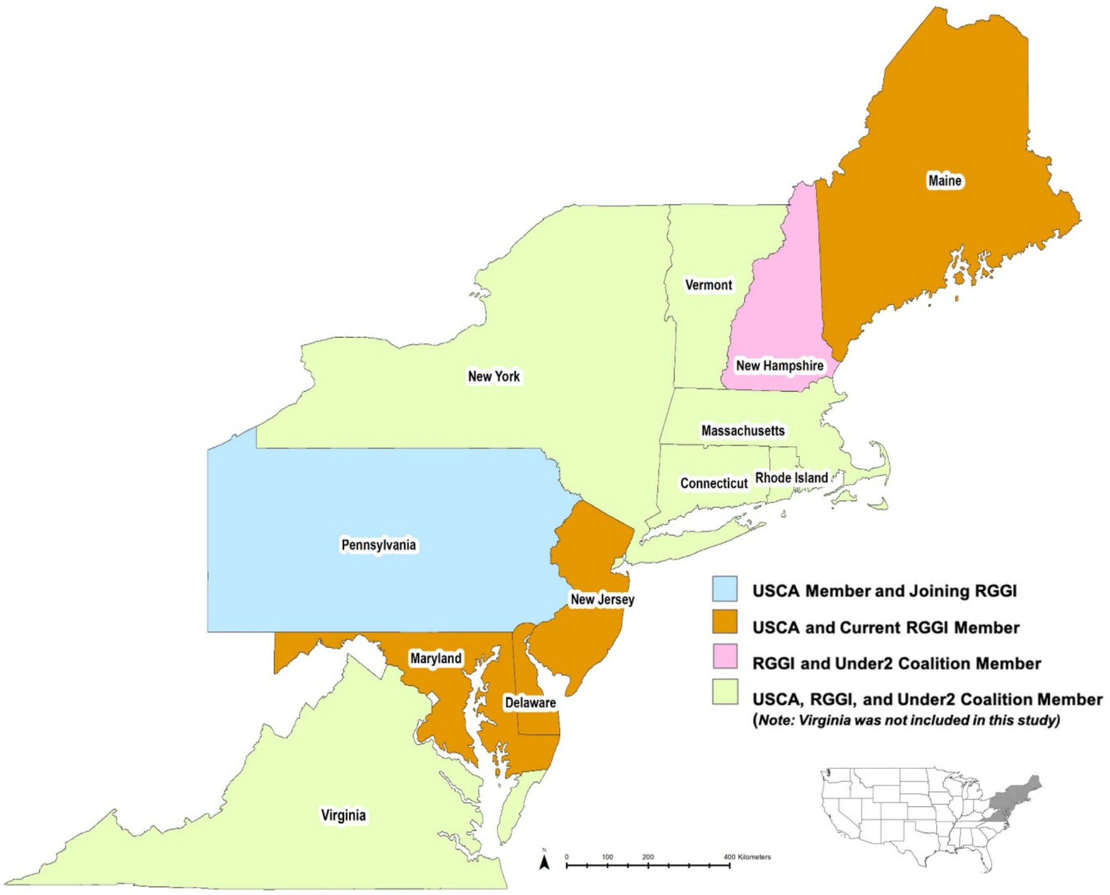

Figure 1. All states in the region belong to one or more multi-state coalitions, including the United States Climate Alliance (USCA), Regional Greenhouse Gas Initiative (RGGI) and the Under 2 Coalition of state and regional governments. Note that while Virginia has recently become a member of RGGI, it was not included in this study.

emissions from electric power plants and auctioned CO_2 allowances. Established in 2009, RGGI has a 10 year track record of coordinating GHG emissions reductions across the region, with other USCA members like Pennsylvania targeting participating in RGGI by 2022. Although land-based carbon is not traded on the RGGI market, a small number of offset allowances, 3.3% of a power plant's CO_2 compliance obligation, attempt to provide limited flexibility in achieving reduction goals via reforestation, improvements in forest management, and other approved sequestration projects (RGGI 2020). Most member states have reinvested auction proceeds in state programs promoting energy efficiency, renewable energy and a broader clean energy economy. However, depending on state law, there is potential to utilize a portion of auction proceeds to advance carbon sequestration on NWLs that is complimentary to regional USCA goals and individual state legislative agendas (e.g. NJDEP 2020).

In this paper, we review the climate mitigation plans for 11 states in the RGGI region (all current RGGI members except Virginia, plus Pennsylvania) and identify opportunities for enhancing action through more systematic development and application of new forest carbon monitoring strategies. We focus particularly on the degree to which forest activities are included in this planning and the primary science approaches used to quantify expected forest carbon sequestration. After synthesizing state efforts, we discuss options and next steps toward a shared carbon monitoring system for the region.

2. Methods

2.1. Data collection

Data and other inputs for this study were collected from governmental documents published by or before 30 April 2020, including legislation, executive orders, climate mitigation plans and appendices, and state GHG inventories. To identify, supplement, and discuss these documents, a series of teleconferences were jointly hosted by the University of Maryland, College Park and the NASA Carbon Monitoring System (CMS) Applications Team between March 2019 and February 2020. All 11 states in the region were invited to join all three Multi-State Working Group (MSWG) calls. Summary reports and presentation slides were shared with participants and published on NASA's CMS website (Hurtt *et al* 2014, NASA CMS 2020).

2.2. Data categories for state-level review

Presentations and published documents were reviewed for information relative to seven overarching data categories including: (a) legislation and executive orders, (b) established GHG reduction goals, (c) climate planning documents, (d) forest activities mentioned within the planning documents, (e) the extent to which forest activities count towards state GHG reduction goals, (f) existing science (tools, methods, approaches) used to generate forest carbon estimates, and (g) identified needs for forest carbon monitoring science (figure 2).

First, we reviewed executive orders and legislation that mandated GHG emissions goals, the creation of GHG inventories, climate change committees and/or climate action plans. Many states have additional climate change legislation focused on clean energy, energy efficiency, electric vehicles, and other related topics. We did not include this legislation within the scope of our review, unless it mandated the development of the state's primary climate mitigation planning document (e.g. in the case of Vermont). Additionally, while many states have separate forestry legislation, we did not include it in our review unless the provisions were included in the core climate mitigation policy (e.g. in the case of New York). We also reported active GHG emissions reduction goals for each state. Most GHG targets were outlined within the executive orders or legislation, or otherwise summarized in state presentations during the MSWG calls.

Next, we reviewed core state climate action plans and climate mitigation framework documents. We defined Climate Action Plans as the primary governmental document outlining specific strategies for measuring, planning, and reducing GHG emissions and related climate change impacts. Some states have not published a climate action plan but have published either guidance documents that outline general recommendations for mitigation or interim reports that signal ongoing efforts to reduce GHG emissions via existing policies. We included these documents as part of a state's core climate mitigation framework. While separate forestry legislation and planning can result in co-benefits for climate mitigation, one goal of this work was to explicitly evaluate how well forest carbon goals and GHG reduction planning are currently integrated.

We reviewed the current version of each planning document for specific climate mitigation activities, options and/or terms that included forests or trees. Relevant forest activities were broadly classified as forestry management practices, reforestation/afforestation, urban tree planting and retention, and forest conservation, including preventing deforestation. As these terms are not often defined within the plans themselves, all activities have been categorized according to the term used by the plans' authors. Each state has utilized a range of stakeholder engagement processes to define, scope, and select forest activities with respect to the laws and policies of that state. For example, many states work with stakeholder advisory groups or a policy task force, with diverse membership across the private and public sectors, to generate and evaluate activity recommendations.

