CLIMATE CHANGE POLICY PARTNERSHIP

The Near-Term Market and Greenhouse Gas Implications of Forest Biomass Utilization in the Southeastern United States

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WORKING PAPER

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Executive Summary

The following analysis explores the potential near-term impacts of expanded forest biomass use in the Southeastern United States. We estimate the boiler-specific amount of energy that could be potentially met from forest biomass when maximizing co-fire potential in existing coal-burning facilities across ten Southeastern states: Alabama, Arkansas, Florida, Georgia, Louisiana, Mississippi, North Carolina, South Carolina, Tennessee, and Virginia. We aggregate this demand both regionally and subregionally to account for spatial differences in both demand and supply of forest biomass. We then model the impact that this increased demand for forest biomass has on resource pricing, forest inventory, harvest removals, and by extension, on existing users of the wood resource. Finally, we examine the greenhouse gas (GHG) implications of such a scenario and identify areas of further research necessary to build upon the initial findings relayed here.

When co-firing at maximum potential, we estimate an aggregate average co-firing rate of approximately 10.1% of total coal generation on a heat-input basis and a total co-fire demand of 59,188,213 green U.S. tons of forest biomass across the Southeast. This level of biomass consumption is equivalent to more than 532 million MMBTU, 5.3% of current nuclear, coal, and natural gas electric power sector energy consumption for the states in our study region, and a region-wide RPS of approximately 5%. Disaggregating the larger region into seven distinct supply subregions, we find that biomass demand varies significantly across the Southeast due to variations in coal-burning facility size, density, and the location and extent of existing industrial use. Despite this variation, increased pulpwood demand and the resulting increase in price are strong, exceeding 20% for both, in five of the seven supply subregions. All subregions are capable of meeting the biomass demand estimated here, but several factors affect the particular supply-side response. Most notably is the size of the forest resource relative to the pulpwood and electricity market demands placed upon it. Also important are the lingering effects of recent planting behavior, where reduced planting activity over the last several years limits the capacity for near-term harvest increases and amplifies the incidence of displacement of existing pulp and paper capacity. Collectively, this translates to differences in regional response: in some supply regions, specifically those in and around the Gulf Coast, a larger portion of co-fire demand is met through displacement. In others, co-fire demand may be met only through increased use of harvest residuals.

Comparing emission reductions attributable to reduced coal usage against changes in forest carbon storage attributable to increases in harvest of biomass, we estimate a maximization co-firing in the Southeast to achieve annual average emission reductions between a low of 8.6 $MtCO_2e$ per year in 2016 and a high of 27 $MtCO_2e$ per year in 2021 under a scenario in which 50% of available residues are utilized. These values equate to 0.4% and 1.1%, respectively, of year 2008 total U.S. electric power sector emissions. If only 25% of available residues are utilized, maximum average annual GHG emission reductions range from a high of approximately 23.3 $MtCO_2e$ per year in 2021, to a low of 8.5 $MtCO_2e$ per year in 2016, or 1.0% and 0.3%, respectively, of 2008 total U.S. electric power sector emissions. These estimates reflect the aggregate impacts of our modeled policy scenario, taking into account large-scale shifts in planting and harvest behavior occurring in response to market drivers over time. We do not account for changes in net emissions directly caused by displacement of current industrial users of forest resources, however, nor do we assess the GHG implications of activity shifted out of the immediate region. We note that this presents only a first-order assessment of potential changes, which are incomplete but likely to dominate in the short run.

Throughout our assessment, we make no assumption on the policy that drives the use of biomass, only that an incentive exists to reduce coal-fired electricity production, and that forest biomass, competitively priced and already possessing an established infrastructure, is the substitute fuel of first resort. Our use of boiler-specific estimates of co-fire demand necessitates that we assume both rates of co-fire adoption and that no coal facility construction, retrofit, or retirement occurs in the near term, whereas our estimation of forest industry production impacts is dependent upon projections of future industry performance. Indeed, much more work is necessary, including more complete evaluation of the multiple factors explored here, to fully grasp the economic, social, and environmental implications of large-scale forest biomass utilization.

Introduction

Interest in renewable sources of energy is increasing for a variety of reasons, including the mitigation of climate change and furtherance of energy independence. This interest is reflected in an increasing number of both proposed and enacted regulations, programs, and initiatives. As of April 2010, 29 states and the District of Columbia had enacted Renewable Portfolio Standards (RPS) mandating that a portion of electricity come from renewable sources, while six other states had put in place renewable energy goals (DSIRE, 2010). At the federal level, a Renewable Fuel Standard (RFS) requires that ethanol and other renewable, biomass-derived fuels be supplied in increasing amounts between now and 2022, while the 2009 American Recovery and Reinvestment Act (ARRA) (P.L. 111-5) allocated $16.8 billion to renewable energy or energy efficiency improvements. In addition, the U.S. House of Representatives passed a bill in the summer of 2009 that would create a national RPS of 20% by 2020 as well as a cap on greenhouse gas (GHG) emissions (H.R. 2454, the American Clean Energy and Security Act of 2009); legislation to limit GHG emissions and encourage renewable energy production is likewise being discussed in the U.S. Senate (e.g., the Kerry-Lieberman American Power Act [May 12, 2010 Discussion Draft]; the Lugar Practical Energy and Climate Plan Act of 2010 [June 9, 2010 Discussion Draft]).

In the Southeastern United States, attention is often focused on the role that biomass can play in meeting these and other policy objectives (English et al., 2004). Although abundant, supply of forest resources in the Southeast is subject to ecological limitations, policy restrictions, economic constraints, and management decisions. For example, soil, site productivity, hydrology, and wildlife habitat may all be affected by greater harvest of forest biomass (Janowiak and Webster, 2010). Natural disturbance events due to weather, fire, or insect pests create spatial and temporal uncertainty in forest biomass supply. The manner in which biomass is defined in policy can likewise limit the amount of forest biomass that qualifies for renewable energy production. Finally, the biofuels, bioenergy, wood pellet, pulp/paper, and wood products industries will compete for access to forest resources. Their collective influence on the market for forest biomass, especially as it relates to the timing and extent of tree planting and harvest decisions, will affect the amount of forest biomass available in both present and future years.

Despite these multiple factors and potential limitations, the impact of renewable energy policy on biomass feedstock has not always been carefully evaluated prior to program inception (See, e.g., Sedjo and Sohngen, 2009). Multiple studies on potential aggregate supply exist (e.g., Pennock and Doron, 2009; Perlack et al., 2005), but relatively few studies explore the potential interplay between increasing resource demand for biofuel and bioenergy and the competition with current users of the resource. Those studies that do contemplate such resource competition (Galik et al., 2009; Lundmark, 2006) generally find that some degree of additional biomass utilization for biofuel and/or biomass purposes is possible, but that so-called tipping points do exist. The severity of these tipping points, along with the point at which they are encountered, have important implications for environmental objectives and the multiple users of the forest resource.

Complicating matters somewhat, past research evaluating competition under increasing forest biomass demand scenarios have generally used strong policy drivers that result in significant new demand for biomass resources. For example, a national 25% RPS and RFS showed the potential to exhaust forest residues in three Southern mid-Atlantic states early in program implementation (Galik et al., 2009). In a separate study, the portion of North Carolina's RPS that is not met by efficiency and set asides was projected to exhaust residuals and impact roundwood prices (Abt et al., *in press*). The question remains as to the effect of more moderate policy drivers, the type of which could be encountered in the early years of a significant policy shift as markets transition from traditional fossil fuels to renewable generation technologies and processes.

The following analysis explores such a policy scenario, specifically the market and emissions implications of near-term maximization of coal co-firing in the Southeast. We choose a scenario based on existing coal facility co-firing as it represents a cost-effective path to biomass utilization in the near term (Robinson et al., 2003; Federal Energy Management Program, 2004; De and Assadi, 2009; Lintunen and Kangas, 2010). Though conversion to co-firing is not without capital cost, especially if a separate fuel feeding system is required, construction of dedicated, low-GHG generation facilities can be more costly and take longer (De and Assadi, 2009).[1]

While we assume that there is an incentive to add biomass to the combustion mix, we make no determinations about the specific type of policy that creates the incentive. Among policies currently being discussed, a GHG cap-and-trade program, carbon tax, or RPS could all provide an incentive to substitute woody biomass for coal. We also assume that forest biomass will be the primary means by which demand for biomass will be met. A wide variety of biomass feedstocks exist by which to satisfy both bioelectricity and liquid biofuel production demands, including agricultural residues (e.g., corn stover), urban wood wastes (construction debris, yard trimmings), and dedicated energy crops (e.g., switchgrass). Our assumptions over the primacy of forest biomass should not be taken as an indication of the lack of potential of these other feedstocks, but rather as a reflection on the existing familiarity, supply, infrastructure already associated with forest biomass.[2] Over time, the other feedstocks noted above may supplant forest biomass as a cost-effective source of biomass. In the short term, however, it is likely that much of the early demand will be met by forest resources.

Accordingly, the analysis that follows first estimates the amount of energy on a heat-input basis that would be potentially met from biomass when maximizing co-fire potential in existing coal-burning facilities across ten Southeastern states: Alabama, Arkansas, Florida, Georgia, Louisiana, Mississippi, North Carolina, South Carolina, Tennessee, and Virginia. We then aggregate this demand both regionally and subregionally to account for spatial differences in both demand and supply of forest biomass. We

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[1] That is not to say that there will be no additional demand for biomass for energy production in these or other applications (e.g., pellet production), only that co-firing represents an initial, near-term draw.

[2] Recent experience with the Biomass Crop Assistance Program (BCAP) is telling in this regard: under the initial rules for the program, 92% of payments as of April 16, 2010 were for forest-related materials (Farm Service Agency, 2010; Forest2Market, 2010). See also Sedjo and Sohngen, 2009.

model the impact that this increased demand for forest biomass has on resource pricing, inventory, removals, and by extension, on existing users of the resource. Finally, we examine the GHG implications of such a scenario and identify areas of further research necessary to build upon the initial findings relayed here.

Methods

A necessary first step in determining the potential of forest biomass for co-fired electricity generation in the Southeast is to define the region and align the datasets used for the assessment. Second is to determine the amount of biomass necessary to meet electricity generation demands under a maximum co-fire scenario. The third step is to evaluate the timber supply implications of this increase in demand, with particular emphasis on price and inventory effects. Finally, we assess the generalized net GHG implications of increased use of woody biomass.

Data Sources

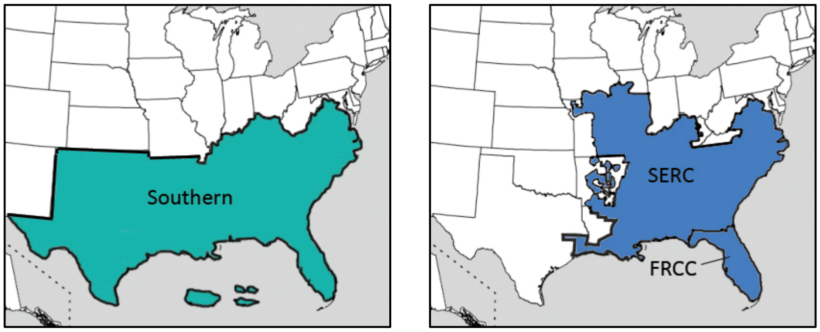
Data for individual coal-fired facilities are available through the U.S. Environmental Protection Agency's Emissions and Generation Resource Integrated Database (eGRID) (U.S. Environmental Protection Agency, 2008). eGRID lists technical specifications and emissions for every boiler, generator, and facility in the United States, and can be filtered to allow for targeted examination by particular attribute, such as state, facility name, and heat input.

