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Environmental and Economic Effects of a Regional Renewable Portfolio Standard with Biomass Carve-outs

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Contents

ABSTRACT

The unique generation, landownership, and resource attributes of the southeastern United States make the region a ripe and important test bed for implementation of novel renewable energy policy interventions. This study evaluates the environmental and economic implications of one such intervention, a hypothetical region-wide renewable portfolio standard (RPS) with biomass carve-outs. It utilizes the Forest and Agriculture Sector Optimization Model with Greenhouse Gases (FASOMGHG) to assess the multi-sector and interregional allocation of increased harvest activity to meet the RPS. It then uses the Sub-Regional Timber Supply (SRTS) model to assess the intraregional allocation of harvests within the southeastern United States.

The analysis finds that forest biomass is the dominant contributor to the regional RPS; national data suggest a substantial reallocation of harvests across both time and space. Existing resource conditions influence the regional distribution of land use and harvest changes, resulting in a spatially and temporally diverse forest carbon response. Net forest carbon in the Southeast is greater in the RPS Scenario than in the No RPS Scenario in all but the final years of the model run. Accounting for displaced fossil emissions yields substantial net greenhouse gas (GHG) reductions in all assessed time periods. Beyond the RPS, both research methodology and findings are applicable to a broader suite of domestic and international policies, including pellet exports to the European Union and GHG mitigation under Section 111(d) of the U.S. Clean Air Act.

INTRODUCTION

Expansion of bioenergy in the southeastern United States is one means by which to meet national renewable and low-carbon energy goals. But it will require novel policy initiatives that address the complexities of developing a robust feedstock system across a diverse and dynamic resource base. The Southeast is a ripe and important test bed for such initiatives. Policies that work in a largely unregulated private resource could be models for using market incentives in other regions. An examination of the economic and environmental impacts of such initiatives could inform a broader suite of domestic and international policy initiatives, from pellet exports to the European Union to greenhouse gas (GHG) mitigation objectives under Section 111(d) under the U.S. Clean Air Act (CAA).

To successfully create and sustain bioenergy systems, policy must take a thoughtful approach to the Southeast's fossil-energy dominated electricity generation. In 2012, coal and natural gas accounted for 28% and 55% of the region's generation, respectively (Energy Information Administration 2014). The only state in the region that exceeds the national average of 12.2% renewable electric power is Oklahoma; Tennessee is just below the national average at 11.7% (Brown et al. 2010).

Whereas the majority of U.S. states have a renewable portfolio standard (RPS), only one southeastern state—North Carolina—has a state-level renewable energy mandate (DSIRE 2013). One argument for the lack of generation requirements in the Southeast is that states in the region have minimal deployable renewable energy resources and that regulations requiring their use could decrease the affordability and reliability of electricity—an argument not supported by the literature (Brown et al. 2012). In actuality, implementing a renewable energy program at the regional level could help alleviate these concerns by providing flexibility in how and where targets are met.

One area of renewable energy displaying particular promise is bioenergy, defined here as the use of biological material for the generation of electricity, process heat, or both. Biomass resources are widely available in the region in the forms of agriculture and forest residue, animal manure, and landfill gas (Milbrandt 2005). Though ownership and land use patterns paint a complex picture of potential biomass supply, research suggests that a single feedstock, woody biomass, may be supplied in sufficient amounts to meet significant bioenergy targets (Abt et al. 2010a; Abt et al. 2010b).

Despite the availability of bioenergy feedstock, there has been no significant increase in bioenergy production at the national and regional level (see, e.g., Energy Information Administration 2013). A primary reason is that levelized costs of energy (LCOE) associated with renewable are higher than those associated with as compared to fossil energy sources (Borenstein, 2011). To overcome this shortcoming, policy to encourage bioenergy production and use has existed for several decades (Duffield and Collins 2006). Given the relatively small contribution of bioenergy relative to total energy production, however, additional policy will likely be necessary to encourage the further development and maturation of a broader bioenergy market.

The literature is replete with examples of model analyses conducted with the express intent of informing bioenergy policy design in the southeastern United States and beyond (Table 1). These models feature different timelines, operate at different spatial scales, and address different arrays of commodities and sectors. They are based on different assumptions regarding the foresight of economic actors and may employ different price elasticities, among other important considerations. Despite its potential benefits, comparative analysis across models or multiple model integration is rare.

Such comparative and integrated analysis is nonetheless important for bioenergy policy given the spatial scales at which individual landowner response is likely to occur, the scales at which natural systems occur, and the scales at which agricultural and forest products markets operate. A hierarchal approach whereby national models feed more localized ones allows the modeling approach to be tailored to reflect this spatial heterogeneity. In the Southeast, forest biomass exists in a predominantly privately owned landscape, where agriculture, urbanization, and forestry land uses compete. Because wood is expensive to move and industry segments tend to specialize on certain feedstock types, local conditions drive the alternative uses, the available feedstock types, and the ecological impacts of increased utilization. Understanding the regional impacts of an RPS requires modeling of the dynamics of local forest product supply and demand. Therefore, analyses that allow for conclusions considering both the aggregate regional or national effects of a particular policy as well as the subregional disaggregation of these effects will ultimately be of more use for policy development, implementation, and evaluation.

This study seeks to evaluate such model integration in the context of a Southeast-wide RPS. It utilizes the Forest and Agriculture Sector Optimization Model with Greenhouse Gases (FASOMGHG) to assess the multi-sector and interregional allocation of increased harvest activity to meet the RPS target. It then uses the Sub-Regional Timber Supply (SRTS) model to assess the intraregional allocation of FASOMGHG-estimated harvest within the southeastern United States. In doing so, the analysis estimates the regional land use and management implications of the policy, with a focus on the forest and agriculture sectors. The analysis further explores the sub-regional forest sector implications of increasing harvest levels on the regional scale, paying particular attention to the aggregate and localized economic and environmental effects of RPS implementation. It concludes by drawing parallels to other potential drivers of demand, posing recommendations to inform the potential development of a robust bioenergy system in the region as aided by a regional RPS.

Table 1: Attributes of selected forest and/or agricultural sector modeling analyses

Study	Model[a]	Type[b]	Time period	Period length	Region[c]	Feedstocks[d]
(McCarl et al. 2000)	FASOM	IO	2000–2090	10	US	RW, MR, LR, DE, SR
(Bolkesjø et al. 2006)	NTM	RD	2000–2010	1	Norway	RW, P, LR, MR
(Galik et al. 2009)	SRTS	RD	2003–2030	1	SE	RW, LR
(Raunikar et al. 2010)	GFPM	RD	2006–2060	1	Global	RW
(Sjølie et al. 2010)	NTM	RD	2003–2015	1	Norway	RW, P, MR
(Trømborg and Solberg 2010)	NTM	RD	2003–2015	1	Norway	RW, P, MR
(Buongiorno et al. 2011)	GFPM	RD	2006–2030	1	Global	RW
(Guo et al. 2011)	SRTS	RD	2005–2030	1	TN	RW, LR
(Ince et al. 2011)	USFPM	RD	2006–2030	1	US, Global	RW, MR, LR
(Kallio et al. 2011)	ForENER	RD	2007–2007	1	Finland	RW, LR, ST
(Lecocq et al. 2011)	FFSM	RD	2010–2020	1	France	RW
(Moiseyev et al. 2011)	EFI-GTM	RD	2005–2030	1	EU, Global	RW, MR, LR
(Abt et al. 2012)	SRTS	RD	2008–2037	1	SE	RW, LR
(Daigneault et al. 2012)	TSM	IO	2010–2060	5	Global	RW, LR
(Galik and Abt 2012)	SRTS	RD	1–25	1	VA	RW, LR
(Lauri et al. 2012)	EUFASOM	IO	2010–2040	5	EU	RW, MR, LR
(Sedjo and Tian 2012)	TSM	IO	1–100	1		RW
(Chudy et al. 2013)	SRTS	RD	2008–2038		SE	RW, LR
(Latta et al. 2013)	FASOM	IO	2010–2040	5	US	RW, MR, LR, AR, DE, SR
(White et al. 2013)	FASOM	IO	2005–2035	5	US	RW, MR, LR, AR, DE, SR
(Nepal et al. 2013)	USFPM	RD	2010–2060	1	US	RW, MR, LR

[a] EFI-GTM, European Forest Institute Global Trade Model; EUFASOM, European Forest and Agricultural Sector Optimization Model; FASOM, Forest and Agricultural Sector Optimization Model; FFSM, French Forest Sector Model; ForENER, Finnish Forest Energy Model; GFPM, Global Forest Products Model; NTM, Norwegian Trade Model; SRTS, Sub-Regional Timber Supply Model; TSM, Timber Supply Model; USFPM, United States Forest Products Module

[b] IO, Intertemporal Optimization; RD, Recursive Dynamic

[c] US, United States; SE, Southeast; TN, Tennessee; VA, Virginia

[d] RW, Roundwood; MR, Milling Residuals; LR, Logging Residues; AR, Agricultural Residues; DE, Dedicated Energy Crops; P, Pellets; SR, Short Rotation Woody Crops; ST, Stumps

METHODS

This analysis uses an integrated approach whereby the regional harvest effects of a hypothetical RPS policy are first determined from state-level electricity production projections and renewable generation carve-outs, then applied within a multi sector model of United States, and finally downscaled to the subregional level. Using FASOMGHG allows the ramifications of the regional policy to be evaluated across multiple regions and economic sectors, namely forest and agriculture. Specific time-series of harvest levels across the South, defined here as the states of Alabama, Arkansas, Florida, Georgia, Louisiana, Mississippi, North Carolina, Oklahoma, South Carolina, Tennessee, Texas, and Virginia, are then disaggregated using SRTS to evaluate the sub-regional comparative advantages of feedstock supply.

