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Trading Food Security for Climate Change Mitigation? The Implications of Renewable Electricity Expansion
on US Food Production and Trade

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1.0 Introduction

Conservation programs, environmental markets, and bioenergy expansion all have the potential to produce important environmental benefits by changing agricultural management intensity or overall land use on existing cultivated croplands. Renewable energy sources such as biomass are a growing part of national and corporate commitments to reduce GHGs. Examples range from the U.S. Clean Power Plan to China's Intended Nationally Determined Contribution (INDC) pledge to increase the share of non-fossil fuels in primary energy consumption to 20 percent by 2030. The latest US Annual Energy Outlook reports (EIA, 2014; EIA, 2015), projects US electricity sector biomass-derived energy generation to reach 50-80 TWh per year by 2040 (which varies by AEO scenario). This represents an increase of more than 500% relative to 2014 levels.

Simultaneously, the demand for U.S. wood pellets as a bioenergy feedstock source has risen sharply in the European Union (E.U.) over the last five years (doubling between 2012 and 2013 alone) and this trend will likely continue as the E.U. seeks to meet stringent renewable electricity goals (Galik and Abt, 2015). It is expected that the U.S. will continue to be the largest supplier of wood pellets to the E.U., which could lead to conversion of agricultural lands to short rotation forest plantations in the Southeastern U.S. to help source a growing number of U.S. pellet mills. Thus, U.S. agricultural and forestry landscapes could change greatly with anticipated growth in biomass electricity generation in the U.S. and globally. Such expansion could require a large area of productive forest and agricultural land to produce the requisite feedstock supply, which increases competition for land resources used to produce conventional commodities. In addition to environmental concerns that bioenergy expansion can degrade land resources and induce land use change, there are food security concerns to consider as well, especially if agriculture plays a key role in supplying requisite feedstock for renewable electricity generation. While previous literature has evaluated the net GHG consequences of biomass electricity (especially for forestry feedstocks), the role of agriculture in meeting renewable electricity

targets and subsequent food security concerns have been largely ignored. Food Security concerns arise if the management or land use changes adopted in pursuit of environmental policy objectives on working agricultural lands result in a meaningful reduction in conventional agricultural commodity production.

The objective of this paper is to discuss and quantify potential food security implications of a U.S. biomass electricity expansion. We utilize the FASOMGHG model (Beach et al., 2010; Adams et al., 2008) to integrate the U.S. agriculture, forest, and bioenergy sectors while providing comprehensive GHG accounting. In addition we develop a methodology to project total calorie loss under alternative renewable electricity scenarios to quantify the greenhouse gas (GHG)/food security trade-offs implicit in such projections. Multiple feedstock eligibility scenarios were constructed to compare impacts across sector sources, within and across agricultural and forestry. We show that as bioenergy requirements increase, it becomes increasingly important to obtain biomass from agricultural sources. A flexible system that encourages feedstock consumption from both sectors yields the greatest GHG benefits while mitigating calorie loss. Furthermore, we also show that encouraging biomass consumption from both sectors can alleviate calorie impacts relative to a case in which only forestry feedstocks are consumed. This result is somewhat surprising, but is due to the difference in potential energy per unit of area of forestry relative to agriculture, which requires more extensive margin expansion of forests onto productive agricultural lands to supply the required forest biomass. Our analysis illustrates the important role that agricultural biomass can play in reducing GHG emissions from electricity generation and that secondary food security impacts would likely be minor.

2.0 Background and Literature Review

The Energy Information Administration's (EIA) Annual Energy Outlook (AEO) provides annual projections of fuel consumption by source, sector, and region. The AEO is produced using the National Energy Modeling System (NEMS), a detailed model of the U.S. energy system that includes specific regional cost assumptions for non-fossil energy, including multiple bioenergy feedstock sources. Projections of biomass demand vary over a series of stylized scenarios that represent different levels of future economic growth and a range of policy assumptions. The baseline, or "Reference Case" scenario presents an anticipated business-as-

usual projection of biomass consumption for electricity generation (henceforth referred to as biopower). The Reference Case traditionally reflects the impacts of laws and regulations that have already been promulgated and assuming current laws and regulations remain unchanged throughout the projection period. Over time, AEO Reference Case projections of biopower have varied dramatically, as shown in Figure 1.

These differences are driven by a number of factors, including:

- Macroeconomic conditions
- Energy sector development and markets— the rise in natural gas over the last six years has impacted the outlook for renewable energy sources as a replacement for coal.
- Policy assumptions—regional and national energy policy assumptions are built into the AEO to the extent possible. As emphasis on specific policy goals (e.g., renewable energy development or climate change mitigation) changes over time, so do AEO projections, and

- Relative prices of alternative renewable energy sources—the 2015 outlook for biomass is more pessimistic than 2014 due to declining cost assumptions for wind and solar that have been updated in the NEMS model.