We subsequently recorded the data sources used to generate forest carbon estimates within the state's GHG inventory or associated with the forestry activities outlined in the plan. Finally, we documented the forest carbon science needs of states as provided to us via the NASA CMS presentations, including key tools (e.g. lidar and modeling) and monitoring requirements (e.g. annual, consistent, reliable, etc).

2.3. Data classification for regional analysis

We synthesized the state-level analysis across the 11-state region to identify emergent patterns across all seven data categories. Given the range of data collected across three data categories (plans, inclusion, and current science), we further classified states with three additional variables (figure 2). Specifically, we evaluated the (a) type of planning guidance for forest activities provided within the climate mitigation framework document, (b) level of inclusion of forest activities towards the state GHG emission reduction target, and (c) the dominant source of forest carbon science used to estimate emissions and planned sequestration outcomes.

First, we classified framework documents according to the type of planning guidance provided for identified forest activities. One class of documents provides general activity recommendations, often originating in gubernatorial committees or working groups, but does not provide specific activities or quantitative carbon estimates ('general recommendations'). A second class recommends specific best practices or options for agency consideration but does not represent planned activity ('range of options'). These documents often highlight ongoing efforts or qualitatively describe areas for expanded GHG reductions but stop short of quantitative estimates. The third class details specific planned activities that state agencies and partners will implement and the expected carbon benefits of these activities ('planned activities').

Next, we evaluated whether identified forest activities counted towards the state's GHG reduction goals. Under the first category, states do not include forest activities towards achieving GHG goals ('not included'). There could be multiple reasons for this, including a lack of reliable data or concerns about inappropriately using a forest carbon sink to offset growing GHG emissions across other sectors. Under a second category, states do not include forest activities towards GHG reductions, but describe forests as an important component of overall climate mitigation within their plans and track net forest emissions separately within their

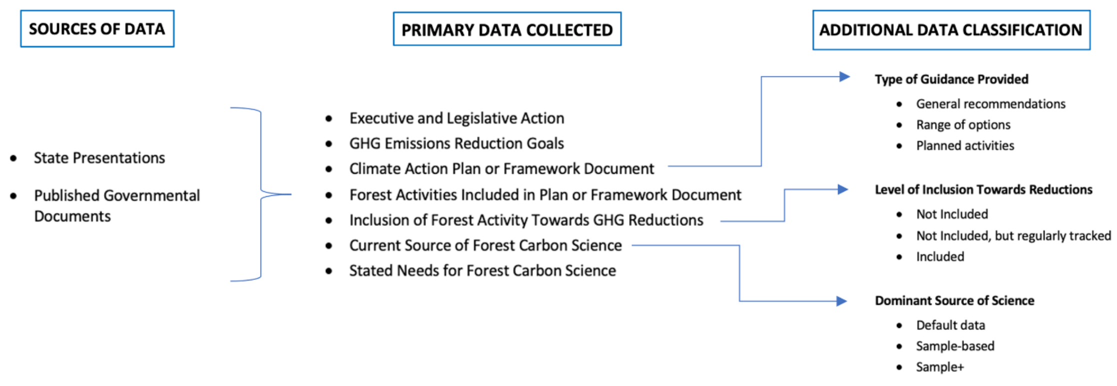

Figure 2. Flow chart of methodological steps for data collection, review, and additional classification of three data categories.

inventories, in an appendix or supplementary analysis ('not included, tracked'). States utilizing this strategy may also share similar concerns to those in the first category but remain interested in reporting the magnitude of their carbon sink relative to total GHG emissions. Under the final category, the state does include forest activities towards overall GHG reductions ('included'), but inventories only emissions and sequestration terms for which they have data.

Third, we categorized states by the dominant source of scientific information used to generate forest carbon estimates related to forest activities in their plans and inventories. The first category includes states using default data directly from SIT, static literature values or regional rather than state-specific sample-based estimates ('default'). A second category involves methods and approaches which utilize USFS Forest Inventory and Analysis (FIA) field data or state-level data summarized in USFS technical reports ('sample'). A third category uses USFS FIA data in addition to either high-resolution modeling or the state's own continuous forest inventory ('sample+').

2.4. Forest carbon science and policy relationship analysis

Finally, we evaluated whether a state's primary scientific strategy was related to higher levels of inclusion in climate policy. We compared the type of guidance provided in the plans (in ascending order of detail provided) to the dominant science used to estimate forest carbon emissions and sequestration (in ascending order of methodological sophistication). We separated and assigned scores to planning documents providing general recommendations for further agency development (score of 1), from those outlining a suite of options and best-practices (score of 2) and those with specific planned activities (score of 3). Regarding the primary scientific strategy, we separated and assigned scores to default approaches (score of 1), from sample-based approaches (score of 2), and sample+ approaches (score of 3).

3. Results

Data collected and reviewed for each state across all seven data categories have been summarized in table 1 and described in more detail by state in the supplementary file (available online at stacks.iop.org/ERL/16/063001/mmedia). Regional patterns have been summarized below by data category.

3.1. Executive and legislative mandates

All 11 states in the RGGI region have climate mitigation policy mandates, directed by either the executive branch or their respective legislative bodies. The earliest statute comes from the State of Maine in 2003, with new and updated mandates continuing across the region for the following 17 years. Eight states in the region have had their original climate mitigation goals established via state legislation, with the remaining three (New Hampshire, Delaware and New York) by Gubernatorial Executive Order, with Delaware's and New Hampshire's goals recommended by a Governor-established Cabinet Committee and Task Force, respectively. Three states (Maine, New York, and Pennsylvania) have had their climate mitigation goals strengthened or expanded over time via the other branch of government (either state legislature or governor). Delaware's goals were functionally updated in 2017 upon joining the U.S. Climate Alliance.

3.2. GHG reduction goals

All states have GHG reduction goals (figures 3 and 4). Five of eleven states in the region have short-term goals established for the year 2020, with the remaining states setting their first set of reductions for the years 2025 (Pennsylvania and New Hampshire), 2028 (Vermont), and 2030 (New York and Delaware), respectively. Two states, Maryland and Rhode Island, appeared to meet their 2020 reduction goals early, as identified via their respective 2017 and 2016 inventories, and have moved forward with medium-term reduction planning. Short-term

Table 1. Summary of state-level data collected across seven data categories.

State	Executive and legislative action (year)	GHG emissions reduction goals	Climate action plan or framework document (year)	Forest activities included in plan or framework document	Inclusion of forest activities towards GHG reductions	Current source of forest carbon science	Stated needs for forest carbon science
Connecticut	CT Global Warming Solutions Act (2008) Executive Order 46 (2015) An Act Concerning Climate Change Planning and Resiliency (2018) Executive Order 3 (2019)	10% below 1990 levels by 2020 45% below 2001 levels by 2030, 80% below 2001 levels by 2050	Building a Low Carbon Future Recommendations Report (2018)	– Forestry management practices – Urban tree planting – Afforestation on marginal agricultural land	Not included towards GHG reductions	Literature values	More reliable LULUCF data
Delaware	Executive Order 41 (2013)	26%–28% below 2005 by 2030	Climate Framework for Delaware (2014) *Plan under development*	– Forest conservation and restoration (slow loss) – Restoring riparian buffers	Not included, but separately tracked within inventory	USEPA SIT/GHG Inventory USFS FIA data DE Forest Service analysis NASA CMS products	Annual carbon flux monitoring
Maine	Act to provide leadership in addressing the threat of climate change (2003) Executive Order 10 (2019)	10% below 1990 levels by 2020 45% below 1990 levels by 2030, On track to achieve 80% by 2040 80% below 1990 levels by 2050, and carbon neutrality by 2045	Climate Action Plan (2004, update forthcoming 2020)	– Forestry management practices – Forest conservation (prevent conversion)	Not included, but separately tracked within inventory	USFS FIA data USFS ForGATE tool	Integration of remote sensing; improved forest monitoring; and integrated modeling

Table 1. (Continued.)