Determination of Regional RPS Configuration

The hypothetical regional RPS evaluated here is based on the characteristics of existing state-level standards. As of July 2013, 30 U.S. states had enacted RPS policies, most in the early 2000s (Figure 1). In addition to traditional RPS mandates, an additional eight states have set non-binding targets, so-called renewable portfolio goals. These goals are typically in the 10%–20% of overall electricity generation range for some target year between 2015 and 2025; West Virginia has a 25% target by 2025 (DSIRE 2013). The most common target year is 2025, occurring, on average, 17 years after the policy is enacted. RPS policies also differ in their target percentage of renewable generation, both for start years and target years; the average overall starting percentage is 6.2% for the first year of the RPS and 20.2% for the target year.

RPS policies typically apply to all investor-owned utilities (IOU) within a state. Municipally owned utilities, rural electric cooperatives, and retail suppliers often have targets similar to but lower than those for IOUs. For example, the two-level North Carolina RPS sets a target of 12.5% overall renewable generation for IOUs, but a slightly lower 10% target for municipally owned utilities and rural electric cooperatives. Although some RPS policies follow a linear annual percentage increase, the average year-to-year increase in RPS (fractional) target percentages is 4% across all states.

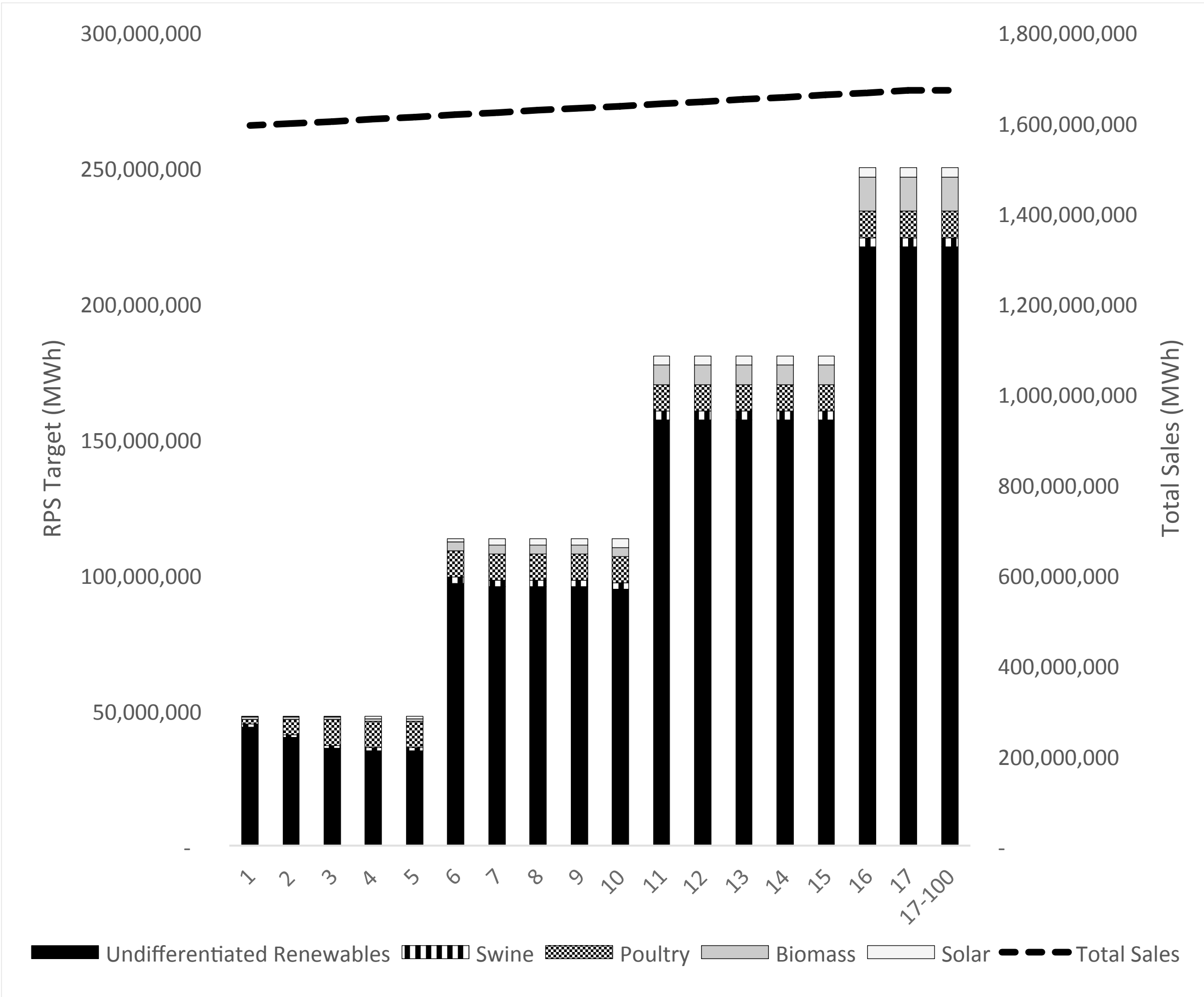
Of those states with RPS targets, a few states have separate targets or "carve-outs" for manure and biomass energy. Specifically, the North Carolina RPS has swine gas and poultry manure bioenergy targets, whereas the New Hampshire and New Mexico RPSs have a defined biomass carve-out. New Hampshire has a 3.6%–8.0% carve-out that includes biomass and methane, and New Mexico has a 5.0%–10.0% combined biomass, hydroelectric, and geothermal carve-out. To demonstrate compliance with state RPS policies, electric utilities use a system to issue and track renewable energy certificates (RECs). Typically, utilities having the lowest cost to meet RPS targets can generate additional RECs, which can be sold to those utilities that cannot meet RPS targets because of higher costs associated with electricity generation from renewables.

On the basis of the characteristics of existing RPS targets described above, the generalized RPS framework of this analysis assumes that a policy enacted in year 'x' will have its first target set for year x+5 and a final target year at x+17. In the scenario modeled below, we assume a 2010 start year and a final target year of 2027. The average starting percentage of generation is 6.2%, and the final target percentage is 20.2%. The annual target increases by 4.1% annually, ranging 0% to 15%. Given data from states with biomass carve-outs, 5% of total generation is likewise a reasonable assumption. These targets are applied to state electricity sales as reported in Energy Information Administration (2012b) and are assumed to grow at a rate of 0.3% per year thereafter.[1] The state level targets are then aggregated to yield a single regional goal for any given year (Figure 1). The analysis assumes that REC trading is allowed

[1] East South Central Residential Total Delivered Energy 2012–2040 growth rate is as estimated in Energy Information Administration (2014).

across all states in the region, the practical effect of which is that a generation facility may be located anywhere within the South.

Figure 1. Estimated residential energy sales and RPS carve-outs



Forestry and Land Use Change Simulation Modeling

Despite an effort to directly utilize the FASOMGHG and SRTS modeling structures of Latta et al. (2013) and Galik and Abt (2012), respectively, some changes in parameterization and modification of bioenergy policy implementation were necessary to integrate the simulations in the most appropriate manner. The following sections describe differences among each model's specification in the aforementioned studies and application for this analysis.