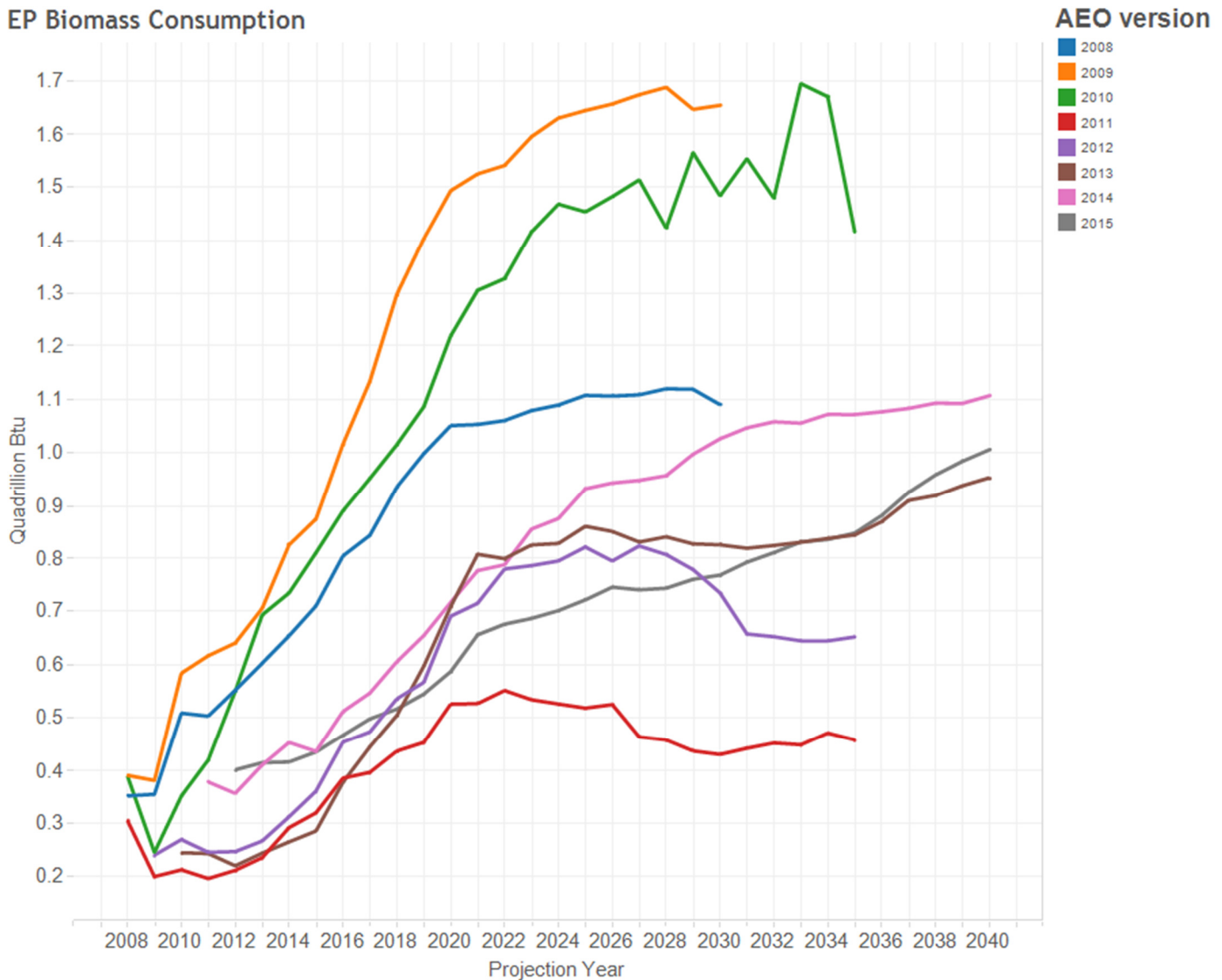


Figure 1: Projected Biomass Consumption in the Electricity Sector from Past AEO Reference Cases

It is important to note that regardless of which AEO Reference Case is evaluated, projected biomass demand is expected to increase significantly relative to a base year (50%-500%), which could place considerable additional pressure on U.S. land resources already constrained by the Renewable Fuels Standard. Furthermore, a seminal paper by Searchinger et al. (2009) argues that treating biomass as carbon neutral relative

to an energy equivalent amount of fossil fuel does not account for emissions on the landscape, and hence incorrectly attributes a full emissions credit to fossil fuel displacement activity. This assertion has been supported by a number of studies that take a stand-level (or local) perspective on biomass harvest for energy generation. Such studies employ physical models of tree growth and estimate carbon payback periods from harvesting a single stand to displace coal or natural gas in electricity generation. These studies typically result in long (>50 year) carbon payback periods, meaning GHG benefits can only be realized over the very long term once all of the original biomass carbon is regrown on the landscape (Zanchi et al., 2010; Bucholz et al., 2015).