Forest resource inventories are conducted by the U.S. Forest Service under the Forest Inventory and Analysis Program (FIA), an annual survey of permanent forest plots that provides information on tree species, size, growth, location, and removals along with various other parameters (U.S. Forest Service, 2005). This information is then used by the Subregional Timber Supply (SRTS) model (Abt et al., 2009), taking note of market conditions and planting and harvesting behavior, to provide short-to-midrange projections of the changes in the forest resource base. Greater discussion of the SRTS model and its application here is provided below under Biomass Demand.

Defining the Regions

Each of the data sources identified above is based on a different definition of the Southeast (Figure 1). FIA defines a Southern region which includes Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, Oklahoma, Puerto Rico, South Carolina, Tennessee, Texas, the U.S. Virgin Islands, and Virginia, though data can be subdivided by state and survey region, all the way down to the individual county level. In eGRID, data can be filtered by state or by North American Electricity Reliability Corporation (NERC) region. The eGRID subdivision that most closely resembles the Southeast for the purposes of our present analysis is a combination of Southeastern Electric Reliability Council (SERC) and Florida Reliability Coordinating Council (FRCC) regions. It is possible, however, to define a Southeastern region comprised of whole states in the FIA and eGRID datasets, as both can be sorted on a state-by-state basis. This allows us to define a common region for both datasets and assess increasing demand for woody biomass and the resultant impacts to the forest resource (Figure 2).

Recognizing that significant biomass potential likewise exists outside of our study region, we limit our study to the ten-state area for several reasons. The first is directly related to the area covered by the SRTS model and its relationship to the regions as defined in the FIA and eGRID databases. Although all data used here are available at the state level, our intent was to align our study area as closely as possible to the larger regions included in these other databases. Our focus on the Southeast was also driven by the large amount of forest resources available, a base of existing users (i.e., forest products industry), and the relative scarcity of other renewable energy resources available in the near term.



FIA Southeast eGRID Southeast

Figure 1. States included in the Southeast region in the FIA, and eGRID datasets.

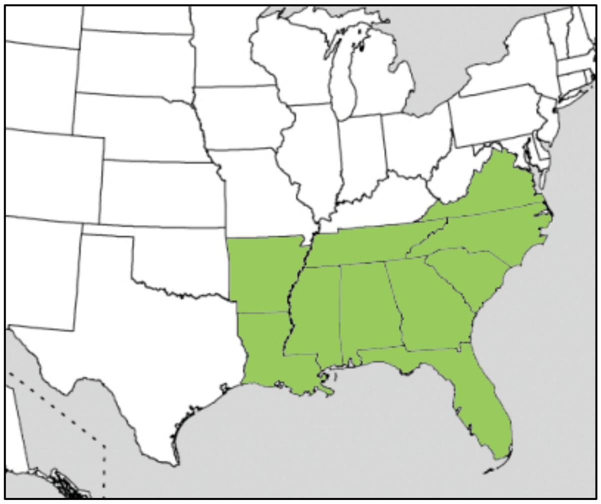


Figure 2. The Southeast region as defined by this study.

Scope of the Assessment

We conduct two general assessments of the impact of increased woody biomass demand, one that is region-wide and one that is spatially explicit. For the first, demand for woody biomass is determined for individual coal-fired facilities under a maximum co-fire scenario as described below, and then aggregated up to the regional level. This demand is then allowed to be met by forest resources from anywhere in our defined region; no restrictions are placed on the relationship between the location of the facility and the location of the biomass. To capture the spatial variability in forest types, age classes, and ownership structure the supply side is modeled as 49 separate supply regions based on FIA survey units, but does not consider the spatial distribution of consumption relative to the spatial distribution of resource supply.

The second assessment is based on an assumption that co-firing would only be feasible if resources can be sourced within a limited distance of the facility. In this scenario, we restrict forest biomass available to meet individual facility co-fire demand to that occurring in counties within a 50-mile radius of the facility. This simple exercise is complicated, however, by significant overlapping of individual facility supply areas.[3] To address this issue, we first aggregate overlapping counties into seven distinct supply subregions, within which any county may supply any facility (Figure 3). This requires us to relax our 50-mile limitation, as we now assume that any facility within a given subregion can be supplied with biomass from any county within that same region, but allows resources to be allocated in the most efficient fashion. As in the region-wide analysis, each subregion is made up of distinct resource supply areas to capture forest heterogeneity.

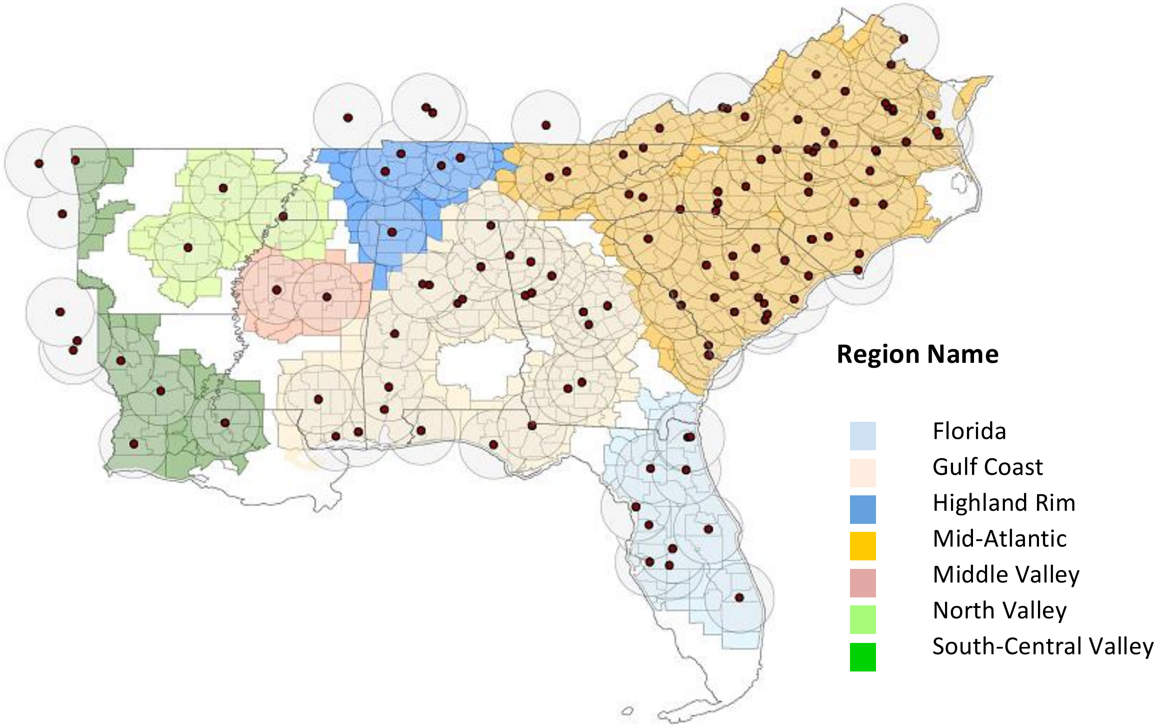


Figure 3. Supply regions used for the assessment of spatially explicit resource impacts. Coal-burning facilities potentially affecting counties in the Southeast region are indicated, as are 50-mile supply radii for each.

Biomass Demand

As discussed further below, determination of aggregate forest biomass demand under a maximum co-firing scenario is a relatively straightforward process. This is contrasted by the process of establishing the baseline trajectory for the forest products industry in the Southeast. Indeed, determining the baseline or BAU in any "with and without" comparison has the potential to predetermine the results.

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[3] For example, envision that two separate facilities each draw from three unique counties and one county that is common between the two. The impact of increased woody biomass demand on the forest resources in the shared county is a function of both the collective demand of the two facilities and the available supply in the other six counties.

This is particularly true when potential displacement of existing industry is being estimated. For example, if we assumed that existing industry would decline under the baseline case, biomass demand would be simply offsetting existing demand changes rather than displacing a competitive demand. Furthermore, the recent recession caused a dramatic downward trend in the forest products industry (Hilburn, 2009), and the degree and subsequent trajectory of industry recovery in the Southeast is quite uncertain.

In this study we assume that industry demand will return to pre-recession levels and remain constant. Specifically, we estimate a 30% decline in demand for four separate product classes (pine pulpwood, pine sawtimber, hardwood pulpwood, hardwood sawtimber) from 2006 to 2010 with a recovery to near pre-recession demand levels by 2013.[4] For the rest of the projection period, we hold demand at pre-recession levels. The recession impact lowers prices and postpones harvest which continues a trend of lower planting rates since the year 2000, which affect the age class distribution during the projection period.

Having set the baseline forest biomass demand scenario, we then calculate the biomass used under a maximization of coal co-fire capacity in the region. Year-2007 coal co-firing capacity for individual facilities is determined at the boiler level using the eGRID database.[5] As burner and furnace configuration affect the amount of biomass that can be co-fired,[6] a maximum co-fire rate is estimated from the literature for each unique boiler type (Table 1). In addition to boiler type, control devices used to scrub NO_x can also impact co-firing capacity. Some evidence suggests that selective catalytic reduction (SCR) reactors could be incompatible with biomass co-firing because alkali content in the ash blocks catalyst reaction sites that scrub NO_x (Baxter, 2005; Strege et al., 2007). Others, however, report successful co-firing with SCR reactors at rates of up to 10% on a heat-input basis (Livingston, 2007). Acknowledging the potential for performance issues, we set boilers employing either SCR or selective non-catalytic reduction (SNCR) at a maximum co-fire rate of 10%. As a whole, the co-fire rates detailed here represent a moderate outlook on co-firing capability consistent with other analyses.[7]

Data in eGRID was filtered further according to “primary boiler fuel”—only BIT (bituminous coal), LIG (lignite coal), SC (synthetic coal, or syncoal), and SUB (sub-bituminous coal) were selected. We remove facilities already co-firing biomass from the dataset so that our estimates of demand represent only new, additional woody biomass consumption. That is not to say that existing biomass consumption is not significant. In 2007, the Southeast generated 20.6 million megawatt-hours (MWh) of electricity from wood and wood-derived fuels (Energy Information Administration, 2009b). The overwhelming majority of this generation, 93%, came from combined heat and power facilities used by pulp and paper and other industries.[8]

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[4] One reviewer notes that our assumption of a 30% decline may be higher than the drop in production recently experienced by pulp and paper industries.

[5] eGRID2007 is derived from 2005 data but adjusted to reflect industry structure and conditions in place as of December 31, 2007 (E.H. Pechan & Associates, 2008).

[6] Fuel composition can also affect the mechanisms of combustion within different boiler types (Tillman, 2000).

[7] For example, the U.S. Department of Energy’s Energy Information Administration (EIA) permits rates of up to 15% in their assumptions (Energy Information Administration, 2009c).

[8] Indeed, the forest products industry produces approximately 55% of its own energy from wood residues and spent liquor (Murray et al., 2006).

Throughout our assessment, a number of unit conversions were necessary. Conversion between gross heat input and total green tons of biomass demand was especially important in our estimation of total biomass demand. The general equation used in the conversion is as follows:

$$Gross\ Coal\ Heat\ Input\ (MMBTU) * \frac{1M\ BTU}{1\ MMBTU} * \frac{1\ dr.lb.biomass}{9{,}000\ BTU} * \frac{2\ gr.lb.biomass}{1\ dr.lb.biomass} * \frac{1\ gr.ton}{2{,}000\ gr.lb.}$$

where 9,000 BTU per pound of dry biomass is the estimated energy content of wood. We acknowledge that different types of biomass have different energy content and that additional energy will be necessary to dry green biomass to achieve this energy content on a per-pound basis. Even so, the value falls in the upper-middle portion of estimates of biomass energy content[9] and is consistent with the conservative nature of other assumptions made herein.