State	Executive and legislative action (year)	GHG emissions reduction goals	Climate action plan or framework document (year)	Forest activities included in plan or framework document	Inclusion of forest activities towards GHG reductions	Current source of forest carbon science	Stated needs for forest carbon science
Maryland	Greenhouse Gas Emissions Reduction Act (2009, updated 2016)	25% below 2006 levels by 2020[a] 40% below 2006 levels by 2030 80%–95% below 1990 levels by 2050[b]	Greenhouse Gas Emissions Reduction Act Plan (2013, 2015, draft update 2019)	– Forestry management practices – Reforestation/ afforestation – Urban tree planting – Forest conservation (avoided emissions) – Planting forested stream buffers – Preservation/restoration of forested areas on Ag land	Included towards GHG reductions	NASA-CMS products USFS FIA data NASA-USDA-DOE study MDNR RAS field study MD Forest Service analysis USEPA SIT WRI-TNC-USCA analysis	Annual carbon flux monitoring
Massachusetts	The Global Warming Solutions Act (2008)	25% below 1990 levels by 2020, At least 80% below 1990 levels by 2050, and net zero emissions by 2050 2030 reduction goal under development	Clean Energy and Climate Plan for 2020 (2010, 2015) *2030 plan under development*	– Urban tree planting and retention	Not included towards GHG reductions, but tracking in inventory appendix	Harvard Forest ecosystem modeling MassGIS analysis State continuous forest field inventory USFS FIA data, USFS reports Literature values	Enhanced lidar capabilities to improve estimates of urban tree/forest carbon
New Hampshire	Executive Order 3 (2007)	20% below 1990 levels by 2025, 80% below 1990 levels by 2050	Climate Action Plan (2009)	– Forestry management practices – Forest conservation (prevent conversion)	Not included, but separately tracked within inventory	USEPA SIT USFS FIA data Hubbard Brook and Bartlett Forest field studies Integrated forest model	Potential valuation of forest ecosystem services, inclusive of forest carbon estimates

(Continued.)

Table 1. (Continued.)

State	Executive and legislative action (year)	GHG emissions reduction goals	Climate action plan or framework document (year)	Forest activities included in plan or framework document	Inclusion of forest activities towards GHG reductions	Current source of forest carbon science	Stated needs for forest carbon science
New Jersey	Global Warming Response Act (2007, updated 2019) Clean Energy Act (2018) Executive Order 89 (2019) Executive Order 100 (2020)	At or below 1990 levels by 2020, 80% below 2006 levels by 2050	Global Warming Response Act Limit Recommendations Report (2009, update forthcoming 2020)	– Forest conservation (no net forest loss)	Included towards GHG reductions	USEPA SIT NCASI Carbon Online Tool USFS FIA data Default IPCC estimates	Improved estimates of land carbon flux; soil carbon data; and improved monitoring, measurement and verification methods
New York	Executive Order 24 (2009) Executive Order 166 (2017) Climate Leadership and Community Protection Act (2019)	40% below 1990 levels by 2030, 85% below 1990 levels by 2050, and net zero emissions by 2050 or as soon as practicable	Forest Action Plan (2020) Climate Scoping Plan under development	– Forest management practices – Forest restoration – Urban forestry – Reforestation – Forest conservation (conserve open space, no forest loss)	Not included, but tracked separately as part of forest sector planning	USFS technical report USFS FIA data	High-resolution estimates of forest carbon; biogenic emissions
Pennsylvania	Pennsylvania Climate Change Act (2008) Executive Order 1 (2019)	26% below 2005 levels by 2025, 80% below 2005 levels by 2050	Climate Change Action Plan (2009, 2015, 2019)	– Forest conservation – Reforestation – Urban tree canopy expansion	Included towards GHG reductions	USFS technical reports State continuous forest field inventory NASA CMS products	Carbon sequestration potential; canopy change detection for monitoring; and lidar applications

Table 1. (Continued.)

State	Executive and legislative action (year)	GHG emissions reduction goals	Climate action plan or framework document (year)	Forest activities included in plan or framework document	Inclusion of forest activities towards GHG reductions	Current source of forest carbon science	Stated needs for forest carbon science
Rhode Island	Resilient Rhode Island Act (2014)	10% below 1990 levels by 2020[a], 45% below 1990 levels by 2035, 80% below 1990 levels by 2050	Rhode Island Greenhouse Gas Emissions Reduction Plan (2016)	– Forestry management practices – Urban tree planting	Not included towards GHG reductions	USFS Forest Carbon Budget model Grey literature values	More reliable land carbon data; and fully understand mitigation potential of urban forests
Vermont	Vermont Statue, 30 V.S.A. § 578 (2005) Under2MOU (2015)	50% below 1990 levels by 2028, 80%–95% below 1990 levels by 2050	Comprehensive Energy Plan (2016)	– Forestry management practices	Not included towards GHG reductions, but biogenic emissions tracked	USFS FIA data	Annual flux monitoring; and high resolution/higher confidence forest carbon sequestration estimates

[a] Goal already achieved.

[b] Goal included in plan as an ambition but not formal goal.

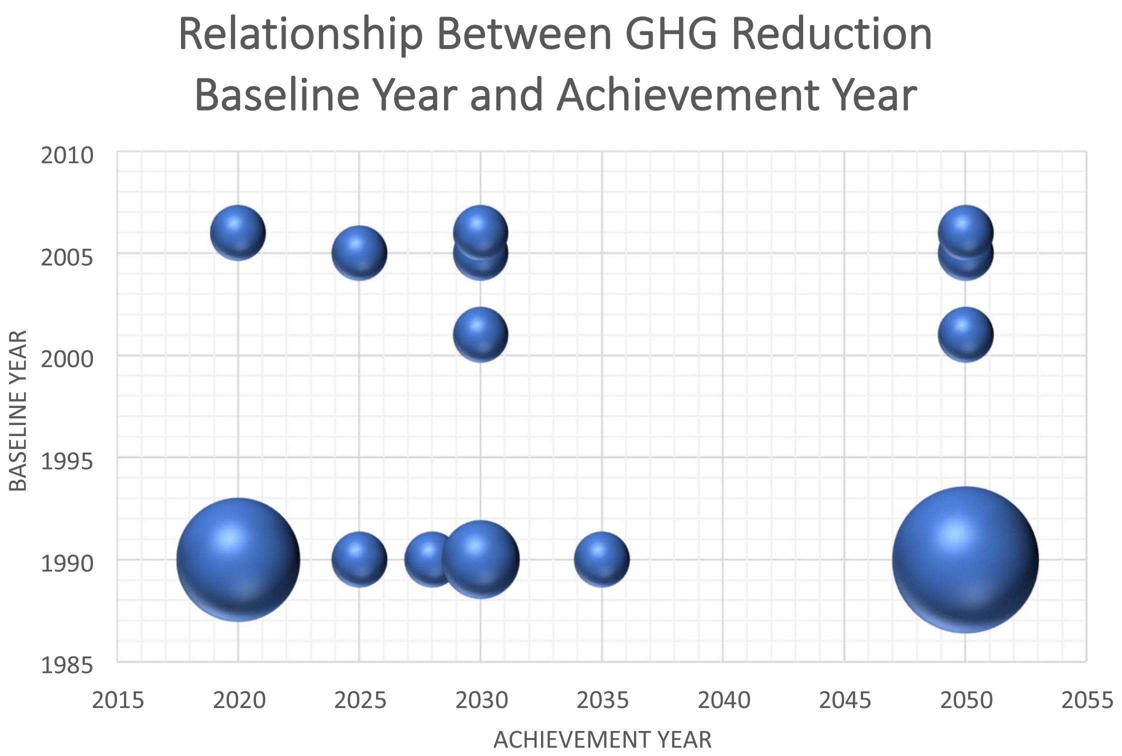

Figure 3. Baseline year of emissions and corresponding emission reduction achievement year for state greenhouse gas (GHG) targets across the RGGI region. The larger the circle, the more frequent the combination of baseline and achievement years. There are a variety of combinations. The most frequent goal sets are short-term goals for 2020 GHG reductions relative to 1990 emission levels (five states), and long-term goals for 2050 reductions relative to 1990 levels (seven)

