MEETING RENEWABLE ENERGY AND LAND USE OBJECTIVES THROUGH PUBLIC-PRIVATE BIOMASS SUPPLY PARTNERSHIPS

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Abstract

Bioenergy is a significant source of renewable energy in the U.S. and internationally. We explore whether creation of localized bioenergy markets near existing military installations in the southeastern U.S. could simultaneously address military renewable energy generation objectives while reducing urban encroachment. We model the use of public-private partnerships to stimulate the creation of these markets, in which stable installation demand is paired with stable supply from surrounding landowners. We employ two economic models – the SubRegional Timber Supply (SRTS) model and the Forest and Agricultural Sector Model with Greenhouse Gases (FASOMGHG) – to assess how markets influence forest and agriculture land use, renewable energy production, and greenhouse gas (GHG) mitigation at the regional and national levels. When all selected installations increase bioenergy capacity simultaneously, we find increased preservation of forest land area, increased forest carbon storage in the region, and increased renewable energy generation at military installations. Nationally, however, carbon stocks are depleted as harvests increase, increasing GHG emissions even after accounting for potential displaced emissions from coal- or natural gas-fired generation. Increasing bioenergy generation on a single installation within the Southeast has very different effects on forest area and composition, yielding greater standing timber volume and higher forest carbon stock. In addition to demonstrating the benefits of linking two partial equilibrium models of varying solution technique, sectoral scope, and resource detail, results suggest that a tailored policy approach may be more effective in meeting local encroachment reduction and renewable energy generation objectives while avoiding negative GHG mitigation consequences.

Keywords

Military installation; U.S. Department of Defense; forest carbon; Southeast U.S.; economic modeling

1. Introduction

Bioenergy provides a substantial portion of existing renewable energy generation in the U.S. and internationally. It is feasible that bioenergy could make even greater contributions to global and national renewable energy generation, but expansion is often constrained by technical, logistical, environmental, social, and economic factors. Against the backdrop of this potential, the U.S. Department of Defense is seeking both to reduce its consumption of fossil fuels by increasing the production and use of renewable energy and to address the encroachment of incompatible land uses in the vicinity of existing installations. The question explored here is whether bioenergy supply partnerships between military installations and surrounding private landowners and feedstock producers can help to address both sets of concerns—increasing the generation of renewable energy for on-base consumption while slowing or redirecting the urbanization of surrounding landscapes. The resulting analysis bridges the divide between research and practice by demonstrating how separate partial equilibrium (PE) forest and agricultural models may be linked to better explore real-world policy scenarios with spatially complex environmental and economic outcomes.

1.1. Bioenergy in Research and Practice

Bioenergy, defined here as the use of forest and agricultural materials to generate electricity, has emerged as a possible means to decrease fossil fuel consumption, mitigate GHG emissions, and provide economic opportunities to rural communities. In 2012, bioenergy supplied approximately 370 TWh of global electricity, or approximately 1.5% of total global

production (International Energy Agency 2015). In the U.S., bioenergy contributed approximately 57 GWh of electricity in 2012, or approximately 11.6% of utility-scale renewable electricity generation in that year (U.S. Energy Information Administration 2015b). Analysis suggests that the use of biomass for heating and energy purposes is likely to increase in the U.S., as is the availability of biomass feedstock to supply expanding capacity (U.S. Department of Energy 2011). The extent to which these potential increases are realized has been a subject of considerable research.

From an individual biomass producer perspective, for example, research has shown that market uncertainty can impede participation in nascent bioenergy markets, particularly when changes in production practices are necessary (Dorning et al. 2015, Galik 2015; Jensen et al. 2007). From an individual installation perspective, the spatial distribution of available biomass supply and the configuration of the end-use application have been cited as important factors to consider (Schmidt et al. 2010). From a broader market perspective, research has shown that subsidies and continued technological development, particularly with regard to potential feedstock, are required for bioenergy to be competitive with fossil fuels and achieve sizable market penetration (McCarl et al. 2000; Khanna et al. 2011). Other so-called non-technical factors have likewise been found to inhibit bioenergy market development, specifically integration with other economic activities, scale effects, competition both inside and outside bioenergy markets, attributes of bioenergy markets themselves, social constraints, and local and national policy (Roos et al. 1999; McCormick and Kåberger 2007; Galik 2015).

These collective technical and non-technical factors underscore the important role that policy plays in the emergence of viable bioenergy systems, giving rise to both multiple layers and types of policy interventions (e.g., Aguilar et al. 2011; Becker et al. 2011) and a variety of

analyses examining bioenergy market response to their deployment. For example, multiple analyses have assessed the influence of renewable portfolio standard implementation on bioenergy system response at the state (Galik et al. 2009; Abt et al. 2010a), regional (Galik et al. 2015), and national (Latta et al. 2013, White et al. 2013) levels, finding generally that bioenergy is capable of meeting substantial renewable energy targets, often with positive greenhouse gas mitigation benefits. Apart from policy-driven changes in bioenergy generation at the state, regional, and national levels, analyses also continue to explore novel bioenergy applications in the pursuit of diverse economic, social, and environmental objectives at the local and sub-regional level, as well (e.g., Saha and Eckelman 2015, Pantaleo et al. 2014).

