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Policy Perspective on the Role of Forest Sector Modeling

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Representing 30% of the world's ice-free land surface area (International Panel on Climate Change, 2019; Food and Agriculture Organization, 2015), forests will continue to play a large role in global environmental systems, economies, and policies, including efforts to reduce greenhouse gas (GHG) emissions – but the extent of that future role is largely unknown. Global forests currently provide important ecological (e.g., habitat, water filtration) and economic [e.g., supported a global forest products economy valued over $US247 billion in 2017 (Food and Agriculture Organization, 2019)] services, and they provided a net global carbon sink over the last century (Nabuurs *et al.*, 2007; Houghton, 2008; Smith *et al.*, 2014). Heightened recognition of the importance of forests in sustainable development and mitigation efforts is reflected in recent reports (e.g., International Panel on Climate Change, 2019; Rogelj *et al.*, 2018; U.S. Global Change Research Program, 2018) as well as commitments to reduce GHGs (e.g., United Nations Framework Convention on Climate Change, 2015). Forest-based mitigation investments represent vast potential GHG mitigation opportunities (Van Winkle *et al.*, 2017; U.S. Environmental Protection Agency, 2005; Sohngen and Mendelsohn, 2003) that are inexpensive relative to other sectors (Rose *et al.*, 2012). In the context of global commitments, land use sector could yield 20%–25% of total emission reductions (Forsell *et al.*, 2016). In the U.S., there has been increased attention to the role of forests in GHG mitigation (U.S. Department of State, 2014; White House, 2016; U.S.

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Department of Agriculture, 2015) and economic development efforts, including advancement of the U.S. bioeconomy (Biomass Research and Development Board, 2016). Consideration of potential future outcomes from land use, land use change[1] and forestry (LULUCF) is integral for achieving these policy goals, especially GHG mitigation goals, as the evolution of forests over time (in terms of size, health, how they are managed and their ability to sequester and store carbon) will have important implications for whether or not commitments can be met (Baker *et al.*, 2017; Van Winkle *et al.*, 2017; International Panel on Climate Change, 2019). It is therefore essential that decisionmakers and the research communities that support them – such as the forest sector modeling community – develop the best data and state-of-the-art tools for evaluating potential future forest sector outcomes to inform policy development. Contributions by the papers in this special issue advance our understanding of forest system dynamics and forest sector mitigation opportunities, and confirm that forest sector tools play an important role in supporting science-based decision making.

Making policy decisions today – including setting future sustainable development and mitigation goals – inevitably affects people, economies and the environment in the future. Therefore, decisionmakers require tools that (1) can assess potential policy outcomes (e.g., Daigneault, 2019; Baker *et al.*, 2017; Fawcett *et al.*, 2015; Havlík *et al.*, 2014), (2) can aid selection of specific future estimates or targets (e.g., United Nations Framework Convention on Climate Change, 2015; U.S. Department of State, 2016), and (3) offer a means to measure progress toward those goals (e.g., United Nations Framework Convention on Climate Change, 2015). Producing historic estimates and future potential projections for any sector has its difficulties, but the forest sector faces unique challenges (Smith *et al.*, 2014; International Panel on Climate Change, 2014a; Irland *et al.*, 2001). Forest ecosystem measurements and related GHG flux quantification are particularly challenging as these ecosystems have significant spatial and temporal variability, species and other environmental heterogeneity and interconnectedness with other ecosystems (Brown, 2002; Pearson *et al.*, 2007; Goetz *et al.*, 2015; Olander and Haugen-Kozyra, 2011). Additionally, forest sector markets are very dynamic, due to (1) the inherent integrated nature of forest products manufacturing systems (see Figure 1, Latta *et al.*, 2018), (2) the interconnectedness and fluidity of global forest product markets (Latta *et al.*, 2015; Forest2Market, 2019), (3) the heterogeneity of land owners and their behavior including responses to market signals via land management regime decisions (Håbesland *et al.*, 2016; Sohngen and Mendelsohn, 2003), and (4) Policy

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[1] Land use change refers to a change in the use or management of land by humans, which may lead to a change in land cover. Land cover and land use change may have an impact on the surface albedo, evapotranspiration, sources and sinks of greenhouse gases, or other properties of the climate system and may thus give rise to radiative forcing and/or other impacts on climate, locally or globally (International Panel on Climate Change, 2014b).