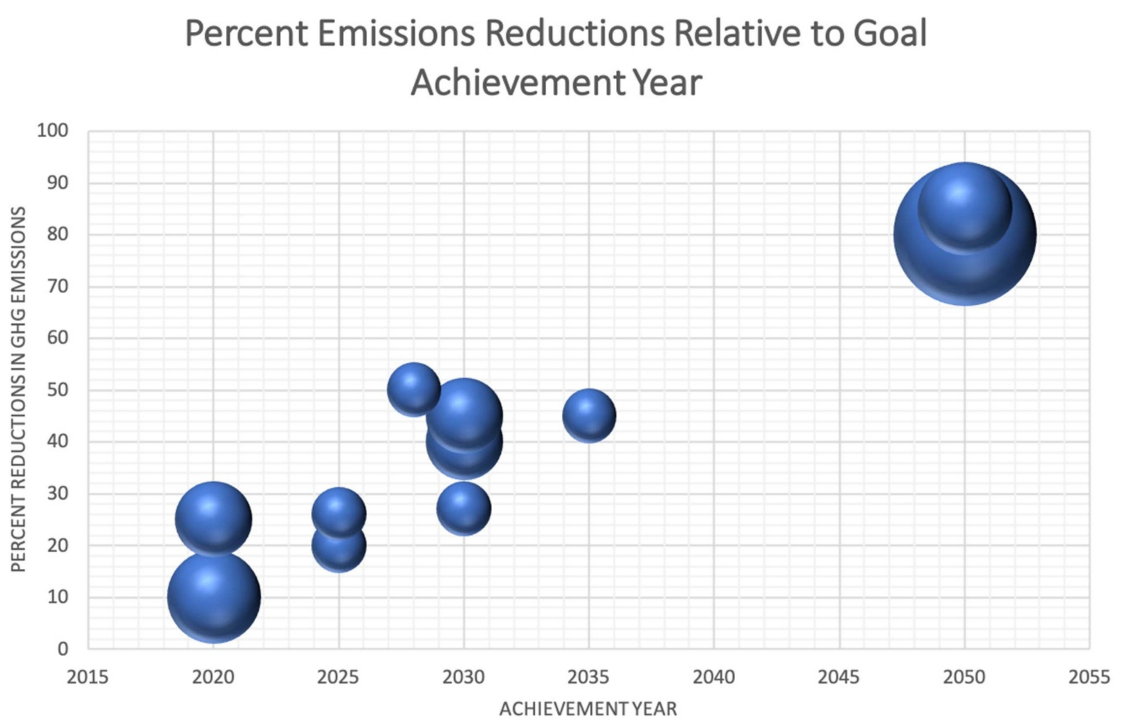

Figure 4. Emission reduction targets paired with their intended achievement year for states across the RGGI region. The larger the circle, the more frequent the combination of pledged greenhouse gas (GHG) emissions reductions by year. The most common goal set is 80% GHG emissions reductions by 2050 (seven states), with three more states pledging between 80% and 95% emissions reductions by 2050. Even with common pledges, the actual amount of emissions reduction will vary considerably by state depending, in part, on the target's baseline year (see figure 3).

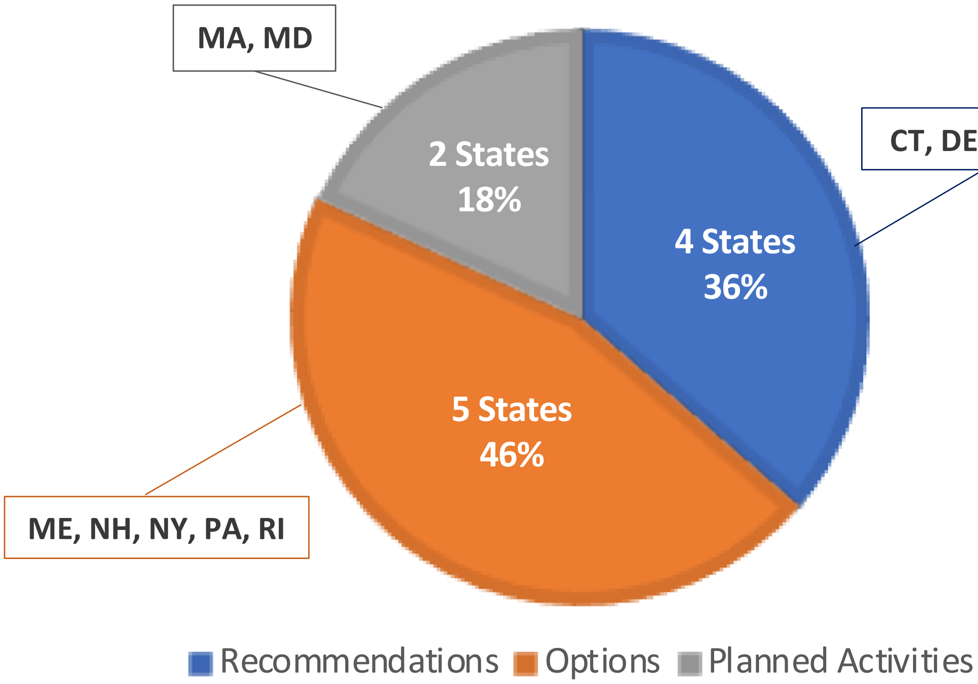

Figure 5. Level of planning guidance for forest activities provided across existing climate mitigation framework documents, including documents providing general and qualitative recommendations for agency consideration (Recommendations); documents providing an array of best-practices and options for potential adoption by agencies (Options); and documents outlining specific, quantitative activities, for planned implementation by agencies (Planned Activities).

reduction goals range between 10% and 50% relative to a ranging baseline year. Seven states have established short-term goals relative to 1990 emissions levels, with three other states at 2005 (Pennsylvania and Delaware) and 2006 (Maryland) levels, respectively. One state, New Jersey, has set short-term reductions for 'at or below' 1990 levels.

Ten states in the region (excepting Delaware) have established long-term planning goals to be met by 2050. Of those states, seven have pledged to reduce emissions by 80% from a ranging baseline year, with Massachusetts specifying a long-term reduction goal of reducing emissions by 'at least' 80%. One state, New York, has pledged an 85% reduction by 2050. Two states, Vermont and Maryland, mention in their plans the long-term goal of reducing carbon emissions between 80% and 95% below 1990 levels in accordance with IPCC recommendations for developed countries, but only Vermont has signed the Under2MOU formally committing to this goal.