What is less represented in the literature, however, are assessments that link these separate but related areas of work: the design and implementation of state, regional, or national bioenergy policy and the role of bioenergy markets in helping to achieve localized land use or management objectives. Though this particular area of work is wanting, recent research on the benefits and complexities associated with broader market analysis coupled with detailed disaggregation has established methodological precedent for how such analyses might be pursued. For example, Igos et al. (2015) link a computable general equilibrium (CGE) and PE model in their analysis of six different sets of energy commodities and resulting life cycle assessment (LCA) of energy system development. Britz and Hertel (2013) likewise integrate CGE and PE models in their analysis of the GHG consequences of EU biofuels mandates. These studies demonstrate the viability of such an approach as a decision support tool for policy makers, while also highlighting the complexities of linking models with different objectives and data structures. Elsewhere in the literature, recent work has explored the influence of disaggregated technology options on the cost of GHG reduction, finding generally that increased

disaggregation can lend greater insight into the economic implications of the policy assessed (Fujimori et al., 2014; Cai & Arora, 2015).

We build upon these collective works by linking separate PE modeling frameworks to assess the national and localized land use change and forest carbon response associated with targeted bioenergy generation deployment. The novelty and significance of this analysis is twofold. Methodologically, we demonstrate the viability of linking two PE models of varying solution technique, sectoral scope, and resource detail, providing insight into how such cross-platform assessments may be undertaken in the future and the potential benefits and drawbacks of such an approach. From a policy perspective, we explore how traditional energy-focused policy decisions may be leveraged to achieve non-energy objectives through the use of novel interventions, an important issue generally, but of particular importance for bioenergy (Dale et al., 2015).

1.2. Bioenergy, Land Use Change, and Military Readiness: Evaluation of a Novel Policy Option

The U.S. Department of Defense (DoD) is the single largest energy consumer in the United States, accounting for approximately 80 percent of the federal government's energy use (U.S. Energy Information Administration, 2015a). Internal DoD analyses have found the military's fossil fuel dependence to present a strategic risk, and that renewable energy and energy efficiency investments are key measures to mitigate this risk (ACORE, 2014). Accordingly, recent years have witnessed a concerted effort to both reduce DoD fossil fuel consumption and increase the production and use of renewable sources of energy.

The production of renewable energy on military installations is influenced by a variety of federal policies, such as the U.S. Energy Policy Act of 2005 (P.L. 109-58), the National Defense Authorization Act of 2007 (P.L. 109-364), and the 2013 Presidential Memorandum on Federal Leadership on Energy Management (The White House, 2013). Pursuant to these broad mandates, each branch of service has developed an energy strategic plan. For example, the U.S. Army seeks to derive 25% of total energy consumed from renewable energy sources by 2025 and to deploy 1GW of renewable energy projects by that same year (U.S. Army, 2009). The Air Force meanwhile seeks to increase facility consumption of renewable or alternative energy to 25 percent of total electricity use by 2025, to achieve 1GW of on-site capacity by 2016, and to acquire 50% of its domestic aviation fuel from alternative fuel blends by 2025 (U.S. Air Force, 2013). The Department of the Navy aims to derive 50 percent of total energy consumption from alternative and/or renewable sources, to deploy 1 GW of renewable energy on Navy installations, and to obtain 50 percent of the fleet’s liquid fuel from alternative sources, all by 2020 (U.S. Navy, 2012). For its part, the U.S. Marine Corps Expeditionary Energy Strategy and Implementation Plan seeks to increase alternative and/or renewable energy consumption on bases and installations to 50% of total energy consumption by 2025 (U.S. Marine Corps, 2011). These collective strategies have led to the expansion of renewable energy generally, and biomass energy, specifically, in affiliation with U.S. military installations and operations (Table 1).

Table 1. Select underway or under development installation-affiliated biofuel or bioenergy projects.

Installation/Branch	State	Size
Fort Drum (Army) ^a	NY	28 MW
Schofield Barracks (Army) ^a	HW	50 MW

Redstone Arsenal (Army) ^a	AL	25 MW
Red River (Army) ^b	TX	N/A
Robins (Air Force) ^c	GA	20 MW
Eglin (Air Force) ^c	FL	25 MW
Dyess (Air Force) ^c	TX	5 MW
Red Rock Biofuels (Navy) ^d	OR	N/A
Emerald Biofuels (Navy) ^d	LA	N/A
Fulcrum BioEnergy (Navy) ^d	NE	N/A

^a Kotrba (2015)

^b U.S. Army (2016)

^c Reynolds (2012)

^d DoD-awarded biorefineries to produce drop-in biofuels for consumption by the U.S. Navy (U.S. Navy, 2014).