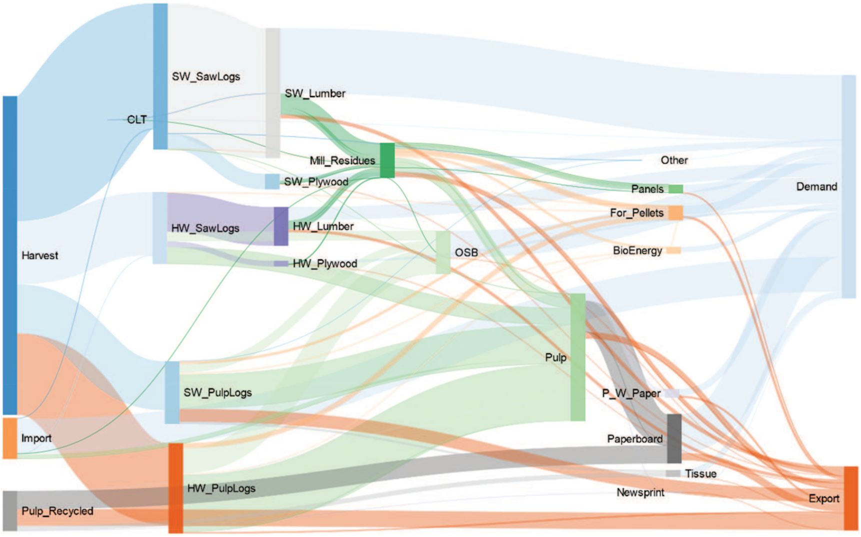

Figure 1: Depiction of U.S. forest production flows within the underlying analysis presented in Latta *et al.*, 2018 using the Land Use and Resource Allocation (LURA) model. Created by Greg Latta (University of Idaho).

interventions that can that affect land-based commodity markets and related land use decisions (e.g., bioenergy policies) (Guo *et al.*, 2019; Wise *et al.*, 2014).

In the context of GHG reduction efforts, setting future mitigation targets requires choosing whether to establish them relative to a historic year, a series of historic years, or some other metric, series of years and how to select those historic elements. Historic emissions flux data related to forest ecosystems is regularly collected via physical observations and/or remote sensing data, including data compiled for national inventories under the United Nations Framework Convention on Climate Change (2005), and can serve as input data for future projections tools, as benchmarks against which future goals can be set, and a means for measuring progress toward established goals (including tests for additionality) (Greenglass, 2015). However, in addition to any uncertainty of the inventory data itself (McGlynn *et al.*, 2019), annually-reported U.S. LULUCF emissions flux estimates must be updated back to 1990[2] using new methods and technologies when available[3] (United Nations

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[2] Though the time series starts in 1990, this start date requires obtaining data from as far back as 1971 in order to understand the legacy effects of land use/land use conversion on GHG flux.

[3] Updating the entire time series is a necessary action when better/different historic data is available or a methodological change is made to ensure time series consistency, a fundamental principle in IPCC GHG Inventory guidance. The intent is that the inventory is improved annually by adopting incremental changes.