Forest and Agricultural Sector Optimization Model with Greenhouse Gases (FASOMGHG)

FASOMGHG simulates the U.S. agriculture and forest sectors through an inter-temporal optimization of markets for numerous agriculture and forest products while meeting biofuels and bioenergy targets (Beach et al. 2010). Because the agriculture and forest markets are balanced simultaneously, the resulting land use allocation within and between sectors as well as choice of feedstocks (including residues and dedicated energy crops) for biofuel processing or bioenergy generation is endogenous. A full description of the basic FASOMGHG structure and parameterization can be found in Beach et al. (2010), with specifics related to the bioenergy sector in Latta et al. (2013).

Prior bioenergy studies conducted with FASOMGHG (McCarl et al. 2000; White et al. 2013) have utilized a national-level policy with feedstock source and regional distribution determined optimally through the net social surplus maximization. For this work, the RPS policy was applied at the regional level through electricity output targets, which then were to be met within that region as determined optimally by the model. Evaluation of initial simulations from FASOMGHG and SRTS indicated a fundamental difference in the generation of logging residues at similar harvest levels. FASOMGHG's forest sector parameterization is based in large part on the 2005 RPA (Haynes et al. 2007); factors relating the cubic feet of growing and non-growing stock logging residues generated per cubic foot of growing stock timber harvested come from Smith et al. (2004). The resource update for the 2010 RPA (Smith, Miles, Perry, and Pugh 2009) included logging residue generation factors for the South that increased by 50% for hardwoods and doubled for softwoods; these newer values more closely approximated the SRTS values and thus were adopted in this version of FASOMGHG.[2] The result is a significant increase in the availability of logging residues for bioenergy generation.

The model is an intertemporal optimization model; therefore, it simulates agriculture, forestry, and bioenergy decisions in a way that allocates resources in the most efficient fashion to achieve the greatest benefits over time. This optimal resource allocation over time is based on an assumed perfect knowledge of current and future market and resource conditions, allowing simulation of current management choices that affect production choices in the future. For example, considering one of the RPS scenarios in this analysis, simulation results would show forest managers in the South immediately increasing area allocated to pine plantation in such a way as to meet the RPS policy goal and take advantage of the higher log prices in the future. Hence, market simulations from an intertemporal optimization model should be viewed as a best potential allocation of sectoral resources. These simulations are intended to be compared to another optimal market allocation without the policy or market shock. Thus it is the changes in harvest and biomass utilization in response to this analysis' RPS scenarios rather than aggregate values that are employed as shifts in the base level of harvesting and biomass utilization of SRTS.

Sub-regional Timber Supply (SRTS) Model

SRTS was developed to take advantage of detailed forest resource information and regional market parameters from the U.S. Forest Service's Forest Inventory and Analysis (FIA) database so as to estimate forest resource dynamics, harvest response, and market consequences at a sub-regional (e.g., multi-county) level (Abt et al. 2009; Prestemon and Abt 2002). It models product demand as a function of product stumpage price and demand shifts through time. The SRTS model uses constant elasticity functional forms. Product supply is modeled as a function of product stumpage price and inventory. The product price and harvest levels by product, subregion, and owner are simultaneously determined in the market equilibrium calculations. In each year, the output from the market module is an equilibrium harvest by product for each region-owner combination. The inventory shift for the equilibrium calculation is estimated using empirically based growth derived from regional Forest Service data, harvest from the market equilibrium module, and land use change.

The model is a recursive dynamic model; therefore, it simulates forestry and bioenergy decisions in a way that allocates resources in the most efficient fashion for the current time period and then updates resource and market conditions between periods as it moves through time. To continue the example of a response to one of this analysis' RPS scenarios, simulation results would show forest managers in the South waiting for a price signal before increasing area allocated to pine plantation in a way that meets the RPS

[2] In 2004, according to Smith et al. (2004, Table 40), the South generated 0.10 and 0.36 cubic feet of logging residues per cubic foot of growing stock harvested for softwoods and hardwoods, respectively. In 2009, Smith et al. (2009, Table 40) found that those values had increased to 0.20 and 0.52.

policy goal and takes advantage of the higher log prices. Hence, market simulations from a recursive dynamic model should be viewed as a best likely market response to a policy and market shock; they would have more variation in projected prices.

Estimation of Regional and Sub-regional Feedstock Effects

The five-year averages for the hypothetical RPS biomass carve-outs were added as minimum biomass-derived electricity production levels in FASOMGHG. In addition to the biomass necessary to meet RPS targets, the analysis included forest- and agriculture-based biomass demand for use in biofuel production stemming from compliance with the renewable fuel standard (RFS2). The analysis employs the reference case of the U.S. Energy Information Administration's Annual Energy Outlook for 2012 (Energy Information Administration 2012a) to shift bioenergy targets through 2035, then hold those levels constant through the remainder of the simulation.[3] Although aggregate U.S. biofuel production of conventional and cellulosic ethanol and biodiesel is fixed, the regional distribution and feedstock choice is determined by the model. [4] Collectively, the consequence is an additional biomass demand of roughly 1,000 GWh/year in the early years of the projection. This demand increases to approximately 12,500 GWh/year on full implementation of the RPS.

FASOMGHG was solved for both with and without the five-year periodic RPS targets through 2080. The resulting harvest levels for the Southeast and South Central regions were then used to create an index by which to shift base harvest levels from a SRTS-generated, without-bioenergy baseline production target. The SRTS model runs for the hypothetical RPS scenario consisted of annual solutions through the year 2050.

RESULTS

Aggregated FASOMGHG Results

A significant amount of biomass is necessary to meet the regional RPS modeled here. The dominant source of biomass to meet the RPS targets comes in the form of logging residues, though some mill residues and short rotation energy crops are likewise included in the total. Once the RPS is fully implemented, more than 12 million tons of woody biomass are used for energy, though year-to-year totals fluctuate as power plants shift capacity from more efficient low levels of co-firing to higher, less efficient levels of co-firing. The peak of production in 2035 marks the point at which this transition occurs and bioenergy production actually exceeds the RPS mandate.

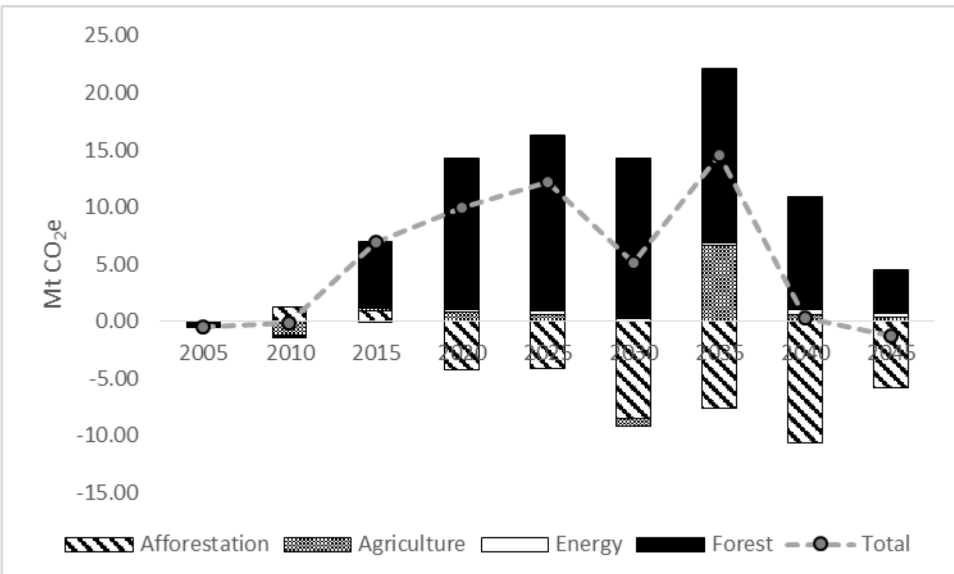
Harvests are increased and reallocated across regions to supply the necessary logging residues. This in turn has a strong effect on forest land use. Pine plantations, in particular, show a strong response to the imposition of a regional RPS. Agricultural feedstocks play a minor role, however, as sensitivity analyses restricting biomass to the forest sector showed little difference with those allowing feedstock from both agricultural and forest sources (see Appendix). This finding is in line with previous studies of bioenergy policy effects in the region, which likewise assumed a large relative contribution from forest biomass (Abt et al. 2010a; Abt et al. 2010b; Galik et al. 2009), but it contradicts prior studies that evaluated bioenergy policy at the national level, where dedicated energy crops and agricultural residues tend to play a larger role (Latta et al. 2013; White et al. 2013).

The hypothetical regional RPS is also shown to have significant GHG implications. In 2025, shortly after the full target is met, GHG storage in both the forest and agriculture sectors of the South is higher than it would have been absent the RPS (Figure 2). By the end of the projection period, however, net carbon storage in forest and agriculture sectors falls into negative territory in the South. Forest totals are higher

[3] Energy Information Administration (2012a) assumes that the RFS2 levels of cellulosic biofuel will continue to be adjusted downward consistent with waiver provisions contained in the Energy Independence and Security Act.
[4] Electricity generated using lignin recovered in the cellulosic ethanol production process is not considered applicable to our hypothetical RPS.