Table 1. Maximum coal co-firing capacity, by heat input for multiple boiler types.

Boiler Type	Assumed Co-firing Rate By Heat Input
Cell	0.10 [a]
Cyclone firing	0.10 [a]
Dry Bottom, Stoker	0.20 [a]
Dry Bottom, Tangential firing	0.10 [a]
Dry Bottom, Turbo	0.10 [a]
Dry Bottom, Vertical firing	0.10*
Dry Bottom, Wall	0.10 [a]
Fluidized bed firing	0.15 [b]
(Listed as "Other" in eGRID)	0.10*
Stoker	0.20 [a]
Tangential firing	0.10 [a]
Wet Bottom, Tangential firing	0.10 [a]
Wet Bottom, Turbo	0.10 [a]
Wet Bottom, Wall	0.10 [a]
(Not Indicated in eGRID)	0.10*

[a] Grabowski, 2004

[b] Federal Energy Management Program, 2004

* No maximum co-fire rate was able to be determined for these boiler configurations; a maximum co-fire rate of 10% is assumed.

Scenario Construction

Our estimates of co-fire biomass demand are based on the type, size, and physical location of existing coal-fired boilers. To generate these estimates, we first assume that coal generation, defined in terms of unadjusted annual heat input, remains constant at levels reported in eGRID 2007, and that no facility construction, retrofit, or retirement occurs. We also assume that boiler type and configuration remain as reported in eGRID 2007 and that the locations of individual facilities do not change. Although it would be preferable to use a dynamic estimate of future coal generation from which to base our analysis, output from large-scale economic models such as the National Energy Modeling System (NEMS)

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[9] For example, http://bioenergy.ornl.gov/papers/misc/energy_conv.html (Retrieved March 26, 2010).

generally lack the resolution from which to evaluate the requisite spatially explicit impacts of increased biomass demand. We also assume that no additional dedicated biomass capacity is added, though evidence suggests that interest in dedicated biomass facilities in the Southeast is increasing.[10]

Our focus on the near-term effects of a policy "shock" should minimize any issues associated with our assumption that individual coal-fired facility operation and region-wide, aggregate generation remain constant. Over time, markets may adjust to the imposition of additional policy drivers. New dedicated facilities may be constructed to supply electricity generated exclusively by renewable energy sources or by lower-emitting fossil fuels (e.g., natural gas). Sustained demand for biomass may be met by increased cultivation of dedicated energy crops, such as switchgrass or hybrid willow or poplar. That being said, options for achieving GHG emission reductions in the existing coal electricity generation infrastructure are limited in the near term (next 10–15 years) (Zhang et al., 2010). Before larger shifts can be implemented, practices such as co-firing biomass at existing coal-fired facilities can be used as a near-term bridge. It is the impacts of these "bridge" practices and fuels used in a time of transition that we are most interested in exploring here.

Furthermore, a policy driver that provides an incentive to co-fire biomass is also likely to discourage continued expansion of coal capacity in favor of other fuels or technologies. To simply add in co-firing to off-the-shelf EIA projections that show expanding coal capacity across the region would model a policy scenario that simultaneously provides incentives to switch away from coal at the individual facility level yet somehow expand the use of it at the regional level. To suggest that such situations could not exist would require a naïve and simplistic view of the electricity generation market, but we find the assumption of static levels of coal generation to be more appropriate in this case. Finally, since it is not realistic that all facilities will immediately begin co-firing at the maximum rate in the first year of the analysis, we allow demand to be scaled up over a 10-year logarithmic horizon beginning in 2012, after which all eligible facilities fire biomass at the maximum identified rate. No reduction or loss in pre-co-fire efficiency is included here, though we acknowledge that some small losses may be possible when co-firing biomass (Mann and Spath, 2001; De and Assadi, 2009).

Biomass Supply

Supply effects of maximization of co-firing in the Southeast are assessed using the Sub-Regional Timber Supply (SRTS) model.[11] SRTS 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.

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[10] See, e.g., "NC utility seeks more for electricity from woody biomass." Biomass Magazine, January 2010. Retrieved February, 23, 2010, from http://www.biomassmagazine.com/article.jsp?article_id=3367.

[11] A detailed description of the SRTS model can be found in Abt et al., 2009 and Prestemon and Abt, 2002.

To simulate the impact of biomass demand, a baseline run of traditional wood-using industries is used to derive estimates of logging residuals. We assume that utilization of residuals would increase over time and peak at a 50% utilization rate in 2020. Utilized residuals were assumed to reduce biomass demand for roundwood. The net roundwood demand was then used to shift demand for both pine and hardwood pulpwood proportionately. The horizontal shift in the supply curve at current year prices leads to harvest and price increases in the market. Because empirical evidence shows that these markets are both supply and demand price-inelastic, the price effect is larger than the harvest impact (Pattanayak et al., 2002). We assume that co-firing demand was not price sensitive within the range of prices we examined.[12] Traditional industries are assumed to exhibit a demand price elasticity of 0.5 (Abt and Ahn, 2003). Together these assumptions allow us to model the increase in harvest and prices from the biomass demand increase and to disaggregate the co-firing feedstock sources into the following categories: 1) logging residuals, 2) increased roundwood harvest, 3) residuals from increased harvest, and 4) harvest from displaced traditional industry.

We note however, that the availability of biomass may be further constrained by policy. These potential constraints are especially important to consider in light of our assumption here that increased biomass utilization will be driven by the implementation of new policy, such as a carbon price, RPS, or RFS. Any limitations placed on what type of biomass may be used to meet policy mandates or where the biomass may be sourced can affect the overall supply of biomass as well as the price of the resource. For example, proximity of a coal facility to wood resources is an important consideration in determining the financial viability of co-firing. The definition of "renewable biomass," itself the focus of significant debate in recent years,[13] is another policy issue that will likely have strong implications for biomass supply.

Net Greenhouse Gas Implications

Not all of the potential policy drivers noted above are primarily focused on the reduction of GHG emissions, but the net GHG implications of fuel switching are nonetheless an important consideration in light of present concerns of global climate change and considerations of comprehensive climate policy. Interest in the net GHG emission implications of forest biomass utilization is likewise not a purely recent phenomenon. Over the course of the last two decades, multiple studies have examined the GHG tradeoffs of forest growth and fossil fuel substitution (e.g., Hall et al., 1991; Marland and Schlamadinger, 1997; Baral and Guha, 2004; Manomet Center for Conservation Sciences, 2010).

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[12] The price responsiveness of a utility may depend on both the ability to pass through increased costs and customer elasticity of demand for electricity. The ability and/or requirement of utilities to pass on increased costs to consumers is itself largely dependent on market structure. See, e.g., Williams, 2008.

[13] The Energy Independence and Security Act of 2007 (EISA 2007) established a narrow definition of biomass for the purpose of compliance with certain components of the federal RFS. Qualifying biomass must have been part of an "actively managed tree plantations on non-federal land cleared at any time prior to enactment" of the legislation (P.L. 110-140, Sec. 201). By contrast, the Food, Conservation, and Energy Act of 2008 (2008 Farm Bill) (P.L. 110-246, Sec. 9001) defined biomass in a significantly more open way—"materials, pre-commercial thinnings, or invasive species from National Forest System land and public lands" and "any organic matter that is available on a renewable or recurring basis from non-Federal land or land belonging to an Indian or Indian tribe." The American Clean Energy and Security Act of 2009 (H.R. 2454) attempted to reconcile these two definitions, and would effectively eliminate many of the restrictions on federal lands contained in EISA 2007.

Expanding use of forest biomass can have both positive and negative GHG implications. The most obvious is the potential reduction of GHG emissions from coal-fired facilities as forest biomass is substituted for coal. Increased use of forest biomass has the potential to decrease standing inventory, however, potentially lowering net forest carbon storage in the region. Any displacement of traditional industry could likewise have direct GHG implications due to the large amount of energy both used and produced by pulp and paper operations. Furthermore, displaced industrial capacity can have indirect but potentially significant GHG impacts outside of the region by inducing shifts of land into production forestry and altering harvest intensity on already-forested land.

Our assessment of net GHG emission implications is based on a comparison of emissions displaced from a reduction in coal usage against the shift in on-the-ground forest biomass carbon sequestration. We first use the eGRID database to generate facility-specific emission factors in units of metric tons CO_2e per MMBTU of heat input. We then apply these emission factors to the amount of coal displaced by biomass at each facility, sum the total, and calculate supply subregion-specific emission displacement for each year of the assessment period. These annual values are then converted into five-year annual averages to be consistent with estimates of forest GHG flux, described further below.

To calculate the GHG implications of shifting planting and harvest behavior,[14] we convert volume of biomass into estimates of Live Tree, Dead Tree, Understory, Down Deadwood, and Forest Floor carbon pools using forest-type-specific relationships and equations defined by the U.S. Forest Service (see Foley, 2009).[15] The management types and regions included in SRTS roughly approximate regions and forest types defined by the Forest Service, though some adjustment is necessary (Table 2). For each five-year time-step of SRTS output, we compare total sequestration in the base case scenario against sequestration levels in two scenarios to generate net carbon flux for a particular interval, one where 25% of available logging residues are utilized, and one in which 50% are utilized. We then convert the difference between the base case and a given residue scenario to an average annual rate of change by subtracting each time step from the one before it and dividing the difference by five years. Finally, we convert the average annual net carbon flux to units of metric tons CO_2e by multiplying by 44/12 and then sum across all regions to estimate the total GHG implications of our co-firing scenarios.

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[14] Though most LCAs assume that biomass is derived from existing resource streams, such as urban wastes and mill residues, the net GHG impacts of an increased use of biomass for co-firing with coal can also be influenced by shifts in harvest activity and resulting shifts in forest carbon storage (Zhang et al., 2010).

[15] We note that inclusion of down deadwood and forest floor carbon pools have the potential to affect estimates of GHG emission reductions as a portion of these pools is likely included as part of residue harvests.

Table 2. Relationship between U.S. Forest Service (USFS) regions and forest types and those utilized in SRTS for the present study.

Region and Forest Type (USFS)	Region and Management Type (Present Study)
South East	Mid-Atlantic, Florida
Loblolly-Shortleaf Pine - High Productivity/ Management Intensity	Planted
Loblolly-Shortleaf Pine	Natural
Oak-Pine	Mixed
Oak-Hickory	Upland
Oak-Gum-Cypress	Lowland
South Central	Gulf Coast, Highland Rim, Middle Valley, North Valley, South-Central Valley
Loblolly-Shortleaf Pine - High Productivity/ Management Intensity	Planted
Loblolly-Shortleaf Pine	Natural
Oak-Pine	Mixed
Oak-Hickory	Upland
Oak-Gum-Cypress	Lowland

The accounting approach outlined here suggests that net GHG emission benefits are accruing when the forgone emissions attributable to displaced coal are greater than a corresponding reduction in forest carbon stock. Specifically, net GHG reductions are generated against a business-as-usual situation if:

$$(B_{Tb} - C_{Tb}) - (Y_{Tb} - X_{Tb}) > (B_{Ts} - C_{Ts}) - (Y_{Ts} - X_{Ts}),\ \text{where } B_{Tb} = B_{Ts} \text{ and } C_{Tb}=0$$

Which reduces to:

$$(Y_{Tb} - X_{Tb}) - (Y_{Ts} - X_{Ts}) < C_{Ts}$$

In the above equations, *Y* is forest sequestration, *X* is total forest removals for both industrial and energy applications, *B* is the baseline level of coal-burning facility emissions, and *C* represents the emissions attributable to displaced coal, all in a given year *T*.[16] For any given year *T*, GHG flux in the baseline scenario is denoted by the subscript *b*, and *s* in the co-fire scenario. As we originate from the same standing forest stock, the change in forest stock can be assumed to be equivalent to $(Y_{Tb} - X_{Tb}) - (Y_{Ts} - X_{Ts})$. Thus, GHG reductions occur relative to a business-as-usual situation if the following simplified expression is true:

Change in Net Forest Stock < Displaced Coal Emissions

Clearly this approach reflects aggregate GHG emission flux. Stand-level impacts are of course important when the question is one of discrete impact of individual action, but aggregate impacts, those that reflect large-scale management and land-use shifts occurring in response to market, policy, or other drivers, are more relevant to the questions and scenarios evaluated here. A full review of the merits and drawbacks of various approaches for estimating the GHG emission effects of bioenergy production is beyond the scope of this paper, however.[17]

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[16] Note that biomass bioenergy emissions are included in X_T, so a separate accounting of this flux is not necessary.