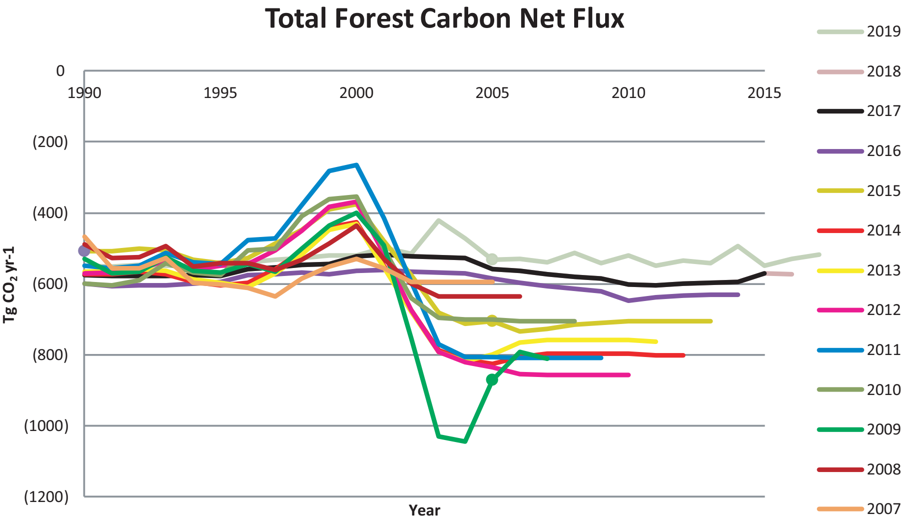

Figure 2: Fluctuations in U.S. net forest sequestration estimates over the last 12 years, as reported in the 2007–2019 Inventory for Greenhouse Gas Emissions and Sinks with three reference bullets for the year 2005 (U.S. Environmental Protection Agency, 2009; U.S. Environmental Protection Agency, 2014b; U.S. Environmental Protection Agency, 2019). Includes the following pools: aboveground biomass, below ground biomass, dead wood, litter, and soil organic carbon, as well as additional pools for 2019 including soil mineral and drained organic soils. Created with Greg Latta (UI).

Framework Convention on Climate Change, 2005; International Panel on Climate Change, 2006), which causes variations in the historic data between annual publications (Latta *et al.*, 2008 and Figure 2).[4] These variations make it difficult to discern consistent forest carbon sink trends and increase the complexity of establishing emissions reduction targets relative to historic values and tracking progress toward or deviation from those targets. Furthermore, historic variability in emissions estimates creates challenges when establishing initial conditions in models that project emissions under alternative future scenarios (Johnston *et al.*, 2019; Mendelsohn and Sohngen, 2019).

Another key LULUCF policy consideration is that past forest ecology and economic trends are not likely to continue in the future. Various studies indicate that U.S. forests are aging and carbon sequestration rates are still increasing but at a decreasing rate (Wear and Coulston, 2015; Nabuurs *et al.*, 2013), with some suggesting they will potentially become a net source of

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[4] According to the IPCC guidelines for national GHG inventories (2006), "using different methods and data in a time series could introduce bias because the estimated emission trend will reflect not only real changes in emissions or removals but also the pattern of methodological refinements."

emissions in the next 10–40 years (U.S. Department of Agriculture - Forest Service, 2012), while others estimate continued or increasing net sequestration (Tian *et al.*, 2018). Forest resources increasingly face pressure due to land use competition for provision of food, fiber, fuel, feed/fodder, and other social and cultural uses as well as biophysical changes related to variations in climatic conditions (U.S. Global Change Research Program, 2018; International Panel on Climate Change, 2019). These pressures plus declining traditional forest-based markets (e.g., newspaper) and emerging markets and technologies (e.g., cross laminated timber) will inevitably cause future forest product market demands and related land use patterns, management activities and GHG emissions to deviate from the past (Daigneault *et al.*, 2019; White House, 2016; Håbesland *et al.*, 2016; Forest2Market, 2019; Gambino *et al.*, Forthcoming). Therefore, as historic trends of forest resources, market interactions and GHG profiles do not necessarily reflect future trends, projections tools should allow for identification of potential opportunities and obstacles per different future conditions and policy designs.

Given the important considerations outlined above, it is imperative to note that future forest GHG projections outcomes depend largely on input data, model type and specifications, scope, spatial and sectoral coverage, assumptions and analytical objectives. A variety of different methods and tools for simulating future trajectories of forest resources and related GHG fluxes exist. Built for varying purposes, with different spatial and temporal scopes, capabilities, and different perspectives concerning future potential forest economic and environmental conditions, these tools sometimes produce divergent estimates of mitigation potential. For example, the 2014 CAR (U.S. Department of State) presented estimates from two different U.S. government forest resource tools to establish a range of future potential forest sector GHG outcomes. Using a range in this context allowed for transparent acknowledgement of the complexity, uncertainties (in data, assumptions about the future, etc.) and differing modeling approaches associated with generating land use sector GHG estimates, while simultaneously giving a general idea of the sector's potential contribution to overall net economy-wide U.S. mitigation estimates.