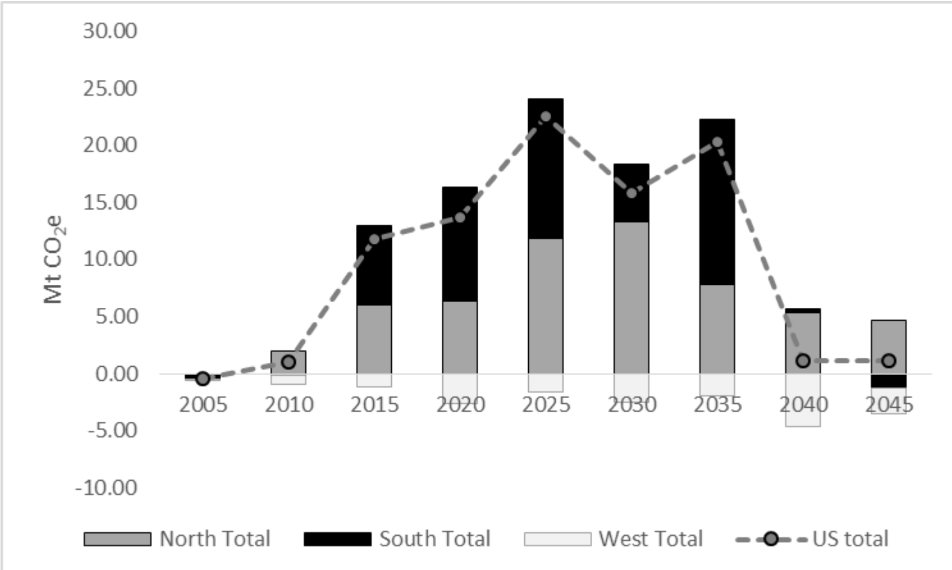
with the RPS as greater investment is made in pine plantations. Afforestation totals are lower because there is less afforestation in the RPS scenario than in the base case, as the model makes greater use of planted pine to meet increased demand. Agriculture accounts are similarly affected, because less land is converted to forest. Hence, a larger amount of land (and therefore carbon) is retained in agricultural production. Timing is also a factor. For example, the rather large sequestration shown for agriculture in 2035 is the result of a shift in acreage from pasture to crop (pasture soils have more carbon) that occurs in 2035 in the base case but that occurs in 2040 in the RPS case.

Figure 2. Cumulative change in carbon storage in the South attributable to implementation of the regional RPS, disaggregated by source



Examining changes in other regions attributable to implementation of the RPS in the South, we see that the North (comprised of the Corn Belt, Lake State, Great Plain, and Northeast FASOMGHG regions) experiences aggregate carbon storage gains, whereas the West (comprised of the Pacific Northwest-East and -West, Pacific Southwest, Southwest, and Rocky Mountain FASOMGHG regions) displays a slight decline in carbon storage (Figure 3). This result is due to a reallocation of harvests to meet demands in the forest and agriculture sectors as harvests are reallocated to account for the imposition of the RPS in the South. Planted pine is added in the South, and softwood harvests slow in the near term to boost harvests in the long run. The reduced near-term harvest activity in the South triggers an increase in softwood lumber production in the West, drawing down inventory and associated carbon stocks. The shift to planted pine in the South likewise triggers a response toward hardwoods in the North, in which near-term harvests are reduced to allow long-term inventories to increase. By the end of the projection period in 2045, the North continues to display a net gain in carbon storage, whereas the West displays a small decline similar to that seen in the South.

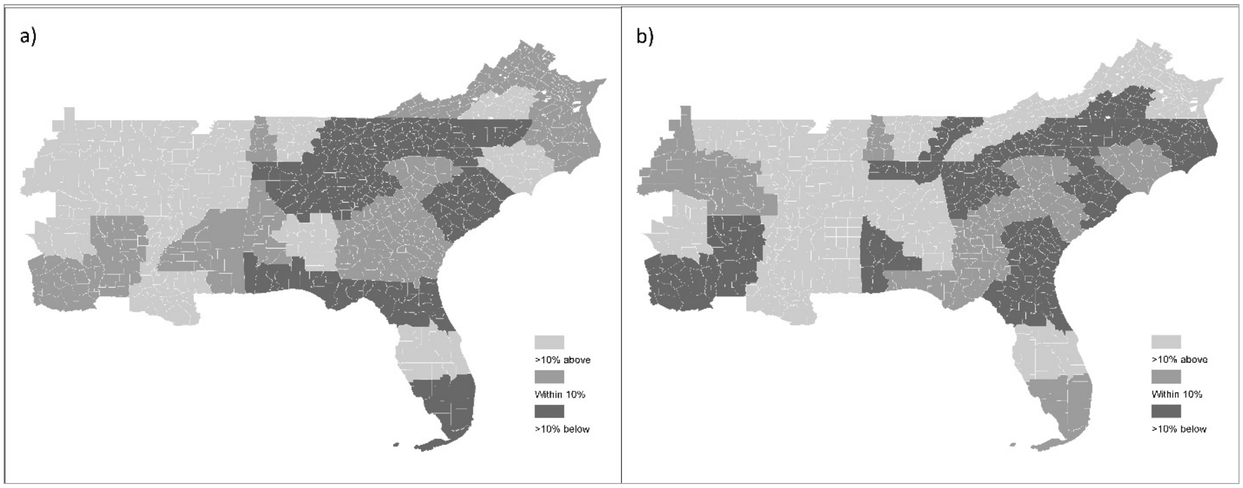
Figure 3. Total U.S. cumulative carbon storage and cumulative change in carbon storage over time attributable to implementation of the regional RPS in the South



SRTS-downscaled Results

Allocation of FASOMGHG-derived harvest data to the subregion using SRTS provides an indication of relative comparative advantage. As seen in Figure 4, some areas of the coastal plain (e.g., South Carolina and north Florida) experience lower-than-average softwood pulp removals as a result of a decline in recent planting activity in the coastal plain, which lowers the long-term availability of material to meet additional harvest demand. Areas of Mississippi and Alabama have not experienced this decline and are continuing to expand their plantation base. Over time, these same trends are reflected in softwood sawtimber, reflecting the temporal connection between pulp and sawtimber inventories. Trends in regional comparative advantage are much more heterogeneous in both hardwood pulp and sawtimber as areas of relative advantage and disadvantage are dispersed across the region in patchwork fashion (see Appendix).

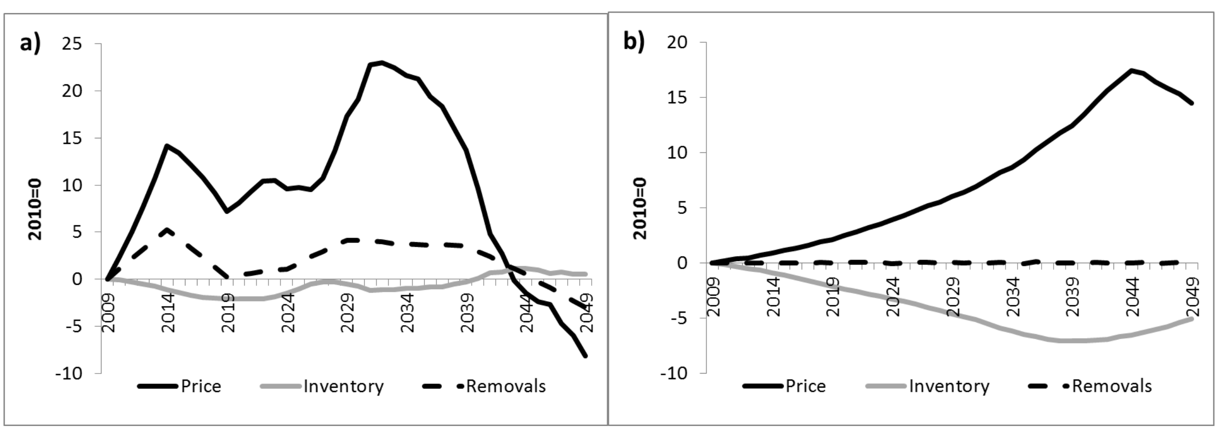
Figure 4. Allocation of FASOMGHG harvest data across the Southeast using SRTS for (a) pine pulpwood and (b) pine sawtimber



Note: Data indicate the relative difference against the FASOMGHG estimate for change in regional harvest activity. An increase indicates that an area is experiencing a harvest change higher than the regional estimate, while a decrease suggests that an area is experiencing a change lower than the regional estimate.