However, this methodology ignores economic incentives and market dynamics. Policies with far-reaching regional, national, and global market impacts should be evaluated within a systems-based framework to project emissions from the entire landscape, and not from a single isolated forest stand. Policies encouraging biopower expansion can lead to extensive and intensive margin changes within and outside of the region of assessment that can only be captured by detailed models that link economic and biophysical systems over aggregate geographic regions. EPA (2014) demonstrates an analytical framework for assessing the additional terrestrial GHG emissions impacts of increased biopower generation based on forward-looking economic modeling. This approach seeks to isolate the impact of additional biomass consumption from a counter-factual policy scenario relative to a future anticipated baseline.

Indeed, there is an emerging literature that evaluates GHG emissions from biopower expansion using similar modeling approaches, though the vast majority of this literature has focused on forestry feedstocks. Daigneault et al. (2012) conduct a global analysis of forest biopower expansion under different policy assumptions varying both the amount of bioenergy feedstock required from the system, and the eligible sources that could meet this new demand. This study finds net GHG benefits from most scenarios, as policies encouraging forest biomass demand incentivize investment and management responses in the sector that increase forest carbon stocks relative to the baseline. However, GHG benefits are reduced when residuals are not eligible to meet increased biopower targets.

Recent regional assessments using economic models have found similar results. Galik et al. (2015) evaluate the net emissions implications of a regional Renewable Portfolio Standard (RPS) in the Southeast U.S. and find an overall reduction in GHG emissions relative to a baseline. Galik and Abt (2015) compare GHG implications of expanded wood pellet production in the Southeast U.S. to assumed European Union target GHG reduction thresholds. The implied cumulative reductions in GHG emissions from these pellet scenarios far surpass the acceptable thresholds over the medium and long term. Dwivedi et al. (2014) find similar GHG savings from pellets produced in the Southeast U.S. for EU consumption.

While these studies are providing increasing evidence that forest-derived biopower feedstocks can provide long-term GHG benefits relative to fossil fuel equivalents, the role of agriculture has been largely ignored despite optimistic projections of both the availability and relative costs of agricultural biomass from the Department of Energy's Billion Ton Update study released in 2011 (DOE, 2011). Latta et al. (2013), which is the basis for this analysis, applied the U.S. Forest and Agricultural Sector Optimization Model (FASOMGHG) to evaluate the effects of different levels of biopower expansion across different feedstock eligibility scenarios. The study showed that the greatest GHG benefits were achieved from scenarios in which the feedstock portfolio is dominated by agricultural feedstocks (energy crops and residues) and forest residues (milling and logging residues).

Trading Food Security for GHG Mitigation?

However, net emissions displacement potential is not the only potential issue with biopower expansion, as displacing conventional commodity production for energy feedstock production raises food security concerns. There is a lengthy literature that elaborates on this issue in the context of biofuel (e.g., corn ethanol) expansion, and to a lesser degree the Conservation Reserve Program in the United States (U.S.), though to our knowledge no study has empirically estimated potential food security impacts of biopower expansion.

Bioenergy demand creates tension in land use between food and fuel production. Unlike the direct substitution between conventional biofuels and corn, bioenergy from inedible feedstocks is linked to food markets through competition for land. As bioenergy is an important GHG mitigation strategy, this important