Three states (Connecticut, Maine and Rhode Island) have separate medium-term GHG reduction goals, falling between their established short and long-term goals. All three of these states have established 45% reductions by either 2030 or 2035. Maine has also established an interim emissions goal, such that the state must show they are on track to achieve their long-term 2050 reduction goal by 2040. One additional state, Massachusetts, is currently in the process of setting a 2030 emissions limit, with expected completion by December 2020. The vast majority of states in the region (81%) have the same baseline year (1990) for all of their established GHG goals, but two states (Connecticut and New Jersey) have more recent baselines for their medium to long term goals (2001 and 2006, respectively). Finally, three states have established additional climate neutrality goals. Massachusetts and New York have pledged to achieve net-zero greenhouse emissions by 2050, and Maine by 2045.

3.3. Climate action plans and type of guidance

All 11 states have a guiding climate action plan or framework document for GHG reductions. State agencies are on the frontlines of policy implementation, sometimes with the support of external climate change committees, and often with directives to achieve ambitious emission reductions across all sectors of the economy relative to established goals. Seven states have final Climate Action Plans, and two (Connecticut and New Jersey) have interim reports relative to the status of planned or accomplished activities. One state, New York, currently utilizes its Forest Action Plan, rather than a Climate Action Plan, to outline planned forest management and restoration strategies with co-benefits for climate change. One state, Delaware, is in the process of developing a Climate Action Plan, moving beyond the initial guidance provided in their 2014 framework report.

The type of planning guidance provided for forest activities varies across climate mitigation documents (figure 5). Only two of eleven states (Maryland

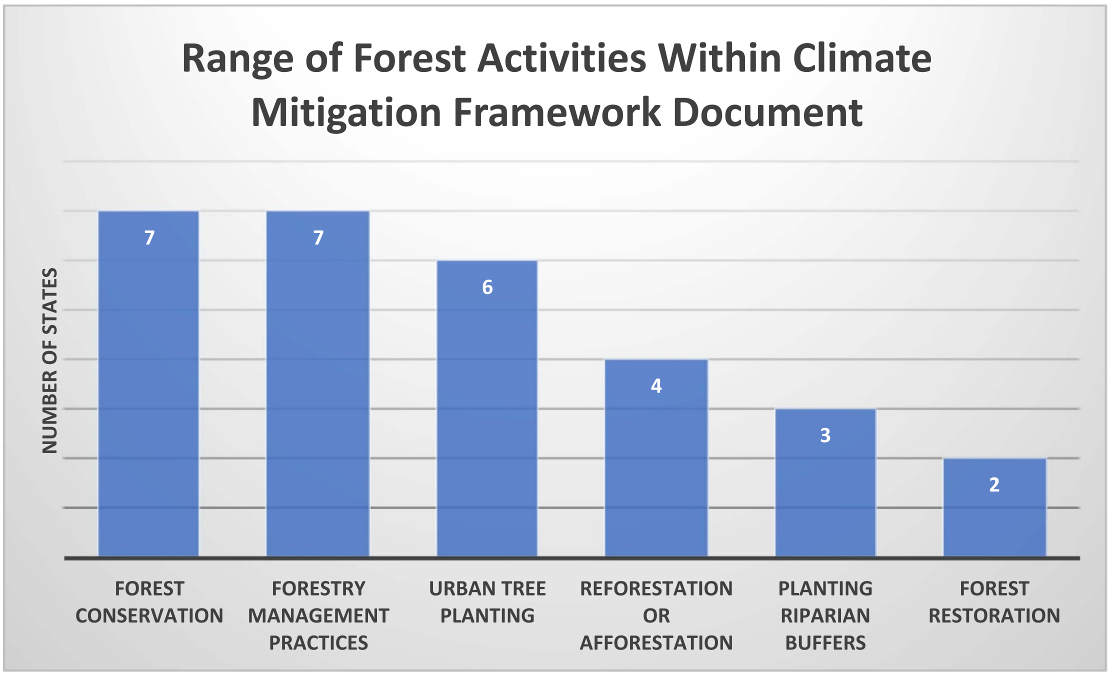

Figure 6. Range and frequency of activities, options and/or terms within the state's climate mitigation framework document that included forests or trees.

and Massachusetts) have outlined specific planned activities that are to be directly implemented by state agencies, with corresponding quantitative estimates relative to expected carbon sequestration goals (see supplemental sections 4 and 5). Five states provide a range of activity options for potential agency implementation, sometimes with corresponding carbon sequestration estimates, but more often qualitatively outlined with a high level of detail. The four remaining states (Connecticut, Delaware, New Jersey, and Vermont) provide general overarching and qualitative recommendations for improving the carbon sink and direct the agencies to further design or determine further activity options or details.

3.4. Forest activities within framework documents

Within each state's climate mitigation document, there are a range of forest activities mentioned in the context of planning. All framework documents mention the importance of trees and forests in the context of maintaining or increasing the respective state's carbon sink. Among the seven distinct terms mentioned across plans (figure 6), 'forest conservation' and 'forestry management practices' were mentioned most frequently, by seven of the 11 states. In the case of forest conservation, there was some variety in application with at least one state (Maryland) estimating avoided emissions, and another four describing their efforts to further prevent loss, slow loss, or maintain no net forest loss. One state, New York, specifically mentioned the importance of forest conservation in broader efforts to conserve open space. Two states (New York and Delaware) also mentioned forest restoration as a separate practice from either forest conservation or improved forestry management practices.

Four states mentioned reforestation or afforestation as overarching strategies for growing the carbon sink. One state, Pennsylvania, only mentions reforestation, while another, Connecticut, only describes afforestation on marginal agricultural land. Preserving or restoring forested agricultural land is mentioned as a separate activity within Maryland's plan, and Maryland and Delaware further specify a potentially related goal to plant forested stream buffers and/or riparian buffers. Finally, six states have explicitly outlined urban tree planting efforts, with at least one state, Massachusetts, additionally emphasizing the retention of existing urban canopy cover.

3.5. Inclusion of forest activities towards GHG reduction goals

The degree to which forest carbon estimates are tracked and included towards GHG reductions varies across the region (figure 7). Three states (Pennsylvania, New Jersey, and Maryland) include emissions and/or sequestration from forest activity as a component of their state GHG inventory and consequently count them as reductions towards their GHG goals. Six states (Delaware, Massachusetts, Maine, New Hampshire, New York, and Vermont), do not count forest activities towards established GHG goals but have put effort into tracking related forest carbon estimates outside of their existing carbon budget or inventory. The final two states, Connecticut and Rhode Island, do not include forest activities towards GHG reductions, nor do they regularly track changes to their forest carbon stocks.

3.6. Existing forest carbon science and dominant strategy

Despite the various scientific sources referenced across the region, states generally evidenced a primary or dominant strategy for generating forest carbon estimates across their plans and inventories (figure 8). Four states (Connecticut, Rhode Island, New Hampshire, and New Jersey) are predominately using default data from the literature, SIT or default data directly from the IPCC. Four more states (Delaware, Maine, New York and Vermont) are using primarily sample-based methods from USFS FIA program or related USFS Technical reports. The final three states are utilizing USFS FIA data in addition to either a statewide ecosystem model (Maryland) or is otherwise utilizing continuous forest field inventory data from their state forest service (Massachusetts and Pennsylvania).

Looking across all science referenced, ten of eleven states in the region use data or tools produced by the USFS, often analysis derived from FIA plots in the form of state or regional technical reports. It is unclear from the documents how many of these states are working in direct partnership with the USFS to utilize spatially explicit estimates of forest carbon within their domain rather than state-wide averages. At least one state (Maine) has utilized the USFS ForGATE, a Forest Sector Greenhouse Gas Assessment Tool, designed primarily to communicate information relevant to the evaluation of projected net GHG exchange in the context of Maine's forests (Hennigar *et al* 2013). At least two states (Massachusetts and Pennsylvania) mention the use of state-specific continuous forest field inventory data, with three more states (Maryland, Delaware, Massachusetts) utilizing data more generally from either their state forest service or state-based long-term ecological research areas.