The net changes in pine pulpwood and sawtimber price, removals, and inventory stemming from the regional RPS are shown in Figure 5. The onset of biomass demand leads to a small increase in pine pulpwood removals and to upward pressure on pine pulpwood price as inventory remains constant. Pine sawtimber is indirectly affected as pulpwood is increasingly utilized to meet additional demand fostered by the onset of the RPS. With less pulpwood available to grow into sawtimber-sized material, inventory gradually falls relative to the base, no-RPS scenario, and prices rise. Hardwood product classes are also affected but display smaller price changes than softwood classes (see Appendix).

Figure 5. Price, inventory, and removals change indices for (a) pine pulpwood and (b) pine sawtimber



Note: Data indicate relative change against a baseline, no-RPS scenario.

Changes in price may lead to other indirect effects. An increase in price reflects implied scarcity. In response to higher prices and competition for scarce resources, harvests may be reallocated away from existing users to new users of biomass. This phenomenon, called leakage or displacement, is commonplace in analyses examining the market implications of increased demand for biomass in the southern United States (Abt et al. 2010b; Galik et al. 2009) and in the dynamics of timber markets more generally (e.g., Wear and Murray 2004). Setting a minimum harvest target, as is this analysis, rather than meeting a set demand, as in Abt et al. (2010a, b) and Galik et al. (2009), does not allow for an estimation of the extent of leakage or displacement that occurs as a result of the RPS. The observed change in price does, however, suggest that such a reallocation may be occurring, as evidenced in the interregional shifts in carbon storage shown in Figure 3. The carbon storage responses seen in the North and West regions would not be expected absent these indirect effects.

At the end of the projection period, the net change in forest carbon stock exhibits a large degree of spatial heterogeneity (Figure 6). Generally speaking, the eastern portion of the region experiences gains in carbon stock, while the western portion experiences greater instances of loss. Comparing carbon stock trends with those in harvest, particularly softwood (Figure 4), suggest that carbon stocks tend to be relatively higher in areas where SRTS-downscaled harvest was lower than the FASOMGHG regional prediction. The surge in demand associated with the RPS raises rents to forest land ownership, which after 20 years leads to higher forest carbon stocks. This phenomenon helps offset some of the price-dampening effect of higher sawtimber inventories in the base run and leads to less decline in timberland acreage. When the bioenergy-based planting surge reaches merchantability, pine pulpwood and sawtimber prices decline (Figure 5), and the resulting loss in timberland area leads to a decrease in forest carbon by the end of the projection.

Figure 6. Change in forest carbon stock by survey unit attributable to the regional RPS in (a) 2029 and (b) 2049

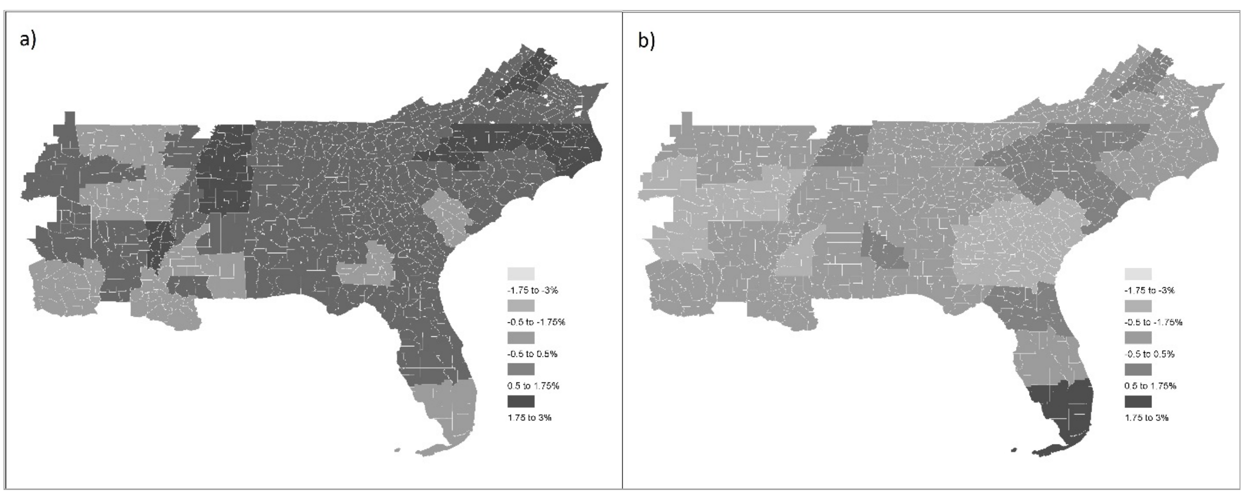
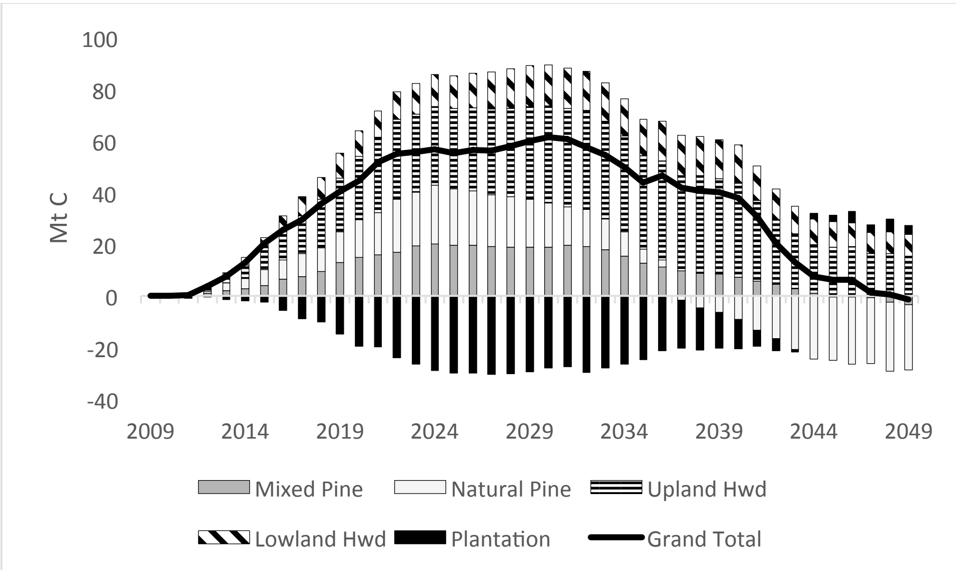


Figure 6 provides a snapshot of aggregate carbon storage at the end of the RPS projection period, but both aggregate storage and carbon storage by forest management type vary substantially over time (Figure 7). The large demand for biomass leads to an increase in harvests from plantations, decreasing in-forest carbon storage. Countering this trend, the increased value of woody biomass also increases the rent of forestland relative to other uses, leading to an increase in carbon storage relative to a scenario in which a regional RPS does not exist.

Figure 7. Change in forest carbon in response to imposition of a regional RPS and changes in individual forest management type over time

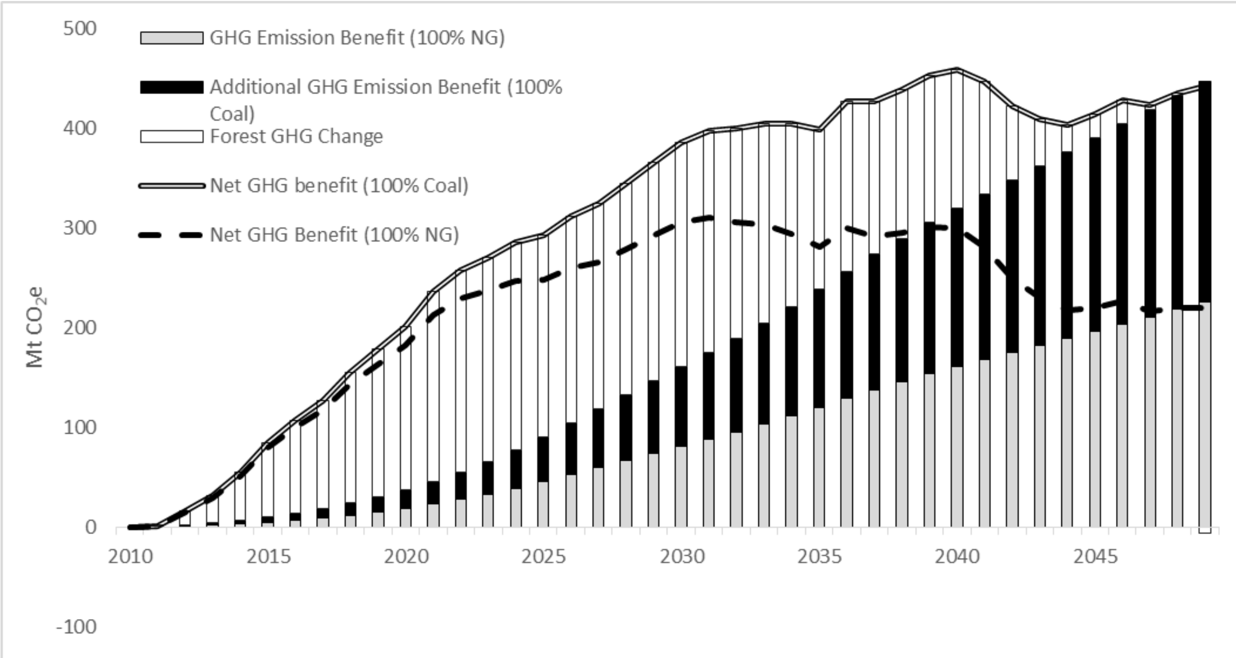


Note: Net forest carbon change is indicated by the black line and equals the combined change in forest carbon storage across all management types.