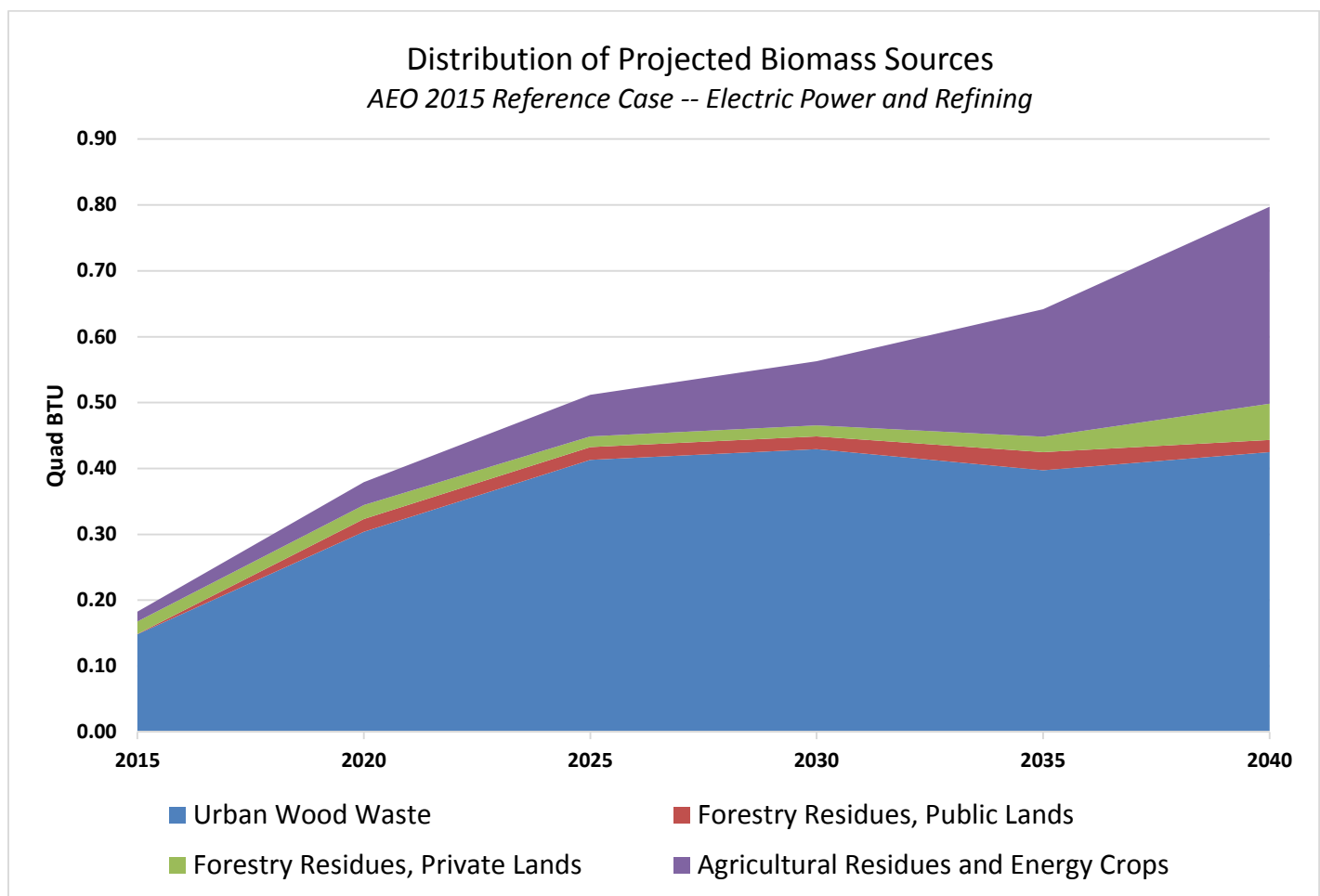
topic has been seized by authors in a number of reports, some of which have made their way into policy debates. For example, Searchinger and Heimlich (2015) cite a FAO report's conclusion that food crop calories must increase 70 percent by 2050 (Alexandratos and Bruinsma, 2012). The authors begin with a somber claim from a reputable source, in this case the FAO: compared to 2006 crop calorie demands will be 70 percent higher by 2050. They revised the population estimates upwards and redefined food security measures to use a higher threshold. They then layer on some additional assumptions, notably a global adoption of renewable transportation fuel mandates that require 10 percent ethanol blends.¹ Their result is that the remaining land seemingly cannot support increasing food and bioelectricity demands. Searchinger and Heimlich recommend “phasing out dedicated use of land to generate bioenergy, including biofuels, while reserving some efforts to generate bioenergy from true wastes.” (p.26).

In March 2015, a letter was submitted U.S. Environmental Protection Agency (EPA) Administrator Gina McCarthy by a group of scientists and policy advocates (including Searchinger and Heinlich) claiming that biomass energy does not produce GHG benefits relative to fossil fuel equivalents, and that current projections of bioenergy demand from the EIA will require a biomass volume equivalent to roughly 70% of the current U.S. timber harvest.

The claims made in these previous two examples can be misleading. First, the perspective offered by Searchinger and Heinlich (2015) does not reflect the potential complementarity between food and energy production systems (e.g., use of agricultural residuals from primary crops as a bioenergy feedstock). Furthermore, increased focus on “true wastes” as a primary bioenergy feedstock can also have indirect implications. By incentivizing use of “wastes” beyond baseline availability, a policy implicitly increases the relative value of the primary product that is the basis of the waste feedstock stream, thus leading to increased production levels and (potentially) GHG emissions.

¹ Searchinger's 10% global biofuel mandate is roughly twice as large as the ethanol projected in IOE2014's high oil price scenario, and almost 5 times current ethanol production. That implies a 5.4 percent annual growth rate, which is twice the current growth rate, and significantly higher than the 3.3 percent annual growth rate in the IEO's high oil price scenario.