[17] We do note similarities in the approach used here to the general accounting structure outlined in Schlamadinger and Spitzer, 1994 and more recently reviewed in Zanchi et al., 2010. We likewise note that our inclusion of biomass

We acknowledge that calculation of the net GHG emissions impact of co-firing woody biomass is a complicated undertaking. Unlike other, extensive LCAs of biomass co-firing (e.g., Mann and Spath, 2001), we do not consider shifts in transportation emissions, combustion efficiency, or energy required to process or dry feedstock here. It is worth noting, however, that previous research finds some of these components, such as transportation, to be small contributors relative to system-wide emissions and consumption (Mann and Spath, 2001). We also do not account for any direct changes in net emissions caused by displacement of current industrial users of forest resources. Finally, we note that reduction in forest carbon stock or displacement of industrial production may have GHG implications outside of the study area, and therefore be subject to additional “leakage” deductions; these effects may be significant but are not quantified here.[18]

Results

Applying our estimations of maximum co-firing rate per boiler type, we generate an aggregate average co-firing rate of approximately 10.1%. This translates to a biomass consumption of approximately 532 million MMBTU or just over 59 million green tons of wood. Upon achieving maximum co-fire capacity, this level of energy production would equal 5.3% of year 2007 nuclear, coal, and natural gas electric power sector energy consumption for the states in our study region.[19] Disaggregating the larger region into seven distinct supply subregions, we find that biomass demand varies significantly across the Southeast (Table 3). As would be expected, the total demand is influenced by both the number and the density of facilities within the region (Figure 4). Some areas, like the Mid-Atlantic and Highland Rim subregions, are quite expansive and also include a greater density of existing coal-fired facilities. Others, such as the Middle Valley, are significantly smaller in both extent and facility density.

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removals as a component of end-use emissions is generally consistent with other recent publications on biomass accounting (Searchinger et al., 2009; Manomet Center for Conservation Sciences, 2010), though differences do exist in the specific accounting frameworks that are used in each.

[18] In assessing the effects of harvest restrictions imposed as part of a program establishing forest set-asides in the South-Central United States, Murray et al., 2004 find that the resulting price effects induce significant harvest activity outside of the region, considerably reducing net GHG benefits. See also Wear and Murray, 2004.

[19] Regional electric power sector energy consumption data derived from Energy Information Administration, 2009a.

Table 3. Total co-fire demand (green U.S. tons) in each supply subregion.

Subregion	Co-fire Demand (green U.S. tons)
Florida	5,989,003
Gulf Coast	20,277,996
Highland Rim	4,534,124
Mid-Atlantic	21,323,771
Middle Valley	639,694
North Valley	3,050,383
South-Central Valley	3,373,239
Southeast Regional Total	**59,188,213**

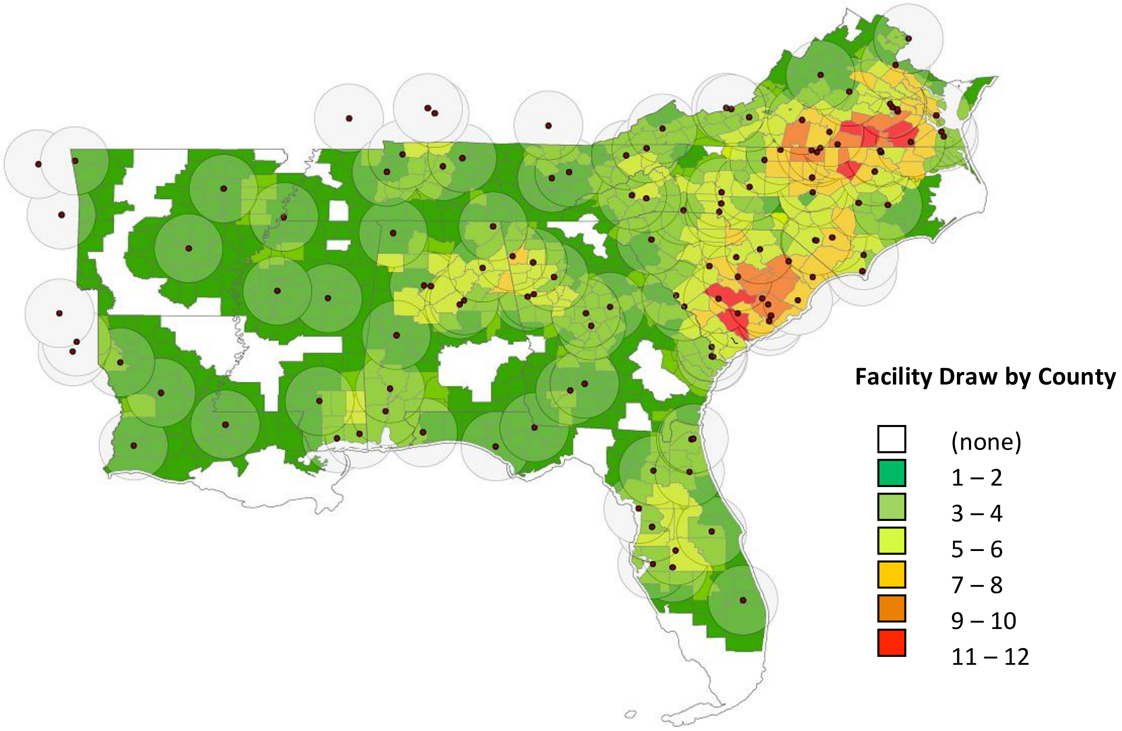

Figure 4. Number of coal-fired facilities potentially drawing upon each county.

<u>Feedstock Source</u>

We next assess the contributions of different feedstock source categories. Specifically considered were shifts in hardwood and pine pulpwood harvests, displacement of existing hardwood pulpwood capacity, displacement of existing pine pulpwood capacity, harvest residues from hardwood or pine pulpwood, and residuals stemming from harvest of roundwood specifically for biomass. Due to the key role that forest residuals could play in meeting increased demand for biomass, along with the uncertainty surrounding the market for forest residues and their harvest efficiency, we assess supply effects under scenarios of 25% and 50% available logging residue utilization. Illustrations of feedstock source are included below for a region-wide, non-spatially explicit assessment under both residue utilization scenarios (Figure 5), and separately for individual subregions under 25% (Figure 6) and 50% (Figure 7) residue utilization scenarios.

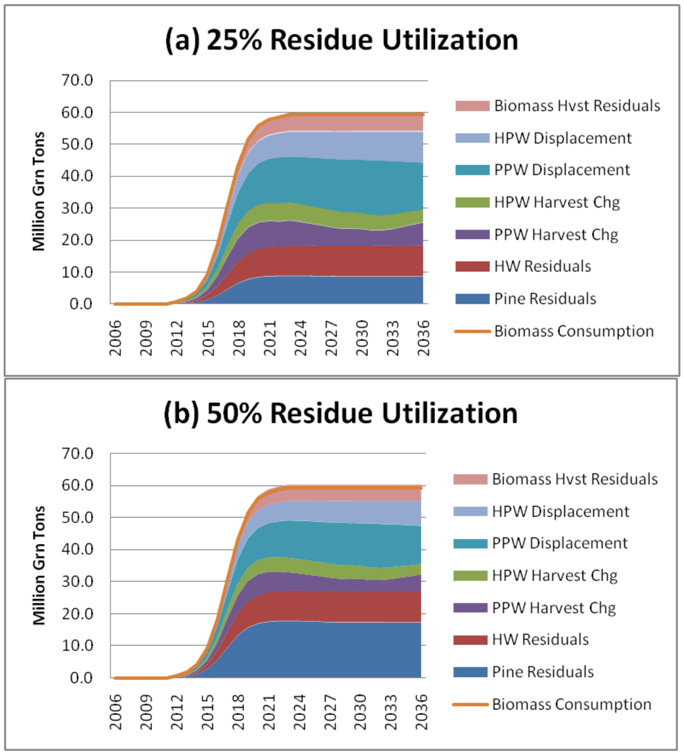

Figure 5. Feedstock source assuming a non-spatially-explicit, region-wide aggregate demand, under scenarios of (a) 25% and (b) 50% residue utilization.

The assumed pattern of co-fire adoption over time is easily seen in the profile of each feedstock sourcing figure. Also note that all subregions are capable of meeting biomass demand under both residual utilization scenarios when limitations on transportation distances are applied (Figures 6–7). The manner in which the demand is met, however, varies significantly. For example, Florida and Gulf Coast subregions meet a larger portion of co-fire demand in both the 25% and 50% utilization scenarios through displacement of existing pine pulpwood capacity than other subregions. Conversely, the Middle Valley subregion appears able to meet all co-fire demand only through increased use of residuals.

Beyond the obvious linkage between co-firing consumption relative to the size of the forest resource, several factors affect the feedstock portfolio over time. For example in regions with significant pine plantation resources (e.g., Florida and Gulf Coast), the age class structure of the forest resulting from reduced planting in the last decade means that harvest increases are limited, amplifying displacement from traditional industry. Toward the end of the projection, however, the plantings induced by the new demand leads to a significant supply response. Hardwood-dominated regions (e.g., Highland Rim) show less sensitivity to age class structure and less long-term supply response. These effects are explored further below.

Although absolute displacement in terms of green tons is observable in Figures 5–7, it is also important to consider the size of displacement relative to baseline pulpwood harvest levels. This provides another measure of impact on existing industrial users. Using the 50% of available residue utilization scenario as an example, we see that relative displacement varies widely by supply subregion (Figure 8). In some subregions, like Florida and Highland Rim, displacement is a significant percentage of projected baseline harvest levels. Within each supply subregion, the observed difference between pine and hardwood is due to differences in inventory trends between the two groups and higher residual availability from hardwoods. South-wide, aggregate estimated pine displacement is 16% and hardwood 13% of year 2022 baseline pulpwood harvest.