One state (Maryland) currently utilizes data and analysis available via the NASA CMS, which offers high-resolution statewide (wall-to-wall) coverage of annual carbon stocks and fluxes via remote sensing and dynamic ecosystem modeling (Hurtt *et al* 2019). Two more states, Delaware and Pennsylvania, are in the process of reviewing existing CMS products for potential inclusion in state planning (e.g., Tang *et al* 2021, Ma *et al* 2021). One state, Maryland, also has a partnership with World Resources Institute (WRI) in the use of their tool to estimate avoided carbon emissions due to forest conservation and has formed relationships with USDA and the U.S. Department of Energy (DOE) relative to an ongoing climate impacts study.

At least four states (Maryland, New Hampshire, New Jersey, and Delaware) use LULUCF data derived from the SIT in either their plans or inventories. One state, New Jersey, uses default IPCC estimates in addition to those from SIT. Three states (Rhode Island, Connecticut and Massachusetts) utilize literature values that are either prepared by third party contractors (grey literature) or published in peer-reviewed journals. New Hampshire, while utilizing ecosystem modeling and field data within their Climate Action Plan, has since returned to using SIT as their primary science approach.

3.7. Forest carbon science needs

All states expressed a need for more data and/or tools to advance their forest carbon science relative to climate mitigation planning (figure 9). Four states (Vermont, Connecticut, Rhode Island, New Jersey) have explicitly asked for more reliable and higher confidence LULUCF data across the spectrum of use. New Jersey has also asked for improved measurement and verification methods. Four other states have explicitly noted the need for higher resolution data on forest carbon sequestration (New York and Vermont) and carbon sequestration potential (Pennsylvania and Rhode Island). Four states (Maryland, Delaware, Vermont and New Jersey) have asked for improved annual carbon flux monitoring capabilities. Maine and Pennsylvania are also interested in improved monitoring capabilities to better detect tree canopy changes. Three states (Maine, Massachusetts and Connecticut) have also indicated a specific interest in better utilizing remote sensing technologies to improve forest carbon estimates (including lidar); especially with reference to capturing urban trees (sometimes also referred to as 'trees outside of forests'). One state, New Hampshire, is interested in improved valuation of ecosystem services, inclusive of forest carbon. And, one other state, Maine, is interested in harnessing integrated ecosystem modeling.

3.8. Forest carbon science and policy relationships

Eight out of eleven states show commensurate levels of policy inclusion (section 3.5) and scientific support for forest carbon estimates (section 3.6) (figure 10). For example, Connecticut and Rhode Island do not currently include or regularly track forest carbon estimates relative to achieving their GHG reduction goals and also maintain a default scientific strategy for estimating their current carbon sink. Similarly, Maine, New York and Delaware heavily utilize USFS FIA sample-based data to track forest carbon stocks and fluxes across their states, but do not include forest activities within their GHG inventories. Maryland and Pennsylvania include forest carbon activities towards their GHG goals and utilize sample+ scientific strategies such as high-resolution models and continuous statewide field inventories. Two states

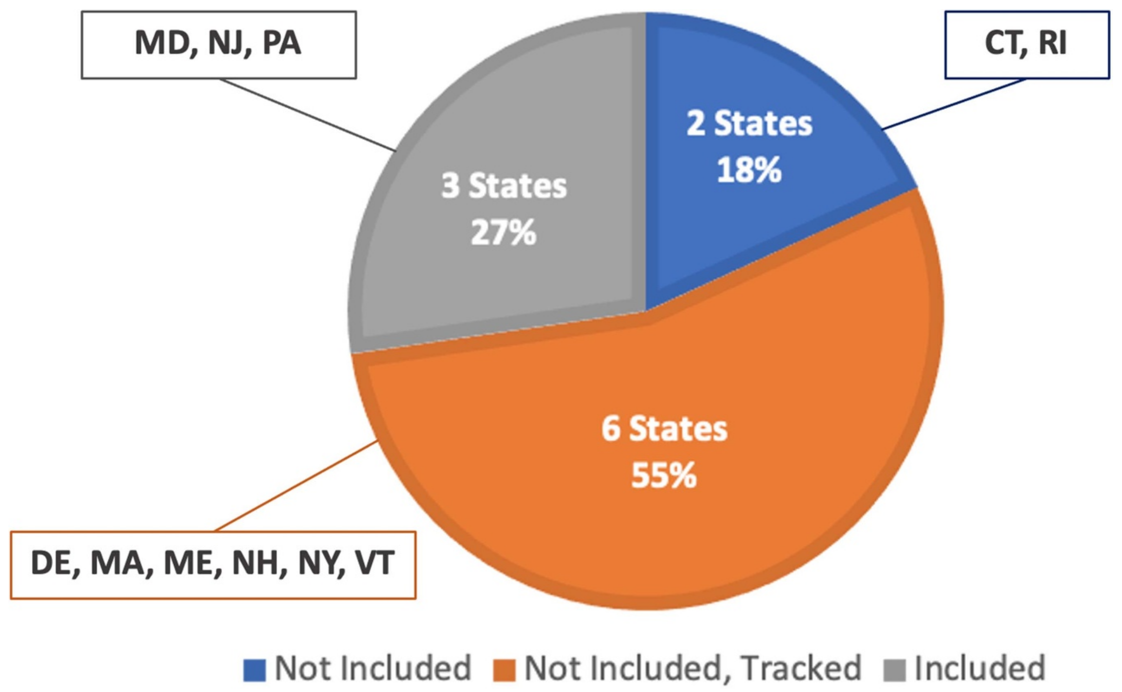

Figure 7. Degree to which forest activities are included towards greenhouse gas (GHG) reduction goals. States may not include forest activities relative to goal completion (not included), states may not include forest activities, but track changes independently of the GHG inventory (not include, tracked), or they may include them directly within their inventories as a component of overall GHG reductions (tracked).