In addition to increasing renewable energy production and consumption, the U.S. DoD is also investing in efforts to minimize conflicts between military training and off-base land uses. Encroachment of incompatible land uses around existing military installations and the “away spaces” needed for flight operations can alter methods, timing, or duration of critical training activities. Such encroachment holds the potential to undercut training capabilities and, by extension, military readiness, prompting the DoD to undertake an increasing number of off-base mitigation measures (e.g., Sentinel Landscapes, 2015).

The most prominent DoD encroachment reduction initiative is the Readiness and Environmental Protection Integration program (REPI). Initiated in 2003, the REPI program seeks to reduce military-community-environmental conflicts resulting from urban encroachment (REPI, 2015). Through the REPI program, DoD funds cost-sharing partnerships among the Military Departments, private conservation groups, and state and local governments to support military readiness by protecting compatible land uses and preserving natural habitat on non-DoD lands (REPI, 2013). Another, more recent initiative to address encroachment is Sentinel

Landscapes, a collaboration between federal, state, local, and private stakeholders that employs a variety of tools and strategies to preserve and sustainably manage working lands near a small number of targeted installations (Sentinel Landscapes, 2015). Also operating within the Southeast is the Southeast Regional Partnership for Planning and Sustainability (SERPPAS), a multi-state partnership comprised of state and federal agencies working to improve resource-use decisions that support conservation of natural resources, working lands, and defense readiness opportunities (SERPPAS, 2015).

It is possible that creation of a new or expanded bioenergy market, one targeted to producers in the vicinity of existing military installations, could jointly pursue both DoD objectives simultaneously—increasing the on-base generation of renewables while affecting land use change around DoD facilities. In creating an additional demand for forest and agricultural feedstock, such efforts could help maintain compatible working lands in the vicinity of existing installations. Research indicates that land rent—the value one receives from his or her land—is an important driver of land use change (Veldkamp and Lambin, 2001; Choi et al., 2011), and the imposition of new demand for a given biomass feedstock could have a positive effect on land use affiliated with the new market opportunity (Ferris and Joshi, 2004; Feng and Babcock, 2010; Abt et al., 2010b; Galik et al., 2015). By targeting markets to discrete geographic areas, such efforts could also create a steady supply of locally-available biomass feedstock, thus helping to address supply concerns and logistical inefficiencies that could increase costs (e.g., Overend, 1982; Aksoy et al., 2011).

In the sections that follow, we assess whether such a hypothetical public-private bioenergy partnership, one targeted to the vicinity of existing military installations in the southeastern U.S., can help to jointly achieve compatible land use preservation and renewable

energy generation objectives. The specific attributes of the hypothetical policy initiative are outlined in Section 2, as is the modeling framework we employ to assess its effects on land use change and other environmental and economic indicators of concern. That is followed with a brief review of the results in Section 3 and further discussion of findings and conclusions in Section 4. The article concludes with a review of policy and methodological lessons learned, with recommendations on how both may be further leveraged in future analysis and policy development.

2. Material and Methods

Assessing the local and national implications of a public-private bioenergy partnership in the Southeast U.S. first requires parameterization of economic models and the policy to be evaluated. This process is outlined below, with an emphasis on justification of key inputs and assumptions. We begin with an overview of the process used to define individual installation bioenergy targets and how these targets were then applied to individual installation supply areas. We then provide an overview the economic models used in this analysis – the SubRegional Timber Supply (SRTS) model and the Forest and Agricultural Sector Optimization Model with Greenhouse Gases (FASOMGHG). We conclude with an overview of how the bioenergy modeling scenarios are applied to both the region and to each supply area to explore the influence of a hypothetical public-private partnership on both land use change and renewable energy production objectives.

2.1. Policy Scenario Overview

To stimulate the creation of a new biomass market in the vicinity of U.S. military installations, we specifically consider the model of a public-private bioenergy partnership, in which suppliers are jointly connected with stable sources of bioenergy demand. As in the case of the Biomass Crop Assistance Program (BCAP), itself authorized as part of the Food, Conservation, and Energy Act of 2008 (P.L. 110-234), linking publicly-sponsored bioenergy development projects (i.e., military installation fuel or electricity generation) with regional growers and feedstock providers could have compounding benefits for both. The public-private partnership concept is a potentially viable option for increasing bioenergy capacity on- or near-base, as evidenced by a BCAP-affiliated project which uses shrub willow as a feedstock for three biomass-to-energy facilities in New York State, including a facility affiliated with the Fort Drum military installation in Jefferson County, NY (SUNY ESF, 2012).

2.2. Modeling Framework Overview

This analysis employs the SRTS and FASOMGHG models, two forest sector PE models differing in level of resource and forest product detail as well as temporal outlook leading to different silvicultural and land use change reactions to future market conditions. Use of both types of PE models allows both sub-regional land use trends and changes in national renewable energy production and GHG mitigation to be jointly observed. Acknowledging the difficulty in direct coupling of CGE and PE models (Igos et al., 2015; Galik et al., 2015), we instead perform a loose coupling of models here, wherein output from SRTS for a given period is passed to FASOM as an input value.