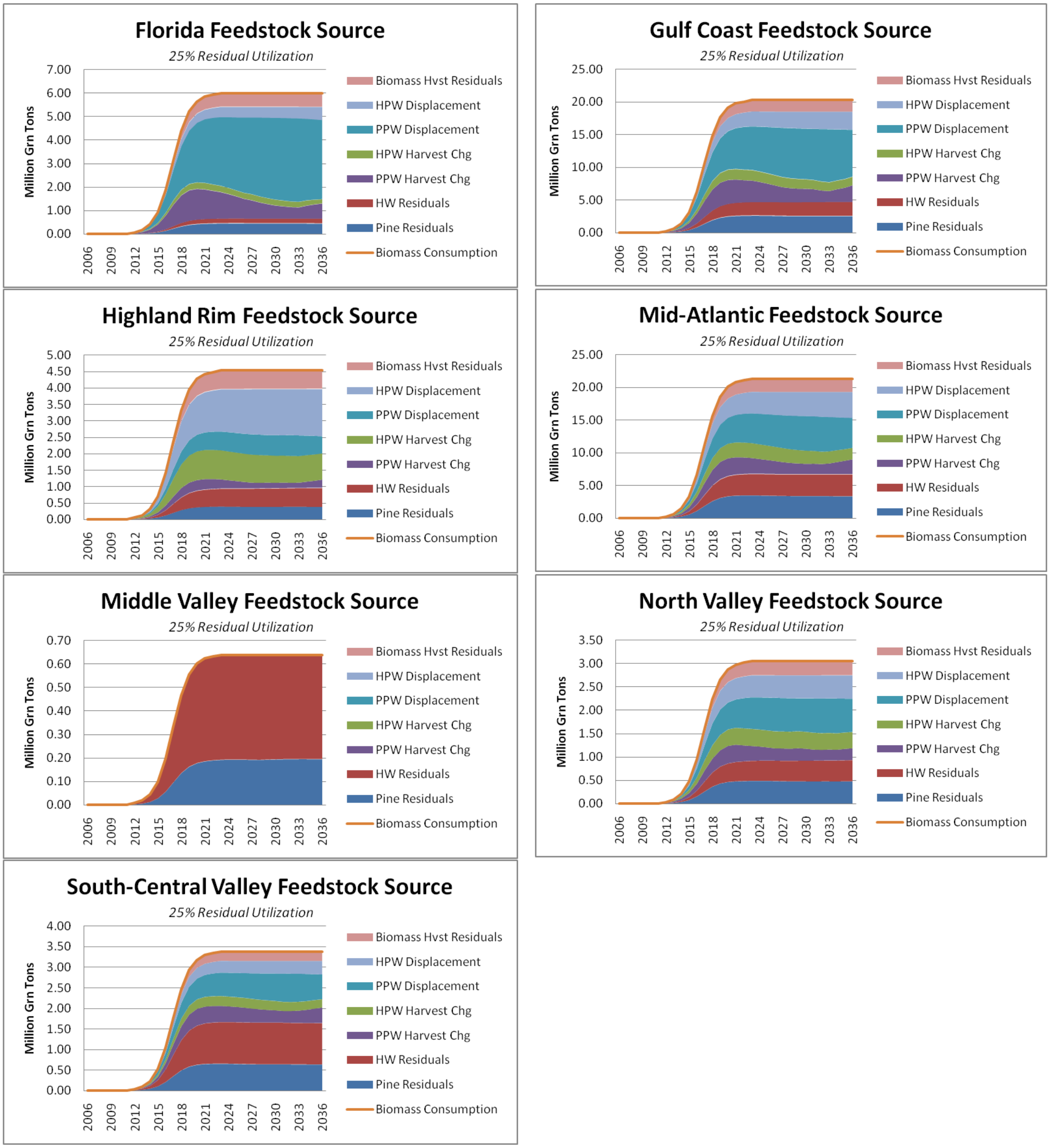

Figure 6. Feedstock source in each subregion assuming 25% forest residual utilization.

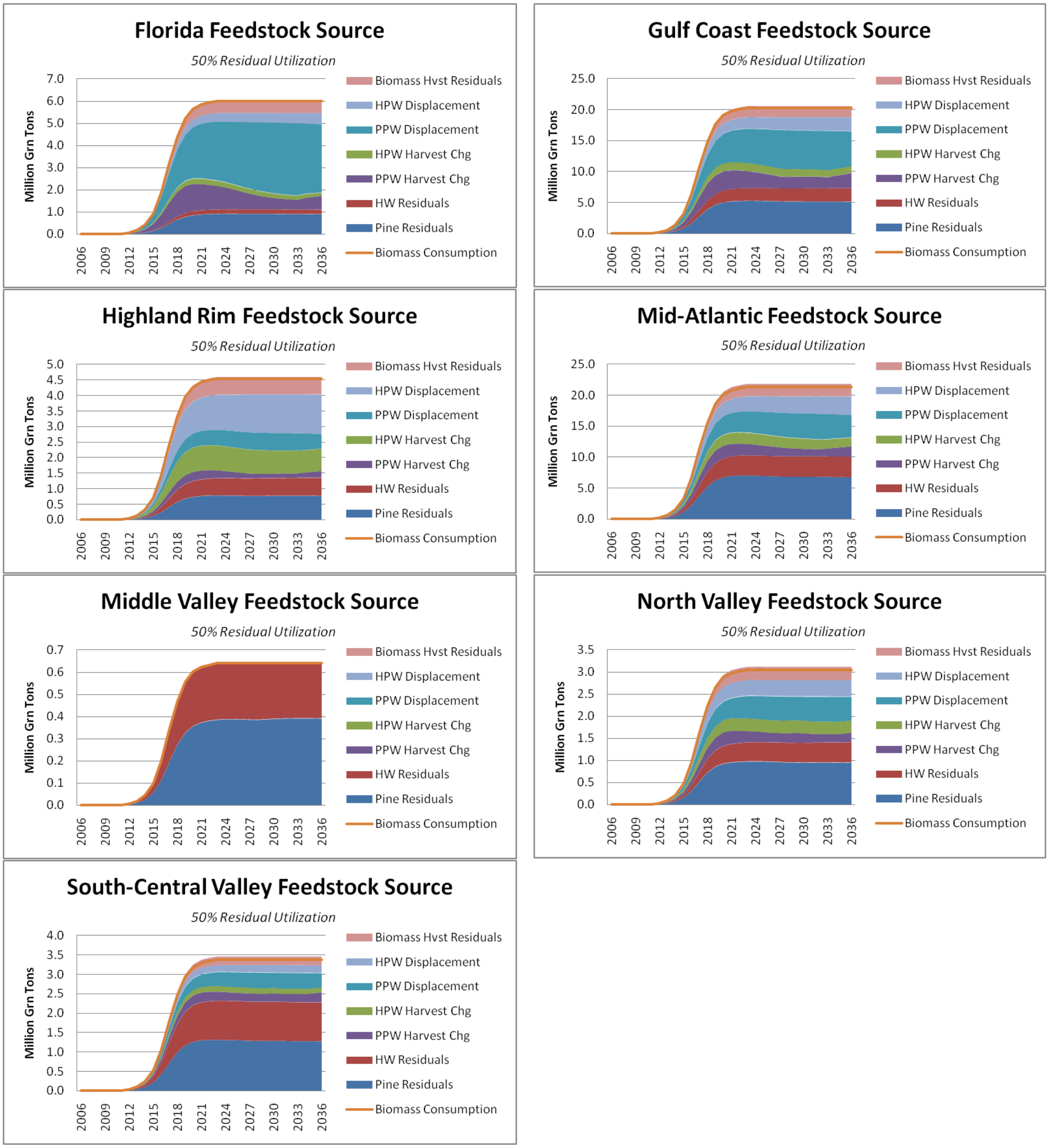

Figure 7. Feedstock source in each subregion assuming 50% forest residual utilization.

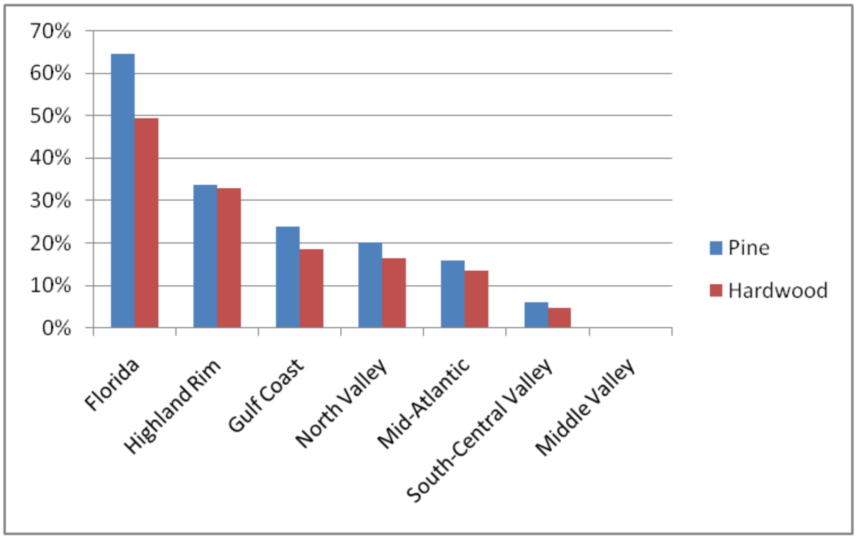

Figure 8. Pulpwood displacement relative to baseline scenario upon maximization of co-fire rate in 2022, assuming 50% residual utilization.

Inventory, Pricing, and Removals[20]

As described above, a baseline resource projection was first constructed for each region. For each of the four separate product classes modeled here, demand was projected to decline by 30% from 2006 to 2010 and a recovery to pre-recession levels by 2013 with flat demand projected until 2036. Figure 9 below shows the pulpwood price change from the starting year to 2022 under the base run by region sorted by pine pulpwood price change.

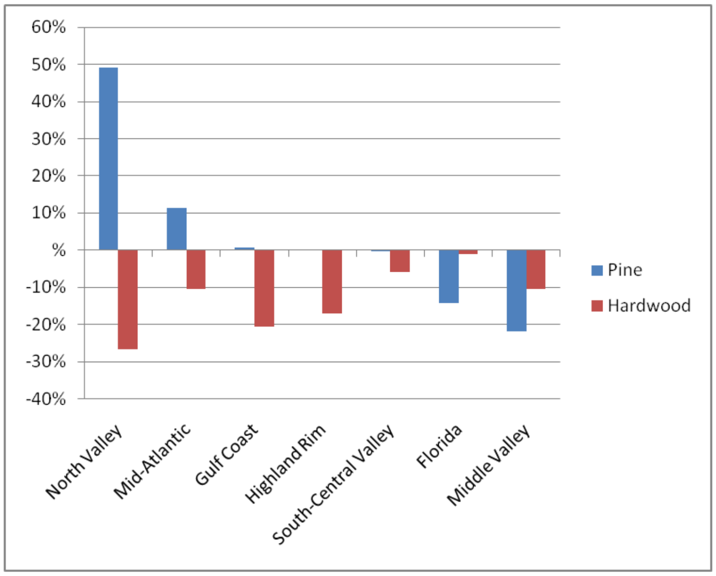

Figure 9. Pulpwood price change in the baseline scenario for the period 2006–2022.

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[20] Full inventory, pricing, and removal results can be found in Appendix A.

In this situation, only the North Valley and Mid-Atlantic supply subregions show upward pressure on prices due largely to the age class structure resulting from reduced plantings in the last decade. Most other regions show no upward pressure, with Florida and the Middle Valley regions showing downward price pressure. For hardwood pulpwood, an upward trend in total hardwood inventories counters upward price pressure. The key supply issue is the availability of hardwood inventory for harvest, as most of it is in non-corporate ownerships on smaller tracts.

Against this supply context, biomass demands from co-firing net of utilized residuals were added to pulpwood markets. South-wide, we estimate a 36% increase in pulpwood demand under an assumption where 25% of available residues are utilized, and an increase of 28% where 50% of residues are used. Disaggregating the region into the seven supply subregions, we see wide variation in the observed change in pulpwood demand upon full implementation of co-firing in 2022 (Figure 10). Florida co-firing capacity has the highest potential impacts at 101%, with greater than 25% demand increases in all other regions except the South-Central and Middle Valley regions.