Below is a high-level discussion of five basic approaches to estimating future potential forest-related GHG emissions (historic reference and extrapolations, ecological models, forest sector economic models, integrated assessment models, and meta-analysis).[5] It is important to note that all efforts to simulate future outcomes inherently include some degree of uncertainty, as assumptions must be made about future conditions. The degree of uncertainty often depends on the quality of data inputs and assumptions used (e.g., Cai *et al.*, 2018), as well as parametric and model structure-based uncertainties. Discourse on the

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[5] This general overview is not exhaustive as other approaches can be used to analyze this sector, and have their own strengths and weaknesses.

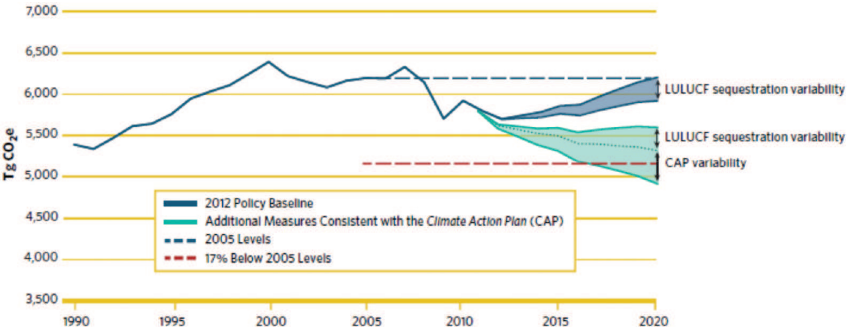

Figure 3: Range of projected emissions for a business as usual baseline (blue) and post-2012 additional measures (green), with variability in LULUCF outcomes represented as a range in the 2014 CAR (U.S. Department of State).

technical differences between modeling approaches– like different perspectives on foresight (e.g., recursive dynamic models with myopic expectations *vs.* inter temporal optimization models with perfect foresight)– and related uncertainties, strengths and weaknesses can be found in the papers in this special issue and other discussions (e.g., Wade *et al.*, 2019; Lauri *et al.*, 2019; Johnston *et al.*, 2019; Sjølie *et al.*, 2015).

- Historic data are useful for tracking observed forest resource changes generally, including GHG fluxes, over time (U.S. Environmental Protection Agency, 2019). Some policymakers would like to use this data at large spatial scales to infer conclusions about how specific drivers, influence large-scale carbon stocks. While the influence of different drivers on observed carbon stock outcomes can be estimated, data users must carefully specify models to ensure that they have identified any causative relationships they estimate. For example, observing that increases in global woody biomass use for energy occur in conjunction with global forest carbon stock increases does not necessarily mean that increased biomass use is causing global carbon stock increases. Other factors (e.g., policy incentives, natural disturbances, changing demand of other forest products) also influence forest carbon stock levels. Also, as mentioned above, historic estimates inherently have some uncertainty. Lastly, extrapolating historic trends into the future may be useful in some contexts (e.g., if evaluating potential future LULUCF outcomes given *ceteris paribus* historic biophysical and market trends,) but forgoes consideration of potential outcomes given any variation in underlying future conditions versus history, thus restricting the ability to assess a full range of policy designs and their implications.

- Using ecological modeling – like biogeochemical simulators, vegetation or process models – to consider future biophysical potential (BP) of forest outcomes (see Figure 4 below) is useful when an analysis focuses on physiological parameters such as maximum yields, forest ecosystem dynamics, and climate change impacts on forests (Kim *et al.*, 2017). However, this approach typically does not factor in economics via forest management regime responses to changing policies or market signals (e.g., demand shifts), or assess important land use change implications like leakage (Murray *et al.*, 2004; U.S. Environmental Protection Agency, 2014a).[6] Omitting economics may produce outcomes that under or overestimate carbon implications, giving policymakers a false sense of direction.