Second, existing energy sector projections of bioenergy demand do not assume that the bulk of bioenergy demand will be met with forestry feedstocks. In fact, the opposite is true. Figure 1 shows the distribution of feedstocks, by source, from the EIA’s Annual Energy Outlook (AEO) 2015 Reference Case projection of electricity sector bioenergy consumption. Note that AEO 2015 projects an increase in biopower generation consistent with the current policy climate, but that the primary feedstock supply is projected to come from urban wood wastes and agricultural sector feedstocks. Only 10%-11% of the projected biomass portfolio is comprised of forestry feedstocks, and this only includes logging and milling residuals.



Nevertheless, if the agricultural sector is expected to play an important role in the U.S renewable energy future, it is important to consider and evaluate the potential food security implications of expanded agricultural feedstock use for electricity generation. This paper is, in part, a theoretical and empirical response to the more rhetorical approaches used by Searchinger and others. We present a joint forestry/agricultural optimization model for the US in combination with data on GHG emissions and food budgets to examine the implications of

varying levels biopower demand. The multisector analysis, simulating a market approach with contributions/expansion of biomass from both agriculture and forestry better simulates the relevant trade-offs compared with single sector approaches. These model interlinkages enable a comparison across sectors into how market forces will affect feedstock choice, and what is the impact when the feedstock choice is restricted. Our unified theoretical framework guards against double-counting, partial accounting, and makes no assumptions about carbon-neutrality of biopower, avoiding several other pitfalls that befall other “simple” approaches.

The rest of the paper is organized as follows: Section 2 presents a review of recent studies, Section 3 discusses our method, including a description of the FASOM-GHG model (Beach et al 2010, Adams et al 2008); Section 4 describes the scenarios, Section 5 presents results; and Section 6 concludes.

3.0 Methods

This paper further evaluates simulation results from scenario results presented in Latta et al. (2013) to evaluate climate mitigation and food security implications of U.S. biopower expansion simultaneously. To simulate market and land use responses to increased levels of biopower from alternative sources we utilize the FASOMGHG model (Beach et al., 2010; Adams et al., 2008). FASOMGHG integrates the U.S. agriculture, forest, and bioenergy sectors using an inter-temporal dynamic optimization approach to simulate market equilibrium values for an array of agriculture and forest products, including biofuels and biopower markets (McCarl et al., 2000; Alig et al., 2010b) while providing comprehensive GHG accounting. Figure 2 **Error! Reference source not found.** shows the basic structural outline of the FASOMGHG model, incorporating linkages between agriculture and forestry in land, product markets, and processing markets.

Key components of the modelling framework for this analysis are;

- Level of detail included in the agricultural sector, including crop production possibilities represented and numerous primary, secondary, and bioenergy commodities.
- Explicit linkages between the crop and livestock sectors through feed markets and competition for land and water resources.

- Explicit linkages between the agriculture and forestry sectors through competition for land resources, product substitution, and bioenergy markets.
- Inclusion of a GHG accounting framework.
- Endogenous biopower feedstock choice.
- Detailed representation of biopower capacity (100% and co-firing options), with regional capacity constraints, capital depreciation factors, and options for endogenously increasing capacity.

The FASOMGHG model includes a comprehensive agricultural, disaggregated into a wide-range of crops used for both conventional and bioenergy means. The model allows for the market response across the agricultural sector to be determined with a high level of detail. For example, livestock feed, trade, and processing markets include a significant amount of the aggregate caloric flow in the US. Incorporating these changes when determining resulting food availability allows for this effect to be accurately computed, avoiding such issues as double counting. Figure 1 provides a conceptual diagram depicting the many interactions of markets and natural resource systems that are captured by FASOMGHG