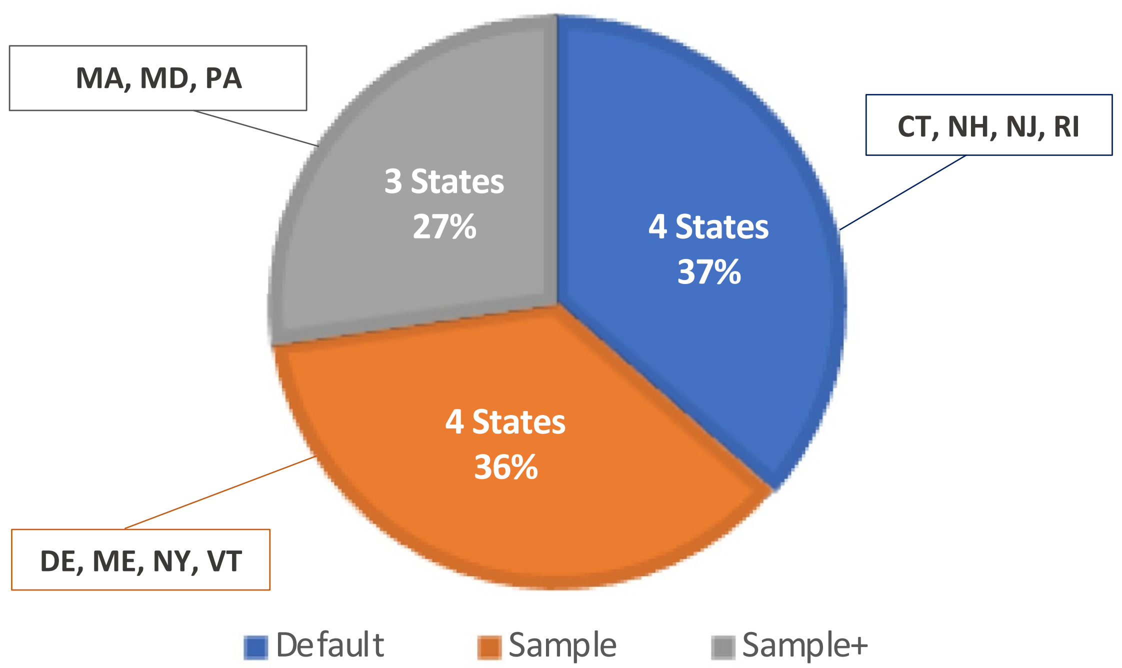

Figure 8. Primary scientific strategy employed by the states to estimate forest carbon stocks and fluxes within their climate mitigation plans or greenhouse gas inventories. Four states use default data directly from SIT, static literature values or sample-based estimates from their region rather than their state (default). Four states utilize USFS FIA field data directly or via USFS technical reports as updated and made available to the states (sample). The final three states use USFS FIA data in addition to either high-resolution modeling or field data from the state's own continuous forest field inventory (sample+).

functioning with higher levels of policy inclusion relative to existing scientific support include New Jersey, which fully includes forest activities towards established GHG goals, but primarily utilizes default data, and New Hampshire, which did include sample+ methods in their climate action plan but has since reverted to using default methods via SIT to track, but not include, forest activity towards their GHG

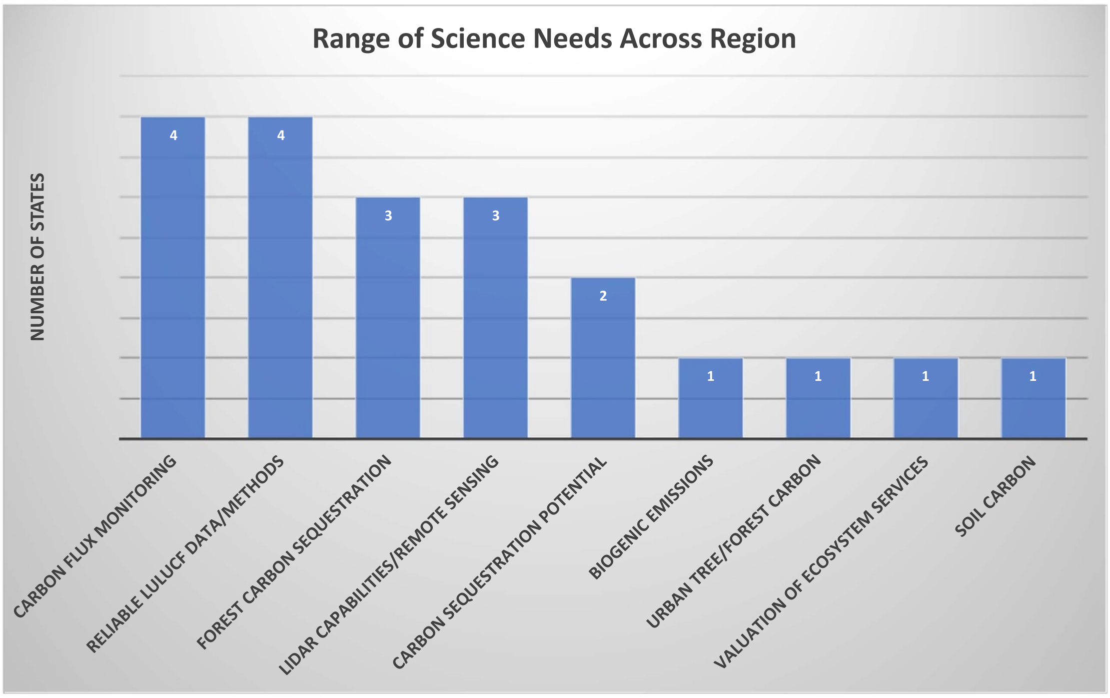

Figure 9. Frequency of reported science needs by states. Reported attributes of such science includes reliable, annual, and consistent data and methods.

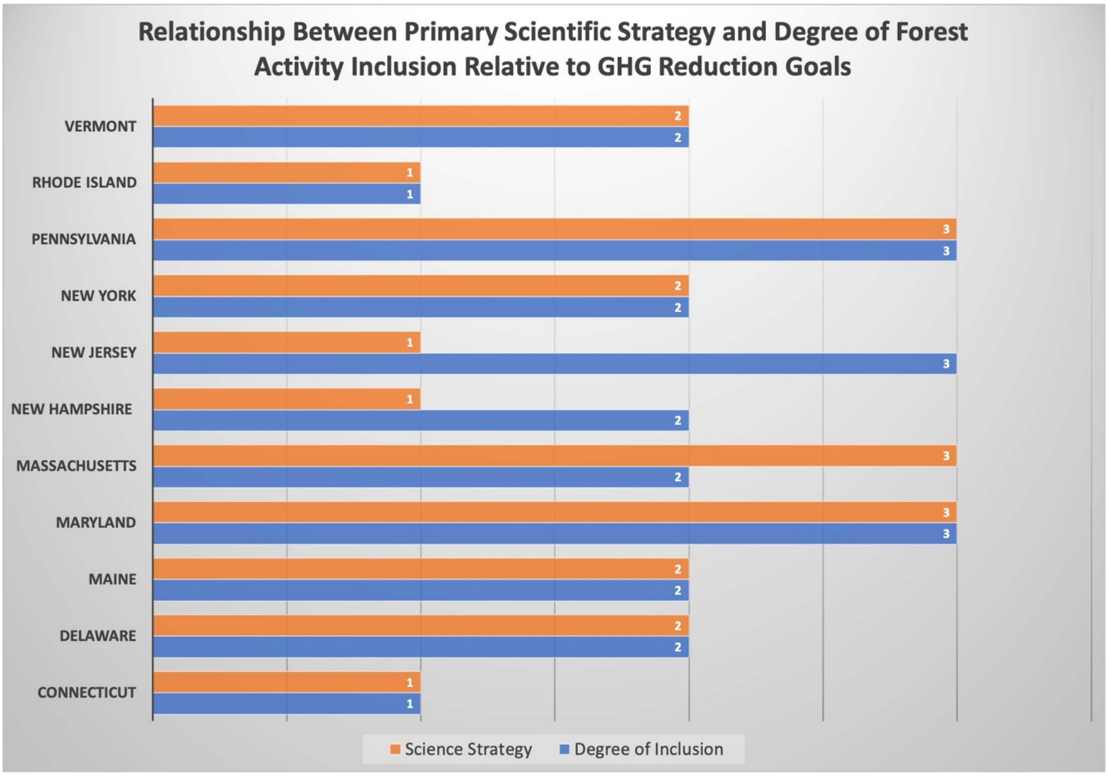

Figure 10. State-by-state relationships between the degree to which forest activities are included towards greenhouse gas (GHG) emissions reduction goals and the primary scientific strategy employed to generate related forest carbon estimates. Science Strategies (1—Default, 2—Sample, 3—Sample+). Degree of inclusion (1—Not Included, 2—Not Included, Tracked, 3—Included). Where levels are the same, scientific and policy support are considered to be commensurate.

goals. The final state, Massachusetts, utilizes sample+ scientific strategies but currently tracks forest carbon estimates separately rather than directly within their GHG inventory.