To estimate a range of potential impacts, the analysis calculates net emissions reductions under two extreme circumstances: all additional bioenergy capacity replaces existing coal and all additional bioenergy capacity replaces new natural gas (Figure 8). Owing to the higher per-MWh GHG emissions associated with coal (2,249 lbs CO2/MWh) than with natural gas (1,135 lbs CO2/MWh), the former scenario would be expected to generate highest level of GHG reductions, whereas the latter would generate the lowest.[5] The actual amount of GHG reductions would likely fall somewhere in between. Furthermore, Figure 8 reflects only the GHG implications of the policy within the southeastern United States. Policies such as the one modeled here can be expected to have indirect impacts beyond regional borders (see, e.g., Wear and Murray 2004). In this scenario, however, the RPS actually results in a net increase in GHG mitigation outside of the region (Figure 3), a phenomenon termed positive leakage. Including those estimates of increased GHG mitigation would only enhance the net mitigation effect of the RPS policy modeled here.

[5] Conversion rates indicate U.S. average for each fuel, and are derived from http://www.epa.gov/cleanenergy/energy-and-you/affect/air-emissions.html (last accessed August 28, 2014).

Figure 8. Change in forest carbon in response to imposition of a regional RPS along with estimate of displaced emissions

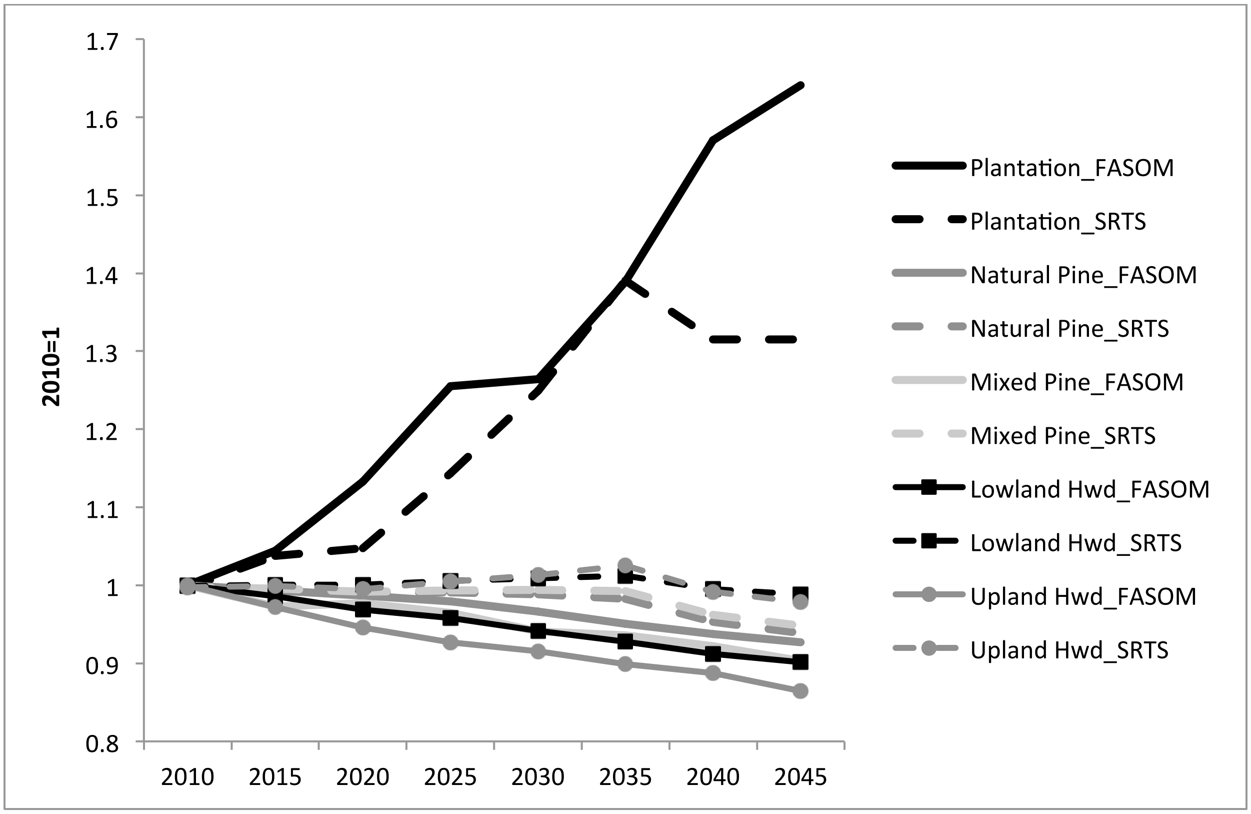


Note: The upper, double line indicates the carbon benefits of switching fuel and replacing 100% coal; the lower, dashed line indicates replacement of 100% natural gas-fired generation.

DISCUSSION AND CONCLUSION

Linking the FASOMGHG and SRTS models allows for an improved perspective on the effects of policy options on forest land use extent and composition. Despite important differences in model assumptions and data parameterization, output from the two models suggests that the models generally agree, at least with respect to general trends (Figure 9). These results provide additional confidence in the central conclusion of this analysis that forest biomass is the dominant contributor to a hypothetical regional RPS with biomass carve-outs. National data output from FASOMGHG suggests that a substantial reallocation of harvests can be expected over time, but that the magnitude of these changes will vary from period to period and that total changes will remain small relative to the total size of existing harvest activity.

Figure 9. Comparison of change indices for acres of each forest management type in response to the RPS scenario



Note: Index indicates the relative change of each forest management type in both FASOM and SRTS model projections relative to the starting acreage of that management type in model year 2010.

Downscaling FASOMGHG harvest data using SRTS, we find that implementation of the RPS will result in a small relative price increase relative to a no-RPS baseline. These price effects may nonetheless lead to changes in land use and harvest activity (figures 2, 3, 5, and 7). Resource conditions, including artefacts induced by previous planting and harvest cycles, in turn strongly influence the regional distribution of these changes (Figure 4). Collectively, these interrelated phenomena result in a spatially and temporally diverse forest carbon response. Changes across individual forest management types are especially pronounced; plantation and natural pine management types decline in forest carbon relative to a no-RPS scenario. Across all management types, net forest carbon in the Southeast is greater in the RPS scenario than in a no-RPS scenario in all but the final years of the model run. Inclusion of displaced emissions from either natural gas or coal-fired generation suggests that the RPS, on balance, leads to GHG reduction relative to a no-RPS scenario (Figure 8).

Other Policy Drivers and End-Use Applications

Although the focus here is on the implementation of a regional RPS, the aggregate demand for bioenergy created by that policy could also be substituted with or augmented by other policy drivers and demands for feedstock. Because only the aggregate demand is used as an input to this analysis, the policy driver leading to that demand is somewhat irrelevant for the model runs themselves. Crafting a meaningful policy driver and translating that driver into a quantity of biomass demand is necessary, however, to increase the relevance of the analysis to policy deliberations.