Localized influence of the public-private bioenergy partnership is thus first assessed using SRTS. SRTS uses forest growth and harvest data from the U.S. Forest Service's FIA

database (U.S. Forest Service, 2015) to estimate forest market responses to the imposition of new demand. SRTS is a recursive dynamic model, meaning that changes in forest markets and conditions in each one- to five-year period are used to update the starting conditions of the subsequent period through the end of the projection period in 2045. Forest product and bioenergy feedstock supply is modeled as a function of stumpage price and inventory; price and harvest levels are simultaneously determined by the model's market equilibrium calculations for each product (hardwood v. softwood, pulpwood v. sawtimber), owner class (corporate v. non-corporate), and subregion. Changes in forest conditions are estimated by modeling the growth of forests using empirically based regional Forest Service data, harvest from the market equilibrium module, and endogenous land-use change based upon commodity price differentials in underlying land uses. A more detailed review of the SRTS model is provided in Abt et al. (2009) and Prestemon and Abt (2002).

SRTS output data for two scenarios—a policy scenario featuring additional bioenergy demand as estimated below, and a baseline scenario without additional bioenergy demand—is then fed into FASOMGHG to estimate the regional and national implications of the public-private bioenergy partnership. FASOMGHG applies an intertemporal welfare maximization framework that maximizes the sum of producer and consumer surplus for most primary and processed agricultural and forestry commodities while tying the sectors together through competition for a combined land base. The basic model specification is as described in Beach et al., (2010) but with additions to biopower and cofiring capacity as described in Latta et al. (2013) and improvements related to logging residue generation as described in Galik et al. (2015). Private land suitable for either sector flows to the use that promises the optimal land value over time. The model clears forest products markets for more than 30 commodities both domestically

and internationally, with some trade specified exogenous and other major trade flows such as Canadian softwood lumber determined endogenously. The model operates on a five-year time step and was solved through 2080.

2.3. Estimation of Biomass Demand and Supply Areas

We focus our analysis on the southeastern U.S., defined here to include the states of Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, Oklahoma, South Carolina, Tennessee, Texas, and Virginia. Prior to our model analysis, we first assess potential bioenergy demand from military installations in the study area. DoD annually reports on its facility energy performance as part of its compliance with federal energy mandates. We use data in reports from years 2010 through 2013 (U.S. DoD, 2011; 2012; 2013; 2014) as a basis for estimating potential installation bioenergy demand. These reports include information on the facility energy activities of the Army, Navy, Air Force, Marine Corps, and multiple other Defense Agencies, and report such information as total site delivered energy, gross square footage, and energy intensity (delivered energy per area). For each reporting year, we recorded data for each installation in our Southeast U.S. study area, including total delivered energy, square footage, energy intensity, military branch, and the state, county, and city in which the facility was located. Detecting no consistent trends in energy use or intensity across branch and year, we simply make use of the latest year data – 2013 – in all subsequent calculations.

Following data collection on energy consumption, we estimated the amount of biomass it would take to meet each installation's annual energy needs. For the purposes of this analysis, we assume that total delivered energy as reported by U.S. DoD (2014) represents delivered electricity only and, by extension, that any new bioenergy capacity must be sized so as to meet this electricity demand. We acknowledge that bioenergy and other on-base facilities could

provide both heat and electricity. While it may be possible to determine what portion of on-base energy demand was allocated to space or process heating versus electricity use and to size an efficient generation system to best meet projected needs, this information is not readily available from the cited source and is likewise not central to our exploration of aggregate regional potential and land use response. Thus year 2013 energy consumption for each installation was first converted from British thermal units (BTUs) to U.S. green tons per year using an assumed energy content of 8,500 BTUs/dry pound of biomass and a conversion rate of two green tons per one dry ton of material. Final results are then converted to metric units and reported as such.

Assuming that larger facilities would be more cost-effective than smaller ones, we then instituted a rough capacity screen, removing all installations requiring less than 10 MW of base load capacity. Base load capacity is calculated using a facilities annual energy demand, an assumed facility efficiency of 30%, and a capacity factor of 0.8. Under these assumptions, we identify 24 installations across nine states possessing sufficiently large demand to support on-base or dedicated near-base generation (Table 2). We make no distinction whether generation occurs on-base or immediately adjacent off-base, so long as the electricity is produced for consumption by the target installation. Note also that the 10 MW base load threshold is used as a screen to exclude smaller units only. The actual demand used in our modeling runs of qualifying facilities is unaffected by this assumption as we use a direct BTU-to-biomass feedstock conversion in establishing the demand for each facility.

Table 2. Select installation location, supply area affiliation, energy consumption, and estimated annual bioenergy demand. Source: U.S. DoD (2014).