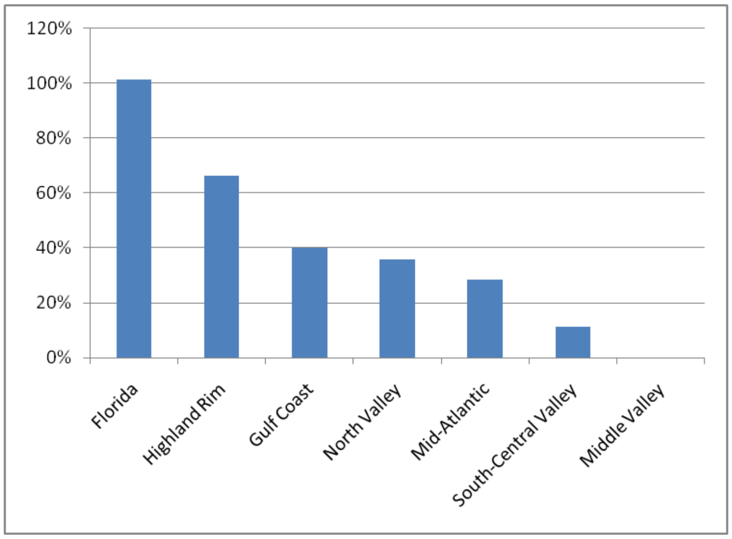

Figure 10. Biomass pulpwood demand increase relative to baseline scenario upon maximization of co-fire rate in 2022, assuming 50% residual utilization.

In the 10 years from 2012 to 2022 there is no opportunity for a supply response other than residual utilization in the model since trees planted in response to higher prices are not merchandized until age 15. The price increases over the baseline by 2022 are therefore highly correlated with the demand change from biomass (Figure 11). Hardwood price changes are lower since available residuals from hardwood harvest are higher, reducing the roundwood demand increase relative to pine. Note that these prices are relative to that region’s baseline 2022 price. In absolute terms, price increases also reflect the base resource outlook (Figure 12). Even though Florida had the biggest demand increase, its 2022 price increase was smaller than the North Valley region. This is due to Florida’s low baseline pressure on the resource relative to the North Valley region.

While price increases are lower on hardwoods due to overall inventory increases and greater residual buffers, by the end of the projection period the long-term supply response from increased planting of pine leads to pine pulpwood prices declining by 6% on average from 2027 to 2036 as compared to a 1.5% average decline in hardwood pulpwood prices over the same period. Though the added biomass demand applied here directly affects only the pulpwood market, downstream effects on sawtimber markets exist due to fewer trees being left to grow to sawtimber size. For all regions except Florida under the 50% utilization scenario, this effect led to less than a 10% price increase in sawtimber. For the Florida region with its high co-firing demand, the 2026 pine sawtimber prices were 50% higher than the baseline. The long-term supply response from planting would ameliorate this increase, but beyond the 2036 projection period examined here.

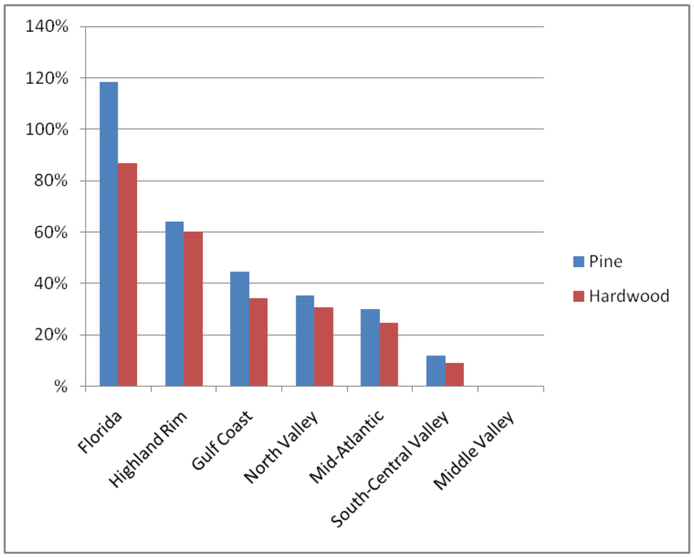

Figure 11. Biomass pulpwood price change relative to baseline scenario upon maximization of co-fire rate in 2022, assuming 50% residual utilization.

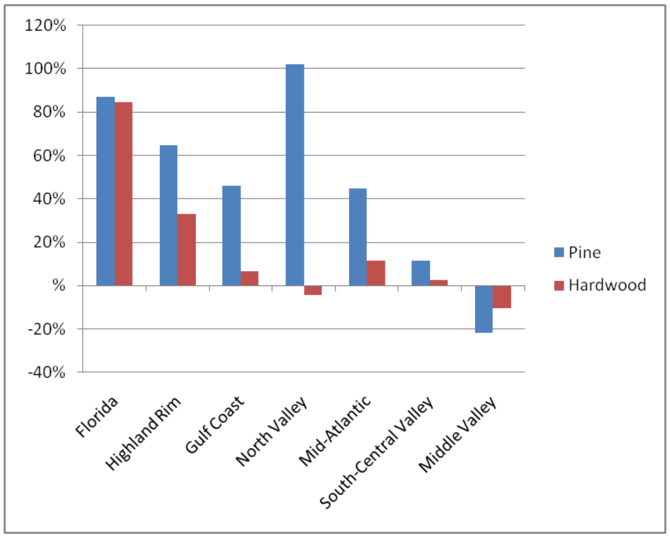

Figure 12. Biomass pulpwood price change relative to 2006 prices upon maximization of co-fire rate in 2022, assuming 50% residual utilization.

Greenhouse Gas Emissions

When co-firing at maximum potential, we estimate that displacement of coal results in region-wide fossil emission reductions of approximately 49,334,218 metric tons CO_2e per year (54,381,666 U.S. tons of CO_2e per year). This is but half of the story, however. Forest harvest and planting decisions are affected by an uptick in demand for biomass, which in turn affects net carbon storage over time. While the harvest and combustion of biomass does increase forest sector GHG flux, it is less than emission reductions attributable to displaced coal, thus generating net GHG reductions relative to the baseline, non co-fire scenario (Figure 13). Specifically, we find that maximizing co-firing in the Southeast under the 50% of available residue utilization scenario achieves approximate annual average emission reductions as high as 38.7 $MtCO_2e$ per year in 2031 and a low of approximately 6.2 $MtCO_2e$ per year in 2016.[21] Under a 25% residue utilization scenario, maximum average annual GHG emission reductions are approximately 37.5 $MtCO_2e$ per year in 2031, falling to approximately 5.7 $MtCO_2e$ per year in 2036.

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[21] Recall however that full diffusion/adoption of biomass co-firing does not occur until 2022.

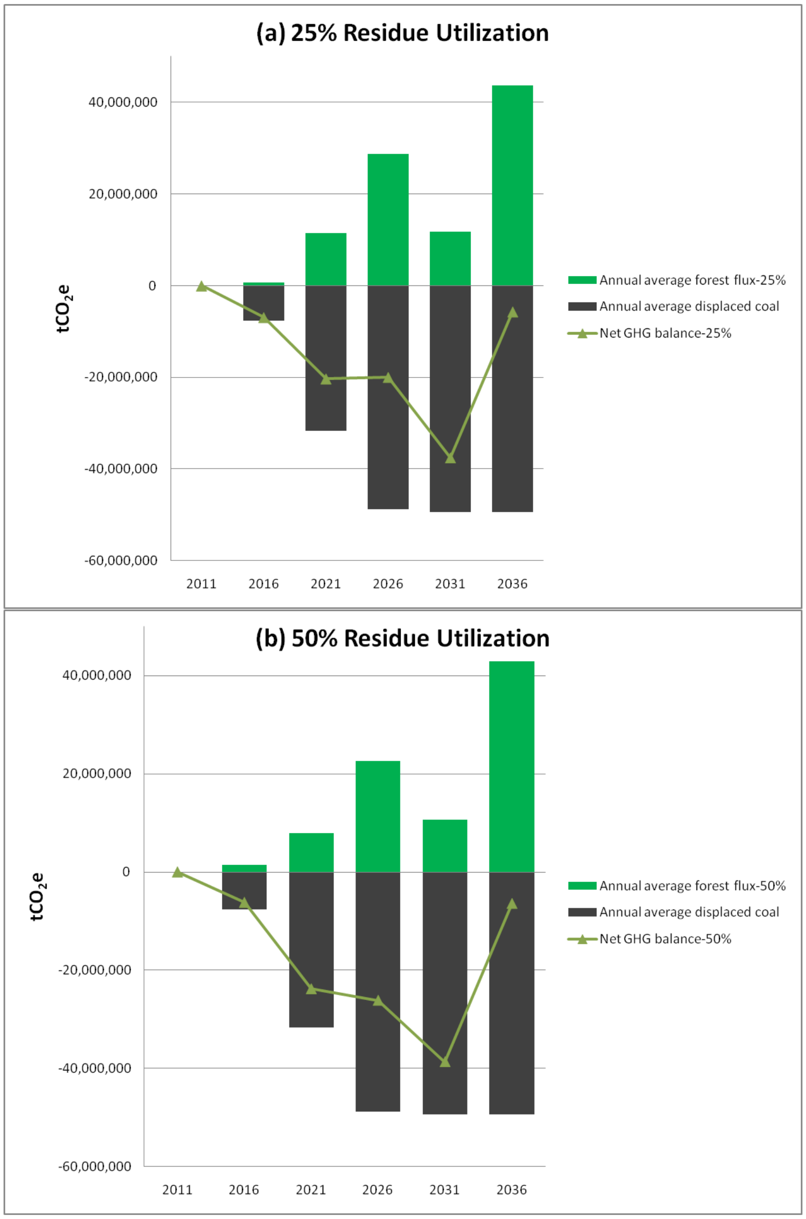
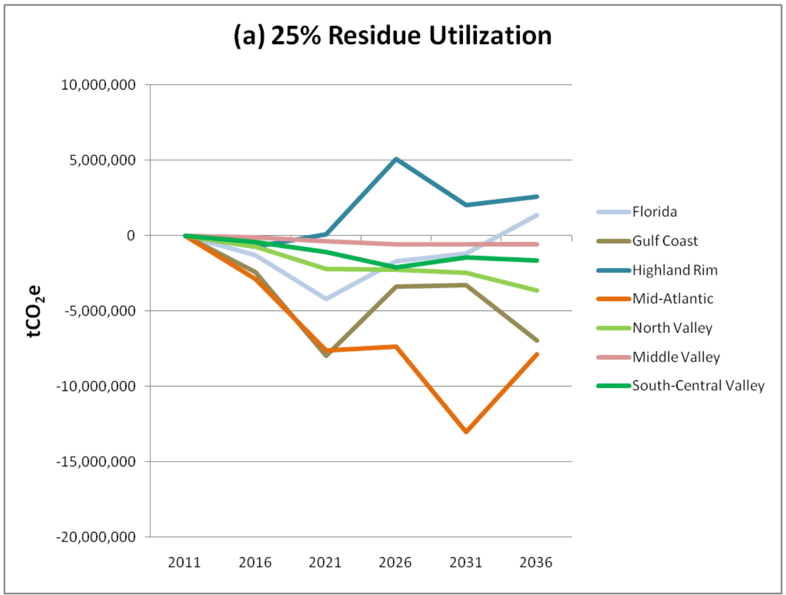


Figure 13. Region-wide net flux of GHG emissions resulting from a maximization of co-firing in the Southeast, assuming (a) 25% and (b) 50% residue utilization. Negative values indicate net emission reductions relative to baseline scenario coal combustion; positive values indicate net increases.