Accordingly, the demand attributed here to a regional RPS can also be thought of as also arising from a variety of other policy drivers. Export of wood pellets to European and other markets represents one such alternative demand. The demand for bioenergy estimated here under a regional RPS is consistent in magnitude with projections for U.S. South pellet exports as estimated by Lamers et al. (2014) and is within the range of exports as estimated by Cocchi et al. (2011). The extent to which pellets from the U.S. South are utilized to meet EU renewable energy goals will depend on the continued evolution of EU energy policy (Bullein 2014; European Commission 2014) and on the eligibility of U.S. producers to meet sustainability and chain-of-custody requirements (see, e.g. Abt et al. in press; Kittler et al. 2012). The comparative advantages created by the proximity of pellet facilities to port facilities for transport to the European Union also portends a different spatial story than the one modeled here, as demand for pellet feedstock will likely be greatest in coastal areas (Abt et al. in press).

Other potential drivers of renewable energy demand include forthcoming federal regulations to control greenhouse gas emissions. The U.S. Environmental Protection Agency is in the process of finalizing rules under section 111 of the Clean Air Act to limit carbon dioxide emissions from the power sector. The EPA proposed performance standards in January 2014 under section 111(b) of the act to control CO_2 emissions from new fossil fuel–fired power plants. It then proposed, in June 2014, its Clean Power Plan, which would regulate CO_2 emissions from existing power plants through section 111(d).

The Clean Power Plan provides each state with unique emissions goals, and states in turn must develop plans to achieve those binding goals. To comply, states can choose from a wide variety of strategies to reduce CO_2 emissions from existing power plants, including co-firing with biomass.[6] States may also work with other states to achieve a joint emissions performance level. The agency recognizes that states may wish to cooperate with one another to increase emissions reduction opportunities and capture low-cost reductions. Some states already participate in multi-state carbon reduction programs, and every state participates in electricity dispatch that crosses state borders. In this manner, implementation of the Clean Power Plan could create the sort of policy incentives to use biomass that are modeled here as a regional RPS.

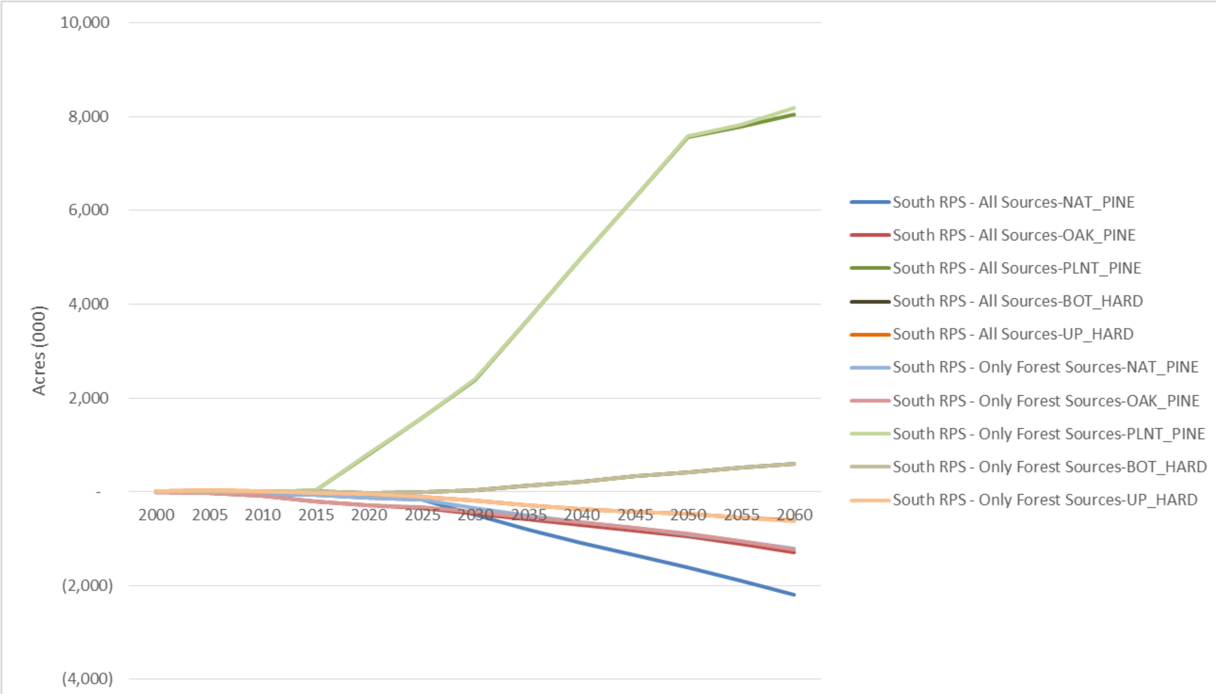
Future Work

Latta et al. (2013) and White et al. (2013) found that different feedstock mixes are chosen at different RPS levels. Research is necessary to evaluate the change in feedstock mix triggered by variation in targets. This study demonstrates that, for a given target, the regional allocation of the feedstock to meet the target can also change the optimal feedstock mix. This finding suggests that it may be hard a priori to determine policy impacts, as feedstock choice will ultimately affect GHG implications. Efforts to integrate FASOMGHG and SRTS models so as to increase our understanding of the environmental and economic consequences of new or untested policy options continue. These efforts will better integrate the two model platforms, explore the consequences of reversing the direction in which data are passed (i.e., from SRTS to FASOMGHG), and evaluate the implications of alternative policy designs.

[6] When it comes to the guidance on quantifying the carbon intensity of biogenic fuel sources, however, the proposals defer to a recently released draft biogenic accounting framework.