4. Discussion and conclusions

In this paper, we evaluated the current context for integrating forest carbon into state climate mitigation planning and identified opportunities for more systematic development and application of new forest carbon monitoring strategies. Our review showed that all states in the RGGI region have developed core climate mitigation planning documents relative to mandated GHG emissions goals, even as some states like New York and Delaware are still developing comprehensive climate action plans. Further, all such planning documents provide at least one reference to maintaining or increasing forest carbon benefits in recognition of its value to overall climate mitigation efforts. These references, coupled with active participation in the NASA CMS MSWG and USCA NWL Challenge, demonstrate the region's commitment towards including and improving estimates of land sector carbon within their planning. However, our results also emphasize considerable variability across the region. Notably, three-quarters of all states in this region do not count forest activities towards their GHG reductions goals, with the most common reason for exclusion surrounding ongoing data needs that extend beyond current national inventory tools. Furthermore, those that do attempt to quantify and track forest carbon estimates, utilize a range of scientific tools and data. Given the pattern of increasing variability in the region, we suggest that an enhanced common forest carbon monitoring system would provide important benefits for states already poised for ongoing regional collaboration.

4.1. Similarities, differences and remaining challenges

Our regional analysis highlights several important patterns. First, most states provide general guidance on the importance of forest protection and restoration relative to climate mitigation but do not offer specific and quantitative forest carbon goals. Of the 11 states, only Maryland and Massachusetts have outlined specific planned activities that are to be directly implemented by state agencies. These activities, such as expanded urban tree planting, have correlating estimates of expected carbon sequestration in the years between plan implementation and GHG goal achievement. The remaining states are split near evenly between those that provide an array of options for potential adoption from those that provide general recommendations for future agency consideration. While this lack of detail may be reflective of perceived uncertainties in the available data, it also presents a challenge for anticipating the full emissions impacts of integrating forest and tree activities into climate mitigation planning.

Second, while all planning documents mention the importance of forest conservation and restoration for climate mitigation, nearly three-quarters of all states do not currently count forest carbon towards their GHG reduction goals. The relationship between plans and inventories can be complicated. Planning documents and inventories across the region are often completed on different time intervals, sometimes based on legislative or executive mandate, sometimes simply based on how much time the responsible agency requires to complete them. In some cases, a state may have a GHG inventory but no established or regularly updated climate action plan. In others, a state may have climate action plans with forest carbon goals, but not directly track forest carbon changes within their inventory. However, the number of states in the region who do not fully integrate net forest carbon emissions relative to GHG goals underscores concerns about access to reliable and regularly updated forest carbon data and how such data can be used to plan for and secure verifiable reductions in carbon emissions.

Third, most states are still using default factors and sampling-based methods to generate current forest carbon estimates. The referenced resources within state plans are often reflective of the type of scientific information made available to the state at the time the documents were created. Some plans have not been updated since the early-to-mid 2000s, and there may be scientific strategies being advanced by state agencies and their partners that are not currently represented in official government documentation. Only one state in the region (Maryland) currently utilizes high-resolution forest carbon modeling to inform their climate mitigation planning, suggesting more opportunity for expanded capacity in this area. This is especially important as current sample-based inventory methods used across the region (i.e., USFS FIA or State Continuous Forest Inventories) are not consistently used for spatially-explicit projections of future ecosystem dynamics over the full range of scales that are relevant to decision makers. Many sample-based methods that cover broad areas also tend to focus more on forests and to exclude trees outside of forests, leading to incomplete assessment of current and projected forest carbon stocks and fluxes across a heterogeneous landscape.

The pressure to better couple policy drivers and science solutions has been bi-directional. In some cases, policy mandates require agencies to develop improved scientific and technological strategies in order to achieve compliance, such as in New Jersey. On the other hand, improvements in scientific capabilities may spur greater inclusion of forest carbon within existing mitigation and planning frameworks, such as in Maryland. Commensurate levels of science sophistication and policy support within most states in the region suggests a general awareness of current capabilities and regular coordination across state governmental agencies and offices. Further, all states in the region have GHG reduction goals and have indicated an interest in improving their forest carbon science relative to climate mitigation planning, as evidenced by the range of data, tools, and methods requested by states; specifically, higher resolution and spatially explicit forest carbon estimates. However, the pace at which new science and technologies are embraced by individual states, is and likely will remain variable if primarily dependent on state resources.

4.2. Implications of current patchwork of approaches

Given the variety of approaches across the region, a default option would clearly be for each state to continue developing its own separate forest carbon planning and monitoring strategies. This strategy retains flexibility in terms of design and implementation across a diverse coalition of states and does not require additional resources or coordination. Some states which are more heavily urbanized, such as Rhode Island, may wish to focus extensively on science which allows for improved estimates of urban tree canopy and related carbon impacts, while more heavily forested states, like Maine, may wish to focus on forest carbon estimates which reflect the lifecycle of carbon related to biomass production or include the carbon storage implications of durable wood products. Maintaining the current patchwork of approaches also allows states with higher levels of access to improved science and technologies to integrate such tools into their own climate planning regardless of other state positions or policies. Further, diverse approaches to forest carbon integration across the region could result in more experimentation and potentially, innovation—and thus could also provide an increasing suite of options and choices for states to selectively implement based on perceived need, and on their own policy timetables.

Maintaining the current, uncoordinated approach, however, has significant limitations. First, those states who do not track forest carbon as part of their GHG reduction strategies cannot adequately plan for forest carbon activities, as it is unworkable to manage well what you do not measure. This means that even if states engage in separate forestry or reforestation planning, strategic afforestation and reforestation initiatives will remain decoupled from larger climate mitigation goals without quantified carbon estimates. While federal investment in the USFS's FIA program and its inclusion within USEPA SIT has sought to provide states with a common basis for LULUCF inclusion within inventories, many states have chosen not to use this data to inform their planning, let alone within their inventories. Second, the splitting of individual state efforts has also resulted in regional scale inefficiencies, with each state investing time and money into building their own carbon monitoring systems with varying levels of scientific quality, institutional robustness, and direct applicability to planning. Such a mix of methods and approaches also makes it difficult to compare or combine carbon estimates across the region, restricting opportunities to include forest carbon into broader carbon trading efforts, especially among states already invested in such collaboration via RGGI.

4.3. Future directions towards a shared forest carbon monitoring system

A common carbon monitoring system that more heavily relies upon the detailed information content of high-resolution imagery and lidar could address some of these limitations. It would also provide important benefits to states, and also eventually to national planning processes within the U.S. and in other countries. A common system would allow for a direct comparison of forest carbon strategies across the region, provide for the scientific needs of all states, and operate more efficiently than multiple systems. The specific attributes of such a shared system need to be further developed by the states, but several aspects of such a system are evident. The attributes of such a system need to meet state needs for baseline reporting, future planning, and annual monitoring. Specifically, our analysis shows that states have already identified a need for high spatial resolution georeferenced capabilities, transparent methods, reliable and consistent data updates, streamlined integration with GHG baseline years, and an ability to capture trees outside of forests. Any proposed system should also endeavor to remain consistent with the IPCC's methodological guidelines for inventory accounting (IPCC 2008, 2019).

Coalitions like MSWG, RGGI and USCA have provided a forum for states to share best practices and pursue joint research in support of finding or supporting the best technology and science available. With at least four ongoing USCA NWL research projects in the region, this collaboration will remain important for supporting improved carbon sequestration planning on natural and working lands, which are still excluded from half of all current GHG inventories in the region. However, individual projects must ultimately be leveraged towards a shared system to maximize the policy-relevance of scientific improvements. Ongoing collaboration among federal and state agencies, non-governmental organizations, and academic institutions is critical to this process and together, these institutions can provide the components needed for a shared regional approach to forest carbon planning and monitoring.

Data availability statement

All data that support the findings of this study are included within the article (and any supplementary files).

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