Disaggregating the larger Southeastern study region, we find that specific GHG impacts vary by supply subregion (Figure 14). As a whole, however, the endeavor results in net GHG reductions relative to the baseline, non co-fire scenario (Figure 15). We estimate rough GHG reductions from a maximization co-firing in the Southeast in this scenario to be between a low of 8.6 $MtCO_2e$ per year in 2016 and a high of 27 $MtCO_2e$ per year in 2021 under a scenario in which 50% of available residues are utilized. These values equate to 1.1% and 0.4%, respectively, of year 2008 total U.S. electric power sector emissions.[22] Under the 25% of available residue utilization scenario, maximum average annual GHG emission reductions range from a high of 23.3 $MtCO_2e$ per year in 2021 to a low of 8.5 $MtCO_2e$ per year in 2016, or 1.0% and 0.3%, respectively, of 2008 total U.S. electric power sector emissions.


(a) 25% Residue Utilization

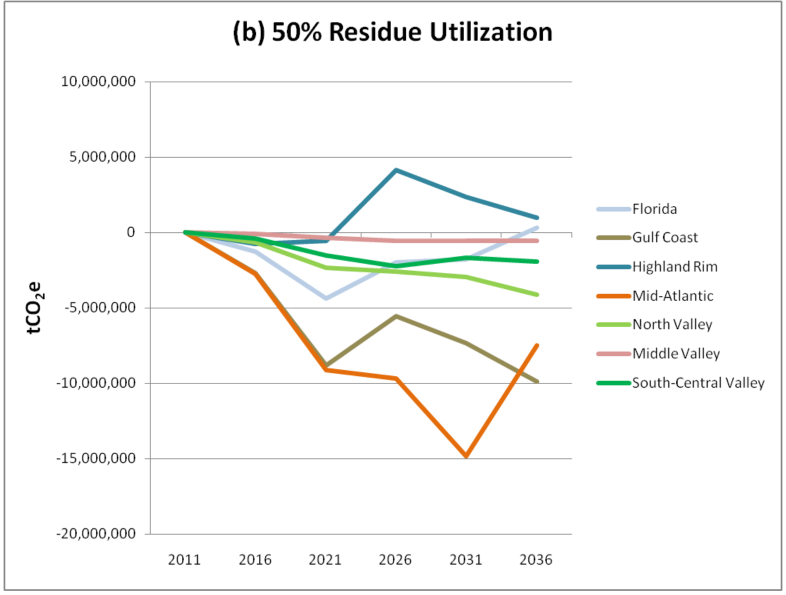

(b) 50% Residue Utilization

Figure 14. Net GHG emission flux resulting from a maximization of co-firing in the Southeast, by supply subregion, assuming (a) 25% and (b) 50% residue utilization. Negative values indicate net emission reductions relative to baseline scenario coal combustion; positive values indicate net increases.

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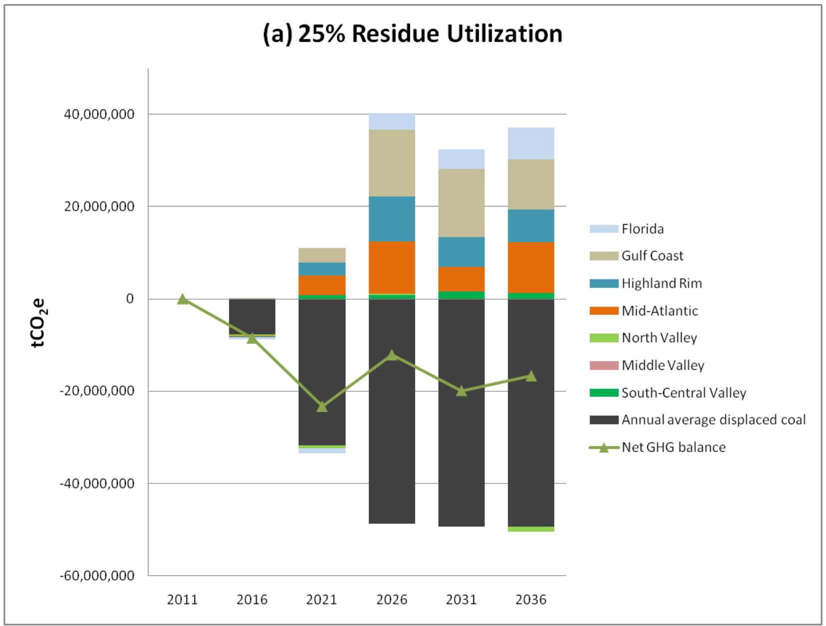
[22] Energy Information Administration, 2009d report total year 2008 U.S. electric power sector CO_2 emissions of 2,359.1 million metric tons.



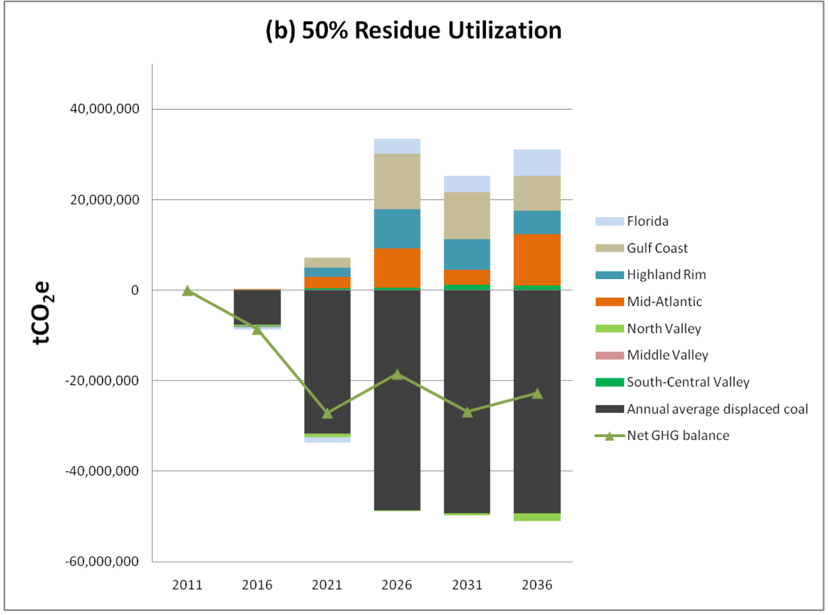


Figure 15. Net flux and source of GHG emissions resulting from a maximization of co-firing in the Southeast, assuming (a) 25% and (b) 50% residue utilization. Negative values indicate net emission reductions relative to baseline scenario coal combustion; positive values indicate net increases. Values for each supply subregion indicate annual average forest flux.

Discussion

We estimate that maximizing co-fire potential in the Southeast will generate significant increased demand for forest resources in the near term. When implemented fully, such a demand scenario would require over 59 million green tons of forest biomass. In terms of energy, comparing this amount of forest biomass to year 2007 electric utility consumption data equates to a region-wide RPS of approximately 5%. Although we characterize such amounts as a moderate level of biomass demand relative to other recent studies (e.g., Galik et al., 2009), it nonetheless represents a significant amount of wood.

The increased demand for such amounts of forest biomass is expected to have both socioeconomic and environmental impacts. The extent of these impacts is in turn influenced by a variety of factors. When disaggregating total demand into seven distinct supply subregions, we note that added demand is influenced by the number, size, and density of the existing coal-fired facilities within the region, factors all potentially influenced by our choice of subregional boundaries. Several factors are also at work on the supply side. Most notably is the size of the forest resource relative to the pulpwood and electricity market demands placed upon it. Also affecting biomass feedstock supply over time are the residual effects of recent planting behavior, especially prominent in regions with significant pine plantation resources where reduced planting activity over the last several years will limit the capacity for near-term harvest increases and amplify the incidence of displacement. The collective influence of these factors is readily apparent in aggregate and subregion-specific feedstock source allocation (Figures 5–7).

Additional Sources of Biomass

Despite our assumption that forest biomass will be the primary feedstock supplied to meet an increased demand for biomass, other potential biomass feedstocks exist, many in significant quantities across the Southeast. We do not explicitly consider the ability of these other feedstocks to meet demand imposed by a maximization of co-fire potential scenario, nor do we moderate our estimates of forest biomass demand to account for the availability of these other feedstocks. We do, however, include a brief sensitivity analysis here to gauge the potential impacts that inclusion of these other sources of biomass could have on expected levels of forest biomass demand.

Multiple biomass supply estimation studies have been published in recent years, and provide a reference point against which to compare our estimated demand for forest biomass.[23] For the purposes of this brief sensitivity analysis, we specifically reference two studies that report estimated quantities of various biomass feedstock at the state level: Walsh et al., 2000 and Milbrandt, 2005. Acknowledging that these two studies seek to estimate different aspects of biomass supply—Milbrandt primarily assesses technical potential, whereas Walsh et al. evaluate the economic potential of biomass at various price points—the use of both studies here provides a range of values against which to compare our estimated levels of forest biomass demand. Depending on assumptions of cost and availability, the total demand for forest biomass estimated in this study is either far greater than or far less than the estimated supply of other biomass feedstock in the Southeast (Table 4). However, if one assumes that energy crops may not be available in significant quantities in the short run and thus limits the assessment to existing residues, the demand for biomass estimated here exceeds estimated supply of other feedstock.

Since we are not simply interested in total amounts of biomass available, but rather the amounts available at prices that are competitive with forest biomass, we must estimate both expected pulpwood stumpage prices and corresponding prices for other forms of biomass.[24] We estimate timber price by

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[23] In addition to the few studies referenced here, see also Gronowska et al., 2009 for an expanded review of recent biomass supply studies in the U.S. and Canada.

[24] As no prices are reported in Milbrandt (2005), we rely solely on the numbers reported in Walsh et al. (2000).

averaging Forest2Market bimonthly weighted stumpage price estimates for 34 separate Southeastern micro-markets from 2004 to 2006.[25] We then take the median price of these three-year averages across all micro-markets, found to be $7.50 and $6.97 for pine and hardwood pulpwood, respectively.

Table 4. Estimated biomass availability (000 green U.S. tons per year) and energy equivalent (000 MMBTU per year) for the Southeast region as compared to an estimated demand for biomass of 532,693,920 MMBTU as derived in this analysis. Sources: Walsh et al., 2000; Milbrandt, 2005.

	Estimated non-forest, non-mill biomass availability by study				
Feedstock	**Milbrandt 2005**	**Walsh et al. 2000 (<$20)**	**Walsh et al. 2000 (<$30)**	**Walsh et al. 2000 (<$40)**	**Walsh et al. 2000 (<$50)**
Crop Residues (000 green tons)	43,654	0	0	5,223	10,356
(000) MMBTU (@7,500 BTU/#)	*327,403*	*0*	*0*	*39,169*	*77,667*
Urban Waste/Residues (000 green tons)	15,227	17,777	29,628	29,628	29,628
*(000) MMBTU (@7,500 BTU/#)**	*114,205*	*133,328*	*222,214*	*222,214*	*222,214*
Energy Crops (000 green tons)	33,030	0	0	50,850	96,948
*(000) MMBTU (@7,800 BTU/#)**	*257,631*	*0*	*0*	*396,631*	*756,194*
Total Energy Supplied (000 MMBTU)	**699,239**	**133,328**	**222,214**	**658,014**	**1,056,075**
% of Biomass Demand	**131%**	**25%**	**42%**	**124%**	**198%**
% Biomass Demand (residues only)	**83%**	**25%**	**42%**	**49%**	**56%**

* From http://cta.ornl.gov/bedb/appendix_a/Heat_Content_Ranges_for_Various_Biomass_Fuels.xls (Retrieved May 14, 2010).