- Forest sector economic models use ecological and economic forest resource data, including historic forest carbon stock estimates, to simulate potential future scenarios of market potential or different degrees of competitive market potential, depending on the modeling framework and scope (Figure 4, MP, CMP_1 or CMP_2). These models accomplish this by using different environmental, socioeconomic and/or policy variables, often with significant sectoral detail (e.g., U.S. Environmental Protection Agency, 2005). The ability of these tools to isolate effects per variation of different parameters offers clarity regarding to key features of interest in the forest sector (e.g., specific analysis of different forest species and/or management regimes that can retain focus on forests that remain forests) and allows for better characterization of different economic and ecological drivers of forest GHG fluxes (Sohngen and Mendelsohn, 2007; Baker *et al.*, 2017). However, these models rely on assumptions about future environmental as well as macroeconomic and specific forest market conditions which adds uncertainty. Model structures can also affect results which adds another level of uncertainty (e.g., Wade *et al.*, 2019; Sjølie *et al.*, 2015).

- Integrated assessment models (IAMs) are models that "integrate knowledge from two or more domains into a single framework" (Nordhaus, 2013), which in the climate analysis context often manifests as frameworks that integrate economy-wide natural and economic systems globally to assess potential policy outcomes and tradeoffs, allowing insights not possible in single sector models (e.g. Calvin *et al.*, 2019; Weyant, 2017; Metcalf and Stock, 2015; Rose, 2014). While these economy-wide competitive market tools (Figure 4, CMP_2) have the unique ability to reflect

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[6] Leakage can be defined as "the indirect impact that a targeted LULUCF activity in a certain place at a certain time has on carbon storage at another place or time" (Intergovernmental Panel on Climate Change, 2000).

potential GHG outcomes across various sectors, including the land use sector, they often have highly aggregated sector representation which does not offer detailed evaluation of specific forest ecosystem and market interactions and related GHG outcomes.

- Some research efforts provide future potential LU sector mitigation quantity and cost estimates using meta-analysis. This approach uses results from a variety of studies – with different methods, objectives and assumptions – to identify similar and disparate potential mitigation estimates (e.g., Van Winkle *et al.*, 2017; Van Kooten and Sohngen, 2007). However, as discussed by Schneider and McCarl (2006), it is crucial that such assessments also identify the uncertainties, limitations and assumptions of underlying studies, and do not add together or directly compare results from different studies that use different estimation methods (e.g., like those listed above). For example, some studies (e.g., Griscom *et al.*, 2017) may directly compare, derive new estimates using and/or add together results from a variety of studies (e.g., biophysical and technical potential analyses and competitive market potential estimates) to estimate maximum mitigation potential. Applied in this manner, this approach may overestimate mitigation potential at a given price because it does not incorporate important resource competition, tradeoffs, and market interactions that would arise as different mitigation practices across sectors are implemented simultaneously, thus reducing mitigation potential.

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Each approach described briefly above offers different perspectives on forest resources as well as different strengths and weaknesses, and they each can be useful in different research applications. However, with the understanding that nothing is constant in the forest sector – e.g., in related ecosystems, markets, and management technologies – decisionmakers ultimately need to understand as much as possible about the potential future conditions faced by forested lands and those that manage them. To the extent possible, forming future policies by evaluating policy designs from only one discipline and only looking to the past as a future guide should be avoided. Specifically, anthropogenic influence on forestry GHG emissions fluxes (via market signals and management responses) is