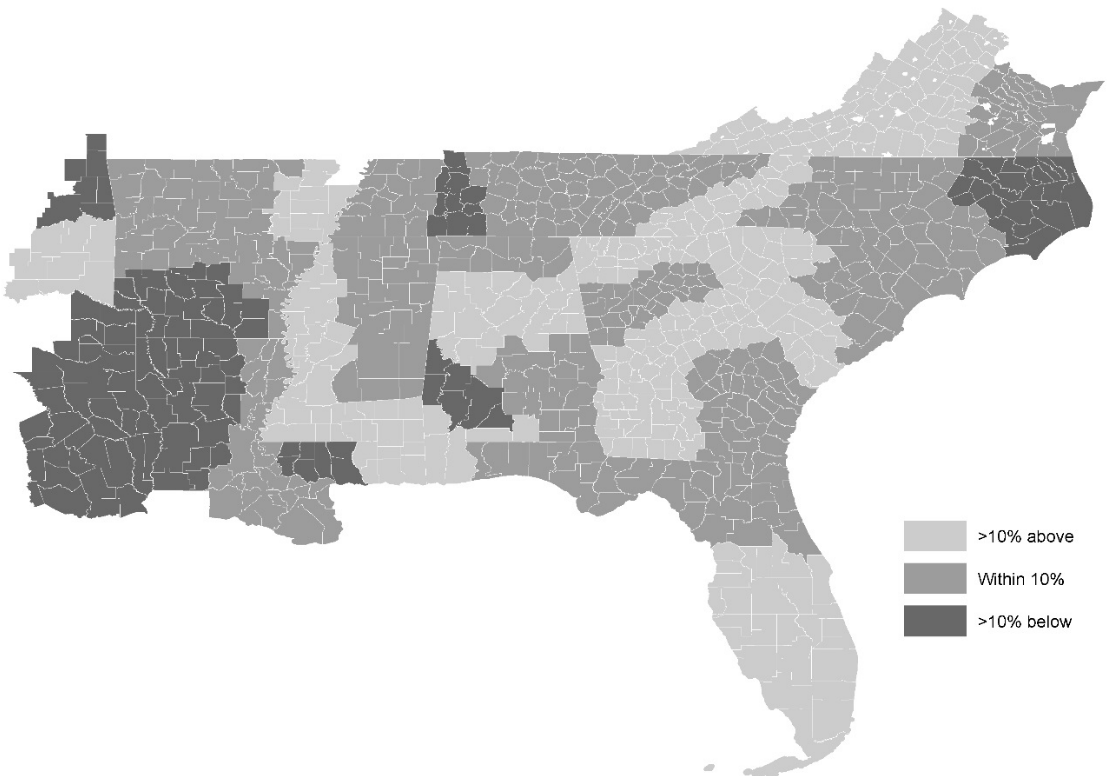
APPENDIX

Figure A1. Change in forest extent under alternative supply assumptions



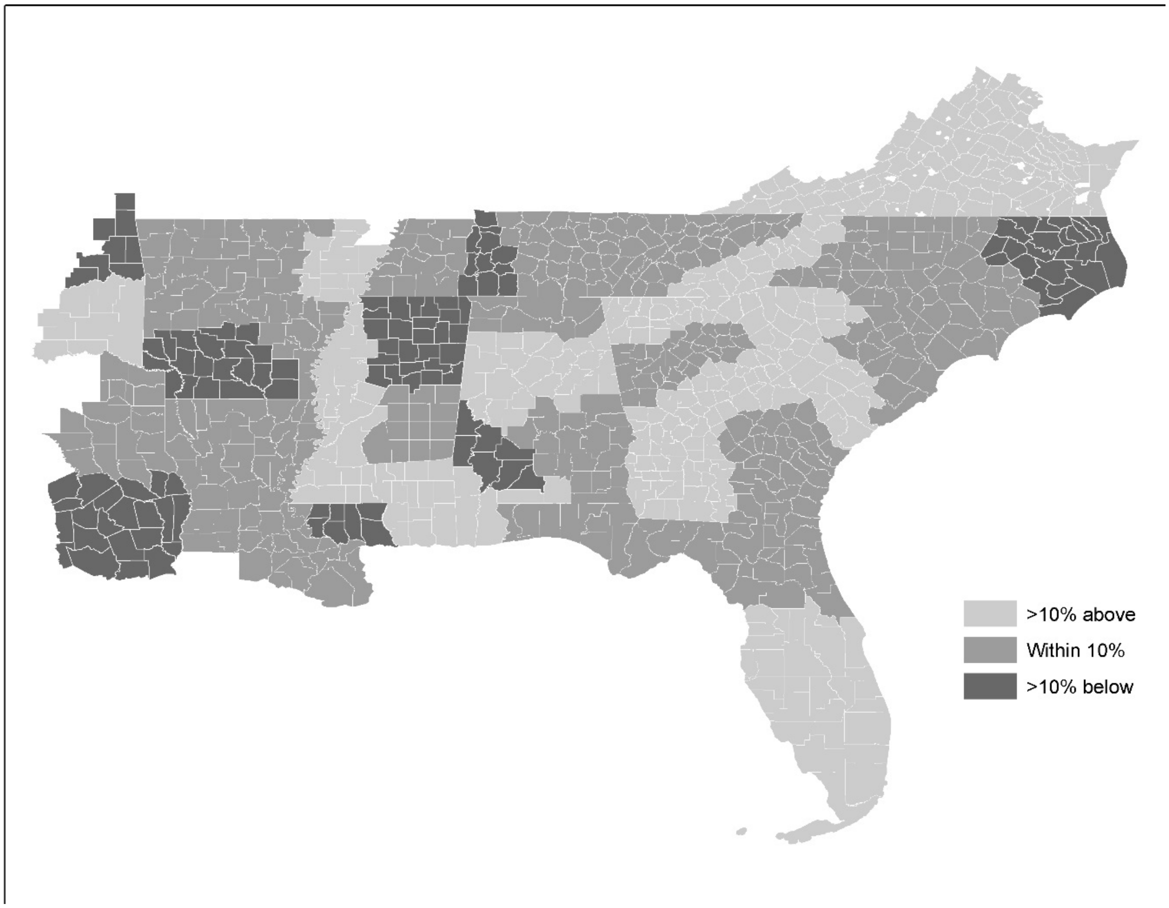
Note: One scenario allows all biomass sources to meet RPS targets, whereas the other limits supply to only forest-derived sources of biomass. The similarity in projections across scenarios suggests a limited contribution from non-forest sources of biomass.

Figure A2. Allocation of FASOM hardwood pulpwood harvest data across the Southeast using SRTS



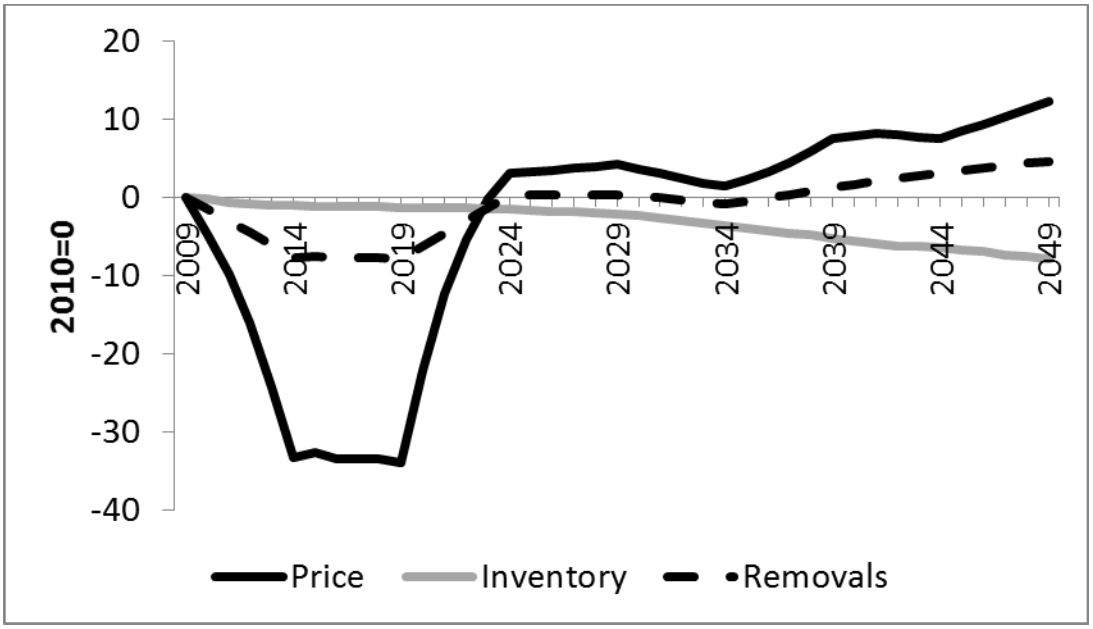
Note: Data indicate the relative difference against the FASOM estimate for change in regional harvest activity. An increase indicates that an area is experiencing higher than the regional estimated change in harvest, whereas a decrease suggests that an area is experiencing a lower level than the regional estimate.

Figure A3. Allocation of FASOM hardwood sawtimber harvest data across the Southeast using SRTS



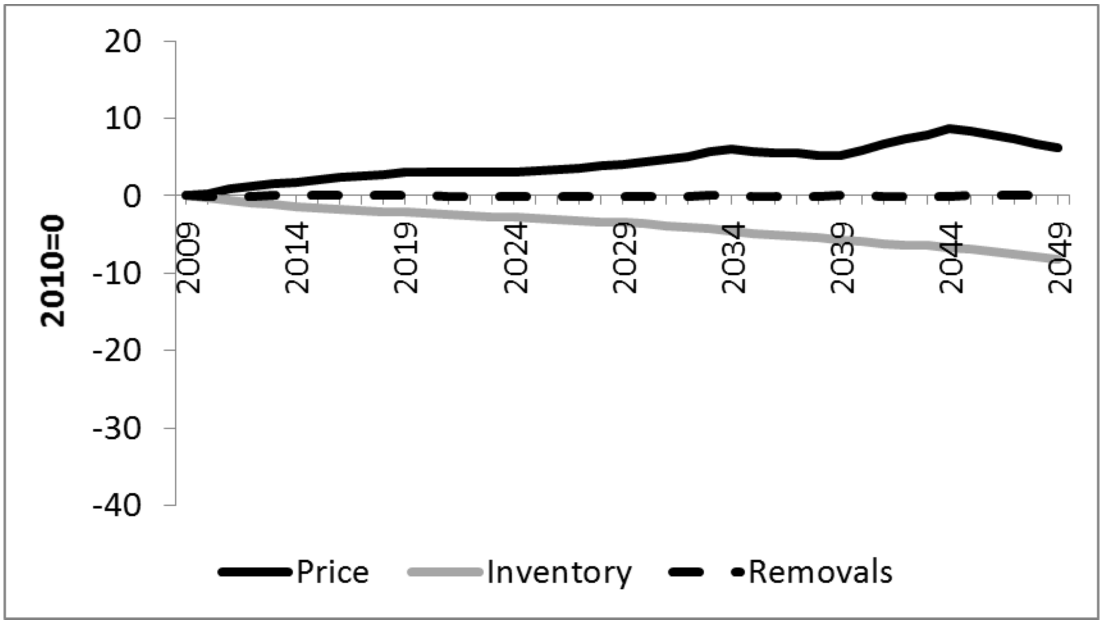
Note: Data indicate the relative difference against the FASOM estimate for change in regional harvest activity. An increase indicates that an area is experiencing higher than the regional estimated change in harvest, whereas a decrease suggests that an area is experiencing a lower level than the regional estimate.

Figure A4. Change indices for hardwood pulpwood



Note: Included are indices of price, inventory, and removals. Data indicate relative change against a baseline, no-RPS scenario.

Figure A5. Change indices for hardwood sawtimber



Note: Included are indices of price, inventory, and removals. Data indicate relative change against a baseline, no-RPS scenario.

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