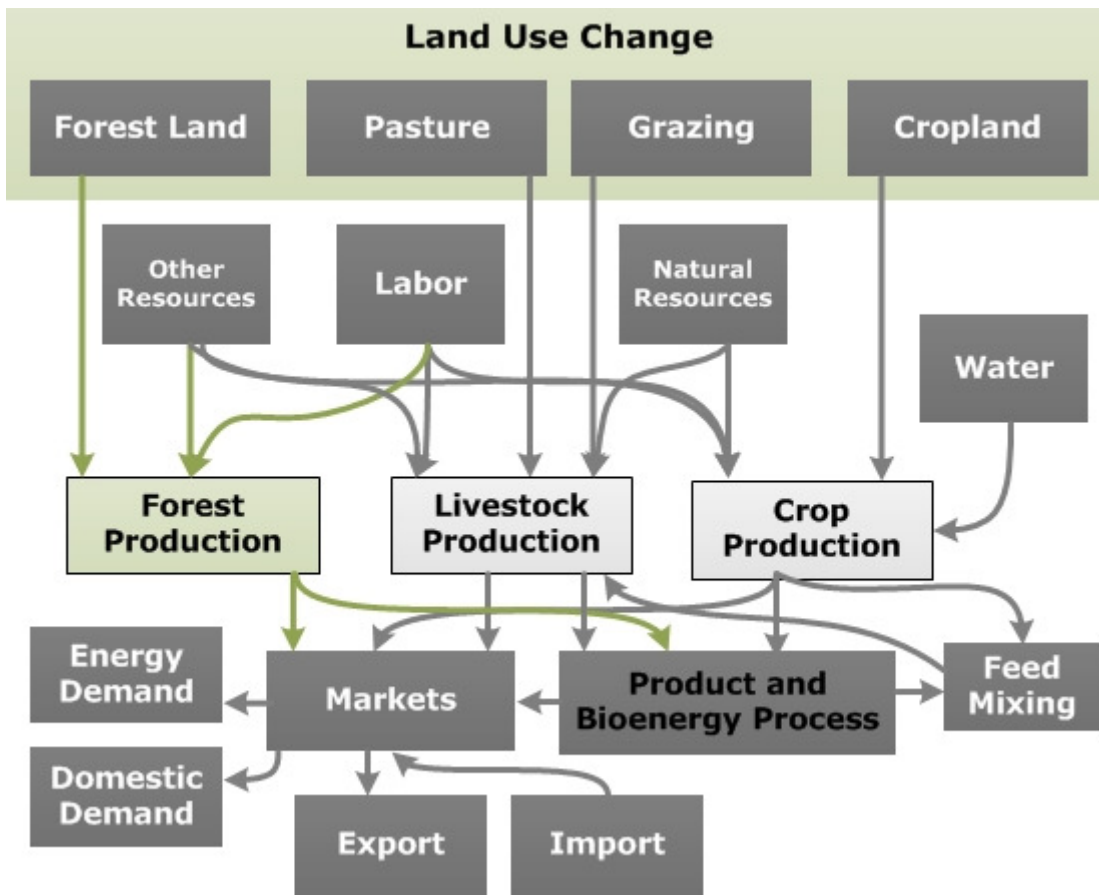


Figure 2. FASOM-GHG Model Components

The linkages between sectors allow for competition and substitution in the use of private lands for production of either agriculture or forest products as well as the supply of substitutable products including pulp and bioenergy feedstocks. The inclusion of hybrid poplar in the model is an example of the sector linkage within the product market. The model assumes this short-rotation woody crop (SRWC) or short-rotation trees are grown on cropland, however may be used in conjunction with traditional forest commodities to produce forest products. The inter-temporal optimization approach allows the model to capture behavioral responses of agents to expected future outcomes of the simulated policy scenario, in this case a renewable energy policy. This includes long term investment decisions related to existing forest silvicultural changes and land use change between sectors.

Forestry GHG accounting in the model includes standing live and dead tree biomass, down dead material and forest understory vegetation, organic litter on the forest floor, and forest soils (Smith et al., 2006).

Fossil fuel emissions in harvesting and silviculture are represented and harvested wood products accounting is based on Skog and Nicholson (2000). Agricultural sector GHG accounting includes emissions from livestock production and manure management, soil disturbance, fertilizer application, and use of fossil fuels in agricultural production. Emissions of N₂O for specific cropping practices are derived from the DAYCENT model (Parton et al., 2001) and CH₄ emissions per head of livestock include the handling of livestock manure as well as enteric fermentation. Fossil fuel emissions include those from use of gasoline and diesel in planting, management, and harvesting of agricultural products. Agricultural soil carbon accounting and soil N₂O emissions are based on the CENTURY agroecosystem model (Ogle et al., 2009) and is influenced by tillage practices, use of irrigation, land use (e.g., land in pasture), and planting of perennials (e.g., switchgrass). A full description of the FASOMGHG carbon accounting methodologies and assumptions can be found in Beach et al. (2010). This implementation of this framework does not require an assumption regarding the carbon neutrality of any bioenergy source, rather, the accounting system allows for the GHG implications to be determined a posteriori.

Biopower modeling in FASOMGHG involves the complex interaction of primary and secondary forest and agricultural products. To isolate the impacts of an expanded Renewable Energy Standard or Renewable Portfolio Standard (RES/RPS) program we simplify the biofuels part of the model by constraining ethanol and biodiesel production levels to those projected by the U.S. Department of Energy in their Annual Energy Outlook. These fixed levels of production are for aggregate volumes of domestic conventional and cellulosic ethanol and biodiesel, but do not constrain the feedstock sources utilized within those biofuel categories. A similar approach is implemented for bioenergy, whereas aggregate constraints are implemented based on each scenario however the choice of feedstock and location of production is determined endogenously. Lignin recovered in the distillation of cellulosic ethanol is not considered applicable to our simulated RES biopower targets.