MW	Installation Name	Supply Area	County	State	Total Delivered Energy (BBTU)	Green U.S. tons/year
25 MW	Randolph AFB	N/A	Bexar	Texas	4,017	472,588
	Fort Bragg	“Fort Bragg”	Cumberland	North Carolina	3,479	409,294
	Tinker AFB	N/A	Oklahoma	Oklahoma	3,184	374,588
	Naval Station Norfolk	“Virginia”	Norfolk	Virginia	1,980	346,353
	Ft Belvoir	“Virginia”	Fairfax	Virginia	1,597	332,471
	NSA South Potomac	“Virginia”	King George	Virginia	2,145	252,353
20 MW	Fort Hood	N/A	Bell	Texas	1,897	223,176
	Fort Benning	“Benning-Robins”	Chattahoochee	Georgia	1,741	204,824
	Redstone Arsenal	“Redstone Arsenal-Anniston”	Madison	Alabama	1,722	202,588
	Robins AFB	“Benning-Robbins”	Houston	Georgia	1,632	192,000
15 MW	Fort Campbell	“Fort Cambell”	Christian	Kentucky	1,579	185,765
	Fort Bliss	N/A	El Paso	Texas	1,502	176,706
	Washington Headquarters Services	“Virginia”	Washington	D.C.	1,284	151,059
	Joint Base Langley-Eustis	“Virginia”	York	Virginia	1,284	151,059
10 MW	Eglin AFB	“Pensacola-Eglin”	Okaloosa	Florida	1,184	139,294
	Fort Stewart	“Jacksonville-Stewart”	Liberty	Georgia	1,109	130,471
	Fort Sill	N/A	Comanche	Oklahoma	1,077	126,706
	Naval Air Station Pensacola	“Pensacola-Eglin”	Escambia	Florida	1,055	124,118
	MCCDC Quantico	“Virginia”	Prince William	Virginia	1,023	120,353
	Fort Jackson	“Gordon-Jackson”	Richland	South Carolina	1,005	118,235
	Naval Air Station Jacksonville	“Jacksonville-Stewart”	Duval	Florida	923	108,588
	Fort Lee	“Virginia”	Prince George	Virginia	908	106,824
	Anniston Army Depot	“Redstone Arsenal-Anniston”	Calhoun	Alabama	881	103,647
	Fort Gordon	“Gordon-Jackson”	Richmond	Georgia	832	97,882

Next, we define supply areas from which feedstock will be sourced to meet the estimated bioenergy demand from either an individual installation or a cluster of installations located in close proximity to one another. To define supply areas for each qualifying military installation, we first assume that biomass will be sourced within 50 miles of the installation. Given the inherent variation in fuel prices, road configuration, and driving conditions, a 50-mile linear distance is not a universal determination of transportation cost-effectiveness, but provides a rough indication of proximity (e.g., Galik et al., 2009). All counties which have at least some portion within a 50-mile radius of a qualifying installation are thus included in the supply area for that installation. Due to the proximity of installations, many counties fall into more than one supply area. In those situations, supply areas were merged along with their corresponding installations. This process reduced the number of discrete installations and corresponding supply areas from 24 to 11. Furthermore, three of the aggregated supply areas occurred in parts of Texas and Oklahoma that have either insufficient forest resources to be relevant to this bioenergy market analysis or fall outside the scope of the SRTS model upon which this analysis depends. Eliminating these three military regions leaves us with a final total of eight aggregated installation/supply area clusters (Figure 1).

Figure 1. Installation location and extent of individual biomass supply areas. Shown are the locations of individual installations meeting the capacity screen (black), as well as aggregated supply areas defining the counties from which biomass is likely to be sourced.

The standard units of analysis (“sub-regions”) in the SRTS model are FIA survey units. Each sub-region is tied to a physiographic category that captures forest conditions and growth in that sub-region. For this analysis, we redefined the standard sub-regions in SRTS to match our 8 installation supply areas. Some counties in our newly defined sub-regions crossed the borders of established physiographic regions. In those cases we associated the physiographic category that best fit the new sub-region.

Having parameterized the forest growth input files for the SRTS model, we then model changes in forest area, extent, and composition across two scenarios: a baseline, without bioenergy demand scenario, and a scenario in which bioenergy demand for every qualifying installation is scaled up simultaneously. The baseline scenario assumes that forest product demand remains constant over time. The biomass demand scenario applies the aggregate demand estimated in Table 2 to the eight military supply areas described above. Markets across the U.S. south are allowed to interact with and adjust to this increase in demand, resulting in cascading effects across the region. As a sensitivity analysis, demand from a single supply area (Benning-Robins) was also assessed, holding all other installation bioenergy demand at zero.

Finally, forest product removals and harvest residue totals from SRTS for the baseline and biomass scenarios were passed to FASOMGHG to assess the broader regional and national implications of a public-private bioenergy partnership in the Southeastern U.S. Additional bioenergy demand in all regions outside of the South was assumed to be zero. The resulting output from FASOMGHG contained information on the magnitude and allocation of biomass harvest totals, GHG emissions, and net renewable energy generation across both multiple geographic regions and sectors (e.g., forest v. agriculture).