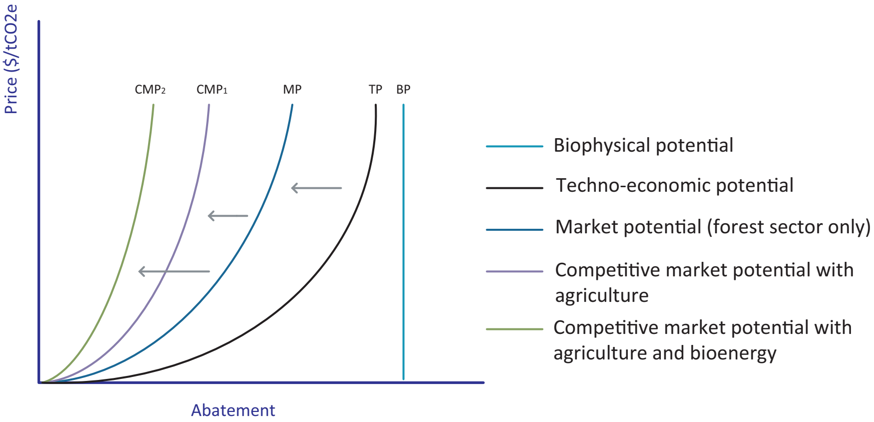

Figure 4: Different approaches to evaluating mitigation potential incorporate different input variables and assumptions, and different capabilities for evaluating competition for limited resources and other tradeoffs. These curves are a general representation of the relative differences between mitigation potential estimation approaches. *Biophysical potential* (BP) estimates the maximum mitigation potential the land offers without consideration of costs, competing land uses, etc, representing an upper bound. *Techno-economic potential* (TP) is basically a marginal abatement cost (MAC) curve analysis for a portfolio of mitigation options and includes costs, yield potential, and GHG emissions changes for each option in geographic areas where that technology could theoretically be applied, thus reflecting rising costs of individual activities, often using a bottom-up cost approach (e.g., Brandt *et al.*, 2018; U.S. Environmental Protection Agency, 2013). The *market potential* (MP) MAC curve reflects specific-sector market interactions, differing from TP as it explicitly accounts for additional elements like market opportunity costs and resource constraints. *Competitive market potential* (CMP_1) builds upon the MP curve by including competition for the same land resource base by multiple land use sectors – e.g., adding agriculture to forest sector mitigation demand – and in CMP_2, further adding in bioenergy expansion. Developed in collaboration with Justin Baker (RTI International) and Greg Latta (University of Idaho) (Latta *et al.*, 2019).

undisputable and should not be excluded when considering policy solutions. Forest sector economic modeling tools can integrate detailed forest ecosystem *and* disaggregated forest sector land management responses (including those on forest land remaining forest land) to market drivers under varied future conditions. As abstractions of reality, such tools can offer useful insights to policy makers designing and implementing polices that affect forestry and land use about the potential directionality and magnitude of policy outcomes given certain conditions, assumptions and constraints, while acknowledging related uncertainties.

This integrated economic and ecologic forest sector modeling concept is certainly not new (Adams *et al.*, 1996; Binkley *et al.*, 1987; Mills & Kincaid, 1992; Adams *et al.*, 1996), but the evolution of new technologies in data collection and remote sensing as well as computing power has enabled new projections capabilities over the last several decades. Nonetheless, uncertainties in model input data, parameters, functionality, and assumptions about future conditions persist and often lead to meaningful differences in U.S. as well as global forestry and carbon stock projections from different models (e.g., Alexander *et al.*, 2016). It is therefore vital for the forest sector modeling community to continually strive to update models with the most recent information and validate models and outcomes, both by evaluating models and their outcomes independently and as part of larger model comparison efforts.

Evaluating projections provided by multiple models, or explicit multimodel assessment frameworks, can help inform policy or resource investment strategies and reduce the implicit bias inherent in single-model projections. The Agricultural Model Inter-Comparison project (e.g., Rosenzweig *et al.*, 2014), Energy Modeling Forum (e.g., Weyant, 2017) and Integrated Assessment Modeling community contributing Shared Socioeconomic Pathway scenarios (e.g., Riahi *et al.*, 2017) are all examples of how harmonized scenario analysis across different models with varying structural attributes can provide additional information on possible future pathways in various sectors of the economy. Highlighting findings that are robust across different models adds to the confidence in estimated outcomes (e.g., Schmitz *et al.*, 2006). Multimodel efforts also offer vital platforms for discussions on why model results differ and to identify and better understand the drivers of those differences to minimize them to the extent possible. Such efforts include comparing forest-related results between not only forest sector models, but also between forest sector models and other modeling approaches like IAMs, which allows for forest sector-specific model outcomes to be considered in a broader, economy-wide context.

This special issue is an important contribution to the literature as the papers therein reflect advancements in forest sector modeling tools that give decisionmakers informed acuity about what kinds of policy frameworks and incentives might be most effective in achieving policy goals. Also, it also allows for the opportunity model developers and decisionmakers alike to further understand and compare different modeling approaches and relevant outcomes, which advances the important role that forest resource tools play in science-based decision making. The extent to which the forest sector modeling community can continue to collaborate, improve data and projections modeling tools, and communicate important findings as well as information gaps with the public and policymakers, may help dictate the degree to which forests ultimately play in reducing global GHG emissions and achieving sustainable development goals.

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