Latta et al. (2013) presents a list of the available biomass feedstocks that FASOMGHG allows to be applied toward the RES targets along with the embodied assumptions of energy and moisture content for each feedstock. The higher heating values (HHVs) reflect the energy output per metric tonne of biomass and take

into account the latent heat requirement for vaporization of the moisture content. FASOMGHG’s unique interconnected agriculture and forestry sector will allow for both economic and environmental impacts to be evaluated in detail as biopower is assumed to increase, and across source scenarios.

Global agriculture faces the dual challenges of improving food security for a growing population while simultaneously reducing the environmental footprint of agricultural production, including net greenhouse gas (GHG) emissions. We use US-specific data from the FAO to convert the crop production into calories, as shown in Table 1:

Table 1. Major Caloric equivalents of US crops (in Kcal per kg)

		Barley	Corn	Oats	Rice	Sorghum	Soybeans	Soybean Oil	Wheat
World	Kcal/Capita	2,555	52,925	1,095	198,925	11,315	5,110	31,025	191,260
	KG	1.0	17.6	0.6	54.1	3.7	1.5	3.6	65.3
	Kcal/Gram	2.6	3.0	1.9	3.7	3.1	3.5	8.6	2.9
USA	Kcal/Capita	1,825	33,945	7,665	28,105	2,190	-	192,355	215,350
	KG	0.5	12.5	4.3	7.5	0.7	0.0	23.2	79.5
	Kcal/Gram	3.5	2.7	1.8	3.8	3.3	0.0	8.3	2.7

4.0 Scenarios

Latta et al (2013) evaluated a series of biomass feedstock production scenarios. This included a wide range of biopower generation levels (ranging from 0 to 200 TWh of electricity per year sourced from agricultural and forestry feedstocks) in combination with alternative assumptions regarding biomass feedstock eligibility by type, substitutability of land between agriculture and forest uses, and substitutability of fiber produced by the forestry sector and that produced from short-rotation woody crops produced by the agricultural sector within FASOM. In this paper, we use simulation results from the same set of scenarios, but focus on a different set of outputs than Latta et al. (2013) in order to explore the potential implications of biopower expansion for food security. All biomass feedstock eligibility scenarios examined in this study are presented in Figure 3, with the set of biomass feedstocks used in each scenario shown on the right and the range of biopower

levels applied shown on the left (see Latta et al., 2013 for additional detail on the scenario definitions). We compare scenarios with 0 – 200 TWh/year of biopower generation to a baseline scenario with no biopower. This allows us to isolate the net impacts of expanding biopower generation on key outputs such as land use/land use change, agricultural/forestry product production, and GHG emissions. The feedstock eligibility scenarios on the right range from least restrictive (top) to the most restrictive (bottom)..