3. Results

The central policy question explored by this analysis is whether bioenergy supply partnerships targeted in the vicinity of military installations in the Southeast U.S. can affect land use change in the surrounding landscape while leading to an increase in the aggregate generation of renewable energy regionally and nationally. With regard to the first component—land use change—our results suggest that increased demand for bioenergy leads to an increase in forest

land area in all installation-associated supply areas (Figure 2). Though the general pattern of forest land use change is similar in all supply areas—a slow increase in acreage until the early 2030s, followed by a slow but uneven decline—the magnitude of change varies from area to area. The similarity in pattern is attributable to the manner in which SRTS model runs are implemented for both the baseline and biomass scenarios. Aggregate biomass demand from all installations was applied to the southeast region as a whole, so all supply areas (military and otherwise) are responding to the same rent effect. In this way, observing rent effects in military regions embedded within the U.S. Southeast market shows the local implications of a broader, regional trend rather than each military supply area operating in isolation.

Figure 2. Land use change by installation supply area relative to a baseline scenario without bioenergy demand as modeled by SRTS.

Aggregating SRTS forest land area change data from all installation supply areas, we see that planted pine comprises a majority of this added acreage, though upland hardwood also shows an increase in area relative to a baseline, without-bioenergy scenario (Figure 3). The mechanisms driving the relative increase in forest area for each management type is different, with the increase in planted pine stemming from the addition of new acres, while increases in upland hardwood stem from a reduced rate of loss. The bioenergy scenario explored here can thus be seen as means of potentially affecting land use and land use change, albeit indirectly.

Figure 3. SRTS-modeled change in area of each forest management type, military supply areas only, relative to a baseline, without-bioenergy scenario.

With regard to bioenergy generation, our modeled increase in biomass demand on installations across the Southeast U.S. yields a national increase in the amount of renewable energy generated (Figure 4). Although military demand remains constant over time, FASOMGHG output shows that total U.S. generation varies somewhat from year to year as nationwide bioenergy generation reacts to changing market conditions. This reflects the net increase in bioenergy generation attributable to the increase in military demand, not just what is being produced for on-base consumption.

Figure 4. FASOMGHG output of national bioenergy generation under the modeled policy scenario, expressed as both a percentage of DoD FY 2013 energy use and in GWh/yr. For the former, additional bioenergy achieved by the modeled policy is shown, as is the 5.6% renewable energy generation already achieved by FY13.

At the Southeast regional level, modeled output from SRTS suggests that the biomass scenario leads to a variable but generally positive pattern of forest carbon storage (Figure 5). These changes in forest carbon storage stem from combined changes in forest land use, changes in forest management and management type, changes in removals, and changes in inventory. As suggested by the land use change estimates for installation supply areas (Figure 3), regional carbon balance is largely buoyed by relative increases in carbon associated with planted pine and

upland hardwood management types. With a few early-year exceptions, these increases more than offset losses in mixed pine and natural pine forest management types.

Figure 5. Total change in forest carbon by management type relative to a baseline, without-bioenergy scenario, as modeled by SRTS for the entire Southeast region.

The results shown in Figures 2, 3, and 5 show the land use and carbon changes stemming from the land use and land use change dynamics associated with additional biomass demand in the Southeast. Recall that our bioenergy demand scenario assumes that all eligible installations scale up simultaneously. Modeling the effects of a single facility operating in a single supply

area within the region is likely to have very different forest market and land use implications. This is shown in Figure 6, which compares the modeled change in forest land use and carbon storage attributable to a single military supply area (Benning-Robins) and the changes modeled for the same installation as part of the multi-installation bioenergy demand scenario explored above. Note in particular that the single supply area scenario results in smaller changes in land use throughout the first half of the assessment, as well as minimal changes in forest carbon storage. Over time, plantations established in the early years of the scenario begin to come online, increasing carbon storage and potential biomass supply. This increase in supply contributes to a decline in forest land rents and the corresponding reduction in forest area shown in the latter half of the figure.

Figure 6. Comparison of SRTS-modeled land use change and forest carbon change data for 1) a single military supply area (Benning-Robins) operating independently, and 2) the same supply area operating as part of a multi-installation biomass scenario encompassing the entire Southeast region.

FASOMGHG-estimated forest carbon storage patterns in the Southeast show a net gain in early years, followed by a short decline and subsequent recovery (Figure 7). As compared to SRTS-modeled output (Figure 5), this pattern of forest carbon storage is similar but lower in magnitude. The net GHG implications of bioenergy use are a function of these changes, as well as corresponding changes in displaced fossil emissions, feedstock transportation, and avoided biomass decay. Of these three, displaced fossil emissions are expected to be the largest driver of

net GHG effect (Gustavsson et al. 2015). The scope of this analysis limits our ability to predict what fuels will be displaced by an increase in bioenergy use, so we instead assess the resulting GHG emissions from the two fuels that are most likely to be displaced in our hypothetical scenario: coal and natural gas. Assuming emission rates of 2,249 pounds CO₂e per MWh for coal and 1,135 pounds per MWh for natural gas (U.S. EPA, 2014), the resulting net GHG benefit is seen to be positive in most years of the analysis.