To estimate the amount of biomass from other feedstock sources that would be competitive with forest biomass at recent historical timber prices, we first adjust supply category thresholds reported in Walsh et al. (2000) to reflect expected farmgate or, as in the case of urban wood waste, point-of-sale prices. We then convert all estimates to 2005 dollars and to units of green U.S. tons. The conversion between delivered prices reported in Walsh et al. and corresponding farmgate/point-of-sale prices is relatively straightforward. For agricultural residues, we simply subtract the $20/dry ton and $8/dry ton that Walsh et al. apply to account for transportation of agricultural residues and energy crops, respectively. For urban wastes, we round down from the median sale prices reported by Walsh et al. for municipal solid waste ($10.50) and construction/demolition ($10.67) facilities, yielding a point-of-sale price estimate of $10.[26] The basis for all estimates derived from Walsh et al. are then adjusted from 1995 dollars in the case of agricultural residues and urban waste and 1997 dollars in the case of energy crops using

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[25] The version of SRTS (v22) used to estimate biomass supply in this study utilizes FIA data for states that were updated between 2005 and 2008. Assuming a five-year revolving assessment process, data included in these updates would have been collected for some states as early as 2001 (for states with 2005 vintage data), with data from other states beginning in 2002, 2003, and 2004. Therefore, the period between 2004 and 2006 represents a rough midpoint of sample years included in the version of the SRTS model used here.

[26] Lacking transportation cost estimates for urban waste/residues, Walsh et al. simply assume that 60% of estimated totals are available for less than $20/dry ton, and the balance for less than $30/dry ton.

Consumer Price Index (CPI) conversion factors archived by Oregon State University.[27] To convert from dry tons, we assume green ton moisture content of 50%. The corresponding biomass availability price categories for different classes of feedstocks estimated through this exercise can be found in Table 5.

Table 5. Adjusted price categories of available biomass feedstocks.

Price category reported in Walsh et al. (2000)	Corresponding urban waste point-of-sale price, $2005	Corresponding agricultural residue farmgate price, $2005	Corresponding energy crop farmgate price, $2005
<$20	$6.41*	$0.00*	$7.30*
<$30		$6.41*	$13.38
<$40		$12.82	$19.46
<$50		$19.23	$25.55

* Denotes a price less than or equal to baseline stumpage price of forest biomass.

Based on this rough assessment, urban wastes appear to be the only feedstock expected to be competitive with forest biomass at recent historical prices. We estimate that the feedstock could supply up to 25% of the heat input demand assumed here to be met by forest biomass if all urban wastes estimated to be available by Walsh et al. in the study area are in fact recoverable. While this relatively minor contribution may for the present time justify our primary focus on forest biomass, we caution that further research is necessary to determine the true availability and competitiveness of non-forest biomass at spatially explicit scales. While we again acknowledge that the two supply assessments referenced here approach the issue differently and have different objectives, the widely ranging estimates they report, especially in situations where economic potential seems to exceed technical potential, give pause. We also note that, as pulpwood prices increase, additional sources of biomass beyond urban wastes may become competitive. Future market conditions are difficult to predict, especially those for which markets are not yet in existence or fully developed.

Net Greenhouse Gas Implications

Multiple aspects of our assessment of the net GHG emission implications of biomass co-firing warrant further discussion. In particular, we note the influence of the scale at which the GHG assessment is conducted, readily apparent in the differences in later-year GHG emission reductions between the spatially explicit analysis depicted in Figure 15 versus the non-spatially explicit assessment shown in Figure 13. In this situation, the large decline in GHG emission reductions shown in Figure 13 between 2031 and 2036, regardless of utilization scenario, is largely attributable to a large increase in plantings experienced in the earlier years of these scenarios. As these plantings mature, they become available to the market, contributing to a drop in resource pricing and corresponding loss of timberland. These findings are partly a function of SRTS land-use assumptions. The present analysis holds agriculture prices constant; less volatility in land-use shifts would be expected should agriculture prices follow similar pricing trends to those estimated for forest resources. A similar late-year decrease in carbon stocks is not experienced in the spatially explicit scenarios shown in Figure 15.

Also important to consider are the subregion-specific GHG implications of a maximization of co-fire capacity, as this can begin to approximate the impact of state-specific climate or renewable energy

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[27] Retrieved May 13, 2010, from http://oregonstate.edu/cla/polisci/sites/default/files/faculty-research/sahr/inflation-conversion/excel/cv2005.xls.

policies. The supply subregions as defined here do not directly correspond with individual state boundaries, making it difficult to draw conclusions on the specific impact of increased forest biomass utilization by any particular state, but a more limited scale of analysis can highlight relative advantages and disadvantages that are masked at the larger, regional level. These disparities can be seen in Figure 14, expressed as variations in both the timing and magnitude of net GHG emissions or reductions.

The relationship between these findings and other relevant work on the issue is also important to consider. Previous work to determine the net benefit of co-firing has indicated a reduction in global warming potential (GWP) by 5.4% to 18.2% at co-firing rates of 5% and 15%, respectively (Mann and Spath, 2001). A clear parallel to the present study is difficult to draw, however, as the feedstock assumed to be useable for co-firing in Mann and Spath (2001) is different (waste wood, mill residues, etc.) rather than the roundwood and harvest residues assumed to be used here. We also provide a more detailed accounting of biomass cost and forest growth dynamics than previous studies. We likewise base our comparison of net GHG emissions on deviation from a business-as-usual forest harvest regime, as opposed to the afforestation scenarios considered in several additional studies (e.g., Marland and Schlamadinger, 1997; Baral and Guha, 2004). Furthermore, we do not model the impacts of short-rotation woody biomass crops, assuming that the development of such cropping systems would take time to develop and implement, nor do we assess the impact that displaced industrial production could have on net global GHG emission reductions.

A recent analysis of the GHG dynamics of forest biomass utilization in Massachusetts (Manomet Center for Conservation Sciences, 2010) is worth discussing here due to both its recent release and its general conclusions. While we track region-wide forest carbon stock and find early and significant GHG emission reduction potential, the Manomet study finds that, depending on the displaced fuel source and generation technology, forest biomass utilization can incur significant “carbon debt” and take many years to generate GHG emission reduction benefits. Similar to the present analysis, the Manomet study was limited to an assessment of forest-based resources. But unlike the present study, the Manomet report calculated the amount of available forest biomass by first estimating recent historical harvest activity, then estimating the amount of additional biomass available under a low-price scenario while applying exogenous shifts in management and harvest behavior to set portions of the forest land base under higher prices. Such an approach provides less insight into the market-driven shifts in planting, management, and harvest behavior, as well as the induced displacement of existing users, that may accompany the imposition of new renewable or climate policy objectives. Indeed, Manomet’s assumption that “additional biomass stumpage revenues will not dramatically alter the acreage devoted to commercial forestry activities” (Footnote 6.7, p99) in the context of their study on Massachusetts forests contrasts markedly with the planting responses noted here. This, along with the obvious differences between the Southern forests considered here and the Northeastern forests considered in the Manomet report, at least partly (if not wholly) explain the large differences in findings generated by the two studies.

In light of these other studies, their different accounting techniques, and their varied findings, it is important to consider how inclusion of additional factors could alter our assessment of net GHG implications. From a purely economic perspective, we acknowledge that our assessment of drivers and decisions by both biomass suppliers and coal-fired facilities are simplistic. When faced with an incentive to reduce GHG emissions, for example, fuel cost plays a key role. Research shows that fuel cost can influence the cost of CO_2 emission reductions, with the per-ton cost of emission reductions increasing as biomass prices increase and coal prices fall, though the ultimate price effect may be relatively small (De and Assadi, 2009). Altering the amount of biomass used can also impact the cost effectiveness of CO_2

reductions, as per-ton costs of emission reductions increase with the fraction of biomass (De and Assadi, 2009). Expanding the GHG reduction options to include other forest management options, research suggests that afforestation may provide lesser carbon savings than either usage of short-rotation woody biomass in biomass-integrated gasifier plants or substitution in coal-fired plants, but nonetheless remained a cost-effective GHG emissions reduction strategy (Baral and Guha, 2004). There is clearly more to this story, and much more work is necessary to fully grasp the economic, social, and environmental implications of GHG reductions on such a massive scale as contemplated here. Work continues to further expand upon the issues explored here.

Finally, the analysis here assumes that forest biomass is being used to displace coal in existing, centralized generation facilities. Such a strategy represents a ready-made, near-term option for the use of forest biomass, but is not the most efficient use of the resource in an energy generation context. For example, Richter et al. (2009) discuss the efficiency benefits of combined production of heat and electricity, along with the potential role of community-based advanced wood combustion (AWC) systems in meeting local energy production needs while providing outlets for local sources of wood and other waste. Increasing the efficiency of forest biomass use would help to dampen the impacts of increased wood demand on other users of the forest resource, as well as on the forest itself. The limited discussion given to such alternative electricity generation strategies in this analysis should not be taken as a discount of their role or potential. The focus on co-firing merely stems from our belief that efforts to increase the utilization of biomass will likely leverage existing generation infrastructure until such time as new, dedicated biomass capacity—or other renewable or low-GHG energy generation capacity, for that matter—can be brought on-line.

The Role of Existing Policy and Other Considerations

At a broader level, the mix and composition of renewable energy and climate policies in place can have implications for the efficiency in which increased use of biomass is achieved (Kangas et al., 2009). Research into the impact of the RFS2 on woody biomass consumption, prices, and trade suggests that the biofuel targets already in place may lead to an increase in pricing (20% higher in the early 2020s than in the absence of the policy), an increase in domestic wood consumption, and a commensurate shift in trade balance (Sedjo and Sohngen, 2009). The potential offshore, international impacts of renewable energy policy thus add another dimension to the analysis beyond the domestic forest, energy, and industrial implications considered here.

It is also worthwhile to include additional considerations when conducting a spatially explicit assessment of demand for woody biomass. Definitions of the area of region from which biomass may be sourced can strongly affect the ultimate findings. There are also issues of facility ownership and scale. For example, a large facility may seek biomass from a larger radius and smaller facilities from a smaller radius. Individual facilities may be operated by the same entity or utility, with limited supplies of biomass allocated differently than the equal share we assume here. Finally, we do not make any predictions of the specific types of generation necessary to meet any unmet electricity demand in light of our imposed freeze in coal capacity, an omission with GHG emission implications in and of itself.

Conclusion

From a supply perspective, our analysis suggests that co-firing forest biomass with coal across the Southeast is technically viable with discernable GHG emission reduction benefits. This general conclusion notwithstanding, findings on feedstock source allocation, along with the conclusions on shifts in forest resource inventory, pricing, and removals, also suggests that use of forest biomass on a scale such as envisioned here warrants careful evaluation of the full and distributive effects. We find, for example, that the potential for significant pulpwood price increases exists, as does the potential for displacement of existing forest industry in some areas of the study region. In other areas, however, pricing effects are more subtle, and increased demand for forest biomass may be met purely through the increased use of harvest residuals. From a GHG emission standpoint, our analysis differs in both approach and result from other recent work on forest biomass. Net GHG emission flux varies both spatially and temporally, reflecting the underlying dynamics of the forest resource base, but as a whole suggests emission reduction potential.

We believe that the analysis adds much-needed information and perspective to the debate over the role that biomass utilization is to play in state, regional, and national climate and energy policy. In reaching our conclusions, however, we acknowledge the strong role that assumptions on future coal capacity, baseline forest industry trajectory, boiler co-fire potential, co-fire adoption rate, viable transportation distance, definition of supply subregions, and GHG accounting framework have on our results, and again note the exclusion of industry, forest composition, and GHG emission effects that occur outside of the study area. Much more work is necessary to fully grasp the economic, social, and environmental implications of such substantial and wide-spread forest biomass utilization. For these reasons, we continue to refine and expand our analysis.

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