Figure 7. Net GHG benefit relative to a baseline, without-bioenergy scenario, as modeled by FASOMGHG across multiple sectors in the Southeast. Total GHG benefit is indicated by the gray band, and is a function of combined land use sectors and the displaced emissions from either natural gas (lower boundary) or coal (upper boundary).

Viewing changes in carbon balance at the national level, FASOMGHG-modeled trends estimated for the southeastern U.S. are not replicated at the national level (Figure 8). Despite early- and late-year gains in the South, overall carbon storage is negative across the modeled scenario. This indicates a spatial trade-off in land use and management between the Southeast and both the North and West regions of the U.S., a phenomenon termed “leakage”. Even when accounting for displaced fossil emissions, the overall GHG benefit of simultaneously increasing bioenergy generation capacity on the largest military installations in the Southeast is negative.

Figure 8. Net GHG benefit relative to a baseline, without-bioenergy scenario, as modeled by FASOMGHG across multiple U.S. regions. Total GHG benefit is indicated by the gray band, and is a function of all sectors in all regions and the displaced emissions from either natural gas (lower boundary) or coal (upper boundary).

4. Discussion

The modeled onset of new demand for bioenergy in the Southeast U.S. brings about several changes, locally, regionally, and nationally. Assuming that all installations increase capacity simultaneously causes significant changes in southeastern U.S. forest markets, leading to substantial gains in forest acreage and forest carbon storage in the near- to mid-term horizon. Agreement in regional forest carbon trends as estimated by the different models (Figures 5 and 7) provides an added measure of confidence in the results given the inherent differences between SRTS and FASOMGHG solution framework and sectoral scope. The projections also suggest that the onset of additional bioenergy demand has the net effect of helping to both maintain forest land area and increase the generation of renewable energy for consumption at DoD facilities (Figures 2-4), thus satisfying both objectives for which the hypothetical public-private partnership modeled here was established.

Without a unit-by-unit transition matrix of land use in SRTS or FASOMGHG model output, it is difficult to say from where the newly-forested area is coming. Given the large differences in urban and non-urban land rents (Lubowski et al., 2008; Choi et al., 2011), it is unlikely that the public-private partnerships modeled here can unilaterally slow urban growth. Rather, new incentives or markets affecting forest lands would likely draw from agriculture or pasture lands as increased forest land rents outpace that of these other land uses. It is also possible that the implied change in land rent driving the modeled changes in forest land use may

influence the direction of urban growth at the margin (even if not reducing its growth in aggregate). Targeted markets may also provide added value to other encroachment reduction strategies (e.g., easements), possibly increasing effectiveness through joint implementation.

The projected changes in the Southeast have significant effects outside of the region. The spatially-explicit nature of the biomass demands imposed here—limited to areas in and around specific facilities—places strong constraints on the sourcing of material to supply installation generation facilities. As a result, a diverse array of feedstocks is relied upon to meet each installation’s bioenergy target, including both forestry residues and roundwood in this case. The added demand for roundwood leads to an increase in harvest activity in the near-term, leading to a decline in forest carbon as removals initially outpace gains attributable to induced land use change before later rebounding. Nationally, forest carbon stocks likewise decline as increased harvests occur to accommodate the shift in harvests for bioenergy production in the Southeast. Even when accounting for potential displaced emissions from coal- or natural gas-fired generation, net GHG benefit is still negative at the national level.

These findings contrast those found recently in Galik et al. (2015). In that assessment, a larger bioenergy demand with no spatial sourcing constraint, feedstock for meeting the target could be sourced anywhere within the Southeast region. Although the bioenergy target was higher in Galik et al. (2015), the ability for feedstock to come from anywhere in the region increased flexibility on the sources available to meet the target. Relaxing the proximity constraint in that analysis allowed residues to play a larger role in the region and for harvest delay and the addition of new plantations in other regions to yield substantial carbon storage gains over the long term.

These differences underscore the strong influence of both bioenergy targets themselves and the configuration of supply area targeted to meet these goals (Schmidt et al., 2010). This reinforced here in the comparison between the disaggregated regional output for an individual supply area (“Benning-Robins”) with the results from a single installation run for the same supply area (Figure 6). In that comparison, standing volumes across all forest management types are higher in the single installation example, translating into a higher forest carbon stock. In time, material from forests established at the outset of the scenario begins to become available, driving prices down and lowering forest land rents relative to other uses, leading to a drop in forest acres. In the disaggregated regional example, we do not see similar volatility in supply or price, which translates to a more stable land use trajectory over time.

What this collectively suggests is that a region-wide, one-size-fits-all type policy has both benefits and drawbacks. Simultaneously converting or repowering every large military installation in the Southeast for bioenergy leads to a long-term increase in forest acres and a sizable increase in renewable energy production in furtherance of established DoD objectives. At the same time, the magnitude of demand, combined with constrained supply areas for feedstock to meet that demand, creates an increased reliance on roundwood. This leads to increased incentives for retaining forest acres but also an increased demand for roundwood itself, increasing harvests and driving down total forest carbon relative to a baseline, without-bioenergy scenario. Results suggest that the effects of individual installation conversion or repowering may be more muted, both in terms of the land use response and in terms of carbon storage, potentially leading to situations of carbon gain rather than loss. Thus, rather than employing a region wide solution, opportunities may instead exist for targeted, one-off strategies that achieve positive near-term land use change and GHG outcomes.

4.1. Conclusion

It is not just the findings of this analysis that are of significance, but rather the methodology employed and the market-response phenomenon that are the important to consider in both research and practice. Drawing from previous research that speaks to the role of increased forest biomass demand in affecting land use change, this analysis models the influence of localized bioenergy markets on U.S. military installation renewable energy production and encroachment reduction goals. The public-private partnerships quantitatively explored here are derived from existing programs. The analysis provides an indication of their potential effect should they be recast, expanded, and targeted with an express focus on helping to achieve these dual military objectives.

We find that simultaneously scaling up multiple sources of bioenergy demand across the southeastern U.S. can lead to significant increases in forest acreage and contribute measureable amounts of renewable energy generation towards DoD's identified production goals. Changes in forest land use and management generally lead to GHG mitigation benefits within the Southeast region. An increase in harvest activity outside of the Southeast leads to a reduction in forest carbon storage at the national level, however, even when accounting for displaced emissions from fossil fuel sources.

The combined SRTS and FASOMGHG model output suggests that these land use change and forest carbon dynamics are partly a function of the size of the market assessed. This in turn suggests that a more tailored approach, one that makes use of public-private partnerships on a case-by-case basis, is perhaps a more effective strategy to avoid broader negative GHG mitigation consequences. While this is at once a straightforward conclusion, the analysis here both quantifies this conclusion and outlines the mechanics underlying the observed results,

allowing policy-makers and other stakeholders to make more informed investment and implementation decisions. It also speaks to the benefits of coupling models with different sectoral and geographic scope so as to better evaluate the various tradeoffs that may arise from even targeted policy interventions. Here, this coupling provides insight into localized land use change dynamics while demonstrating a potential trade-off between local carbon gains and national carbon declines.

Caveats accompanying any modeling exercise also apply to this analysis. As we are employing forest and agricultural models in our analysis, we must make explicit assumptions on how the magnitude of forest land rent change will affect land use change rates. As we assume that urban rents far exceed that of competing uses, urban land use change is not estimated endogenously within either FASOMGHG or SRTS, but is instead set exogenously. We must also hypothesize how higher forest land rents will influence conversion to other uses. Although the relationship between land rent and land use change has been identified elsewhere in the literature, our assumptions of the exact nature of that relationship as applied in the Southeast have a direct bearing on the outcomes of this analysis.

It is also important to again emphasize that we are employing two different modeling frameworks making use of different underlying assumptions about forest manager response to increased market opportunities for a given commodity. In the specific case of FASOMGHG, an intertemporal optimization model, we would expect landowners to adjust efficiently in advance of expected market changes, reaching an optimal allocation of resources across both space and time. Under SRTS, forest resource managers are more likely to wait for sufficient pricing signals to adjust planting and harvest behavior. Relative to one another, we would therefore expect the FASOMGHG solution to overpredict market response in the early years of a new market or

policy, while SRTS may underpredict it. The most true-to-life answer perhaps lies somewhere in the middle. General agreement between models on direction of forest carbon response, for example (Figure 5 and 7), provides a degree of confidence despite differences in observed magnitudes of change.

Future research is necessary to determine both the scale of operation and the biophysical conditions under which benefits can be maximized and trade-offs between different objectives minimized. Public-private bioenergy supply partnerships may nonetheless contribute to the toolbox of available options to address installation encroachment in the Southeast, especially when added to the existing suite of programs already operating in and around the region. An absolute conclusion on the effectiveness of the tool as applied is difficult to reach, however, as there are multiple market and policy uncertainties that could both promote or hamper the use of supply partnerships as an encroachment reduction and renewable energy strategy. Increased availability and decreased price of natural gas, combined with decreases in military spending, could impede the development of new bioenergy generation infrastructure. Concerns likewise exist over the potential for increased bioenergy demand to negatively affect other environmental attributes or objectives (e.g., Natural Resources Defense Council, 2015). This analysis does not assess the influence of these collective economic, environmental, and social considerations on the evolution of forest markets in the region, but they remain important areas for further study.

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