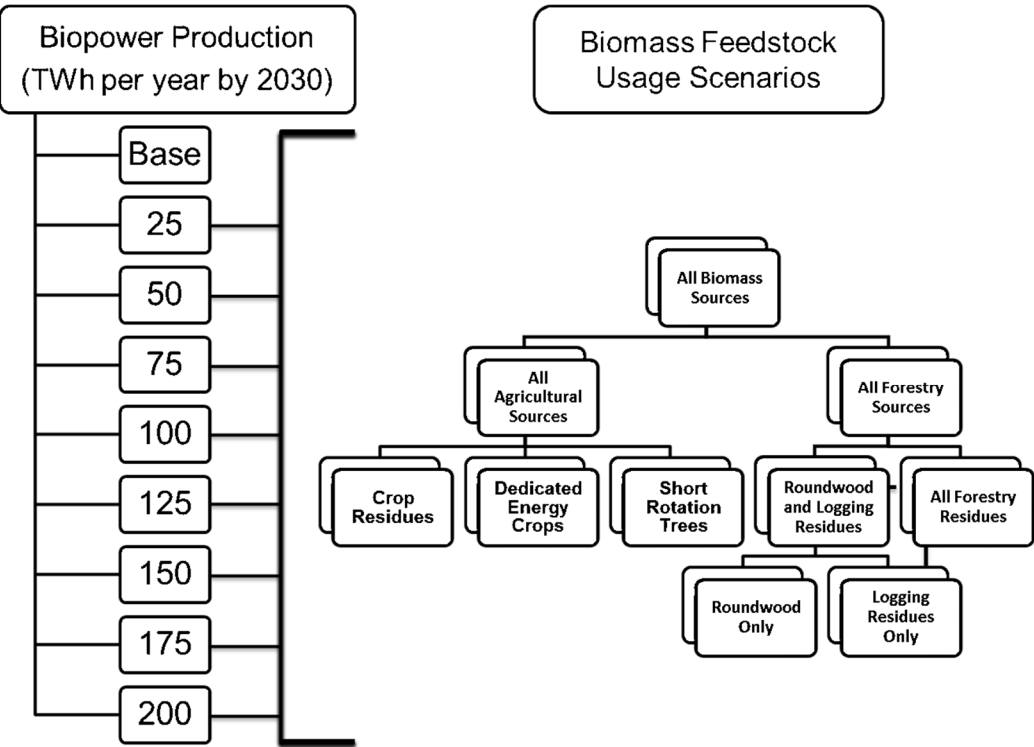


Figure 3. Biomass Feedstock Scenarios

5.0 Results

While substitution of biopower for fossil fuel generation can reduce GHG emissions, the increased demand for agricultural and forestry biomass will also tend to impact land use and commodity markets. Focusing on the impacts of expanded biopower generation on food security, we present changes in feedstock utilization, land use, cropland allocation, agricultural production and consumption, and GHG emissions

reductions in both the short-run and long-run. We present results across a range of biopower levels to capture the extent to which tradeoffs between emissions reductions and food security vary with the magnitude of biopower used.

Feedstock Use—All Scenarios

Feedstock utilization depends on a number of complex factors that influence the relative costs of alternative biopower feedstocks. In general, as flexibility increases in terms of timeframe and eligible feedstocks, it becomes cheaper and easier to produce a given level of biopower. However, there are a number of reasons why it could potentially be important to design policies to restrict the feedstock types and quantities that can be used due to considerations such as long-term forest dynamics, economic impacts on the forest products sector, food security, and indirect land use change. Table 2 compares feedstock use across scenarios for both short- and long-run time frames. In the unrestricted all biomass sources scenario, we find that crop and forest residues provide less than half of the necessary feedstock supply even in our lowest biopower scenario of 25 Twh/year. Although such residues are often thought of as a “free” or low-cost resource, there is limited availability of these residues and the costs of collecting and transporting them may be substantial. In addition, there are opportunity costs associated with diverting milling residues from other uses and impacts on fertilizer requirements for crops as soil nutrients are removed along with the residues. Substantial increases in biopower production are likely to quickly exhaust the availability of low-cost residues and induce the introduction of dedicated feedstock production.

As feedstock demand increases towards 200 Twh/year, dedicated energy crops increasingly dominate the feedstock mix. This is evident in both timeframes, though energy crops represent an even higher share of the feedstock use in the short-run as they provide the most efficient way to generate large amounts of feedstock per unit due to their high yields. Feedstock supply response is non-linear in the short-run. Lower biopower generation levels are satisfied entirely with energy crops, crop residues, and milling residues. As biopower generation is increased, we initially see increases across the board in all feedstock categories, including those that were not used at 25 Twh/year. However, as biopower generation levels are further increased towards 200

Twh/year, feedstock use becomes increasingly concentrated on energy and woody crops. In the longer-run, as the biopower generation levels specified by each scenario are fully phased in, the absolute quantity of energy crops used continues to increase but agricultural and forest residues, woody crops, and roundwood all provide a larger share of the total feedstock for the highest biopower generation scenario in the longer-run than the short-run. This change in mix is indicative of larger total biomass requirements resulting in a large enough increase in land competition and land rental rates that forest and crop residues become more competitive again. In addition, we see more reliance on roundwood in the longer-run with rising biopower generation requirements as roundwood becomes more competitive in some regions with rising biopower feedstock prices, especially given a long enough timeframe for forest landowners to adjust forest management accordingly.

A similar effect is seen when evaluating the agriculture and forestry sector source scenarios, where energy crops and roundwood, respectively, are used to generate biopower at the 200 Twh/year level. When further restrictions on the agricultural-side sourcing are implemented, and only crop residues are permitted, wheat residue constituted the majority of the crop residues used at lower biopower levels while corn residue (stover) became increasingly prevalent as biopower requirements were increased. Under the short rotation woody crops scenario, both hybrid poplar and willow were found to be important sources for biopower, with willow accounting for a larger share of SRWCs as biopower levels increase. Overall, energy crops were found to be the dominant feedstock choice for any scenario where they are eligible, largely because they produce the largest amount of biomass, and therefore energy, per unit area. This results in a relatively lower opportunity cost of land for energy crops compared with other feedstocks. Our scenario where only forestry sources are eligible relies primarily on roundwood, especially as the required biopower levels increase, because the volume of available logging and milling residues is not enough to meet the demand for forestry feedstocks.

Table 2. Total Feedstock Use across Scenarios

Policy Feedstock Group	Short-Run (2010-2025)			Longer-Run (2025-2040)		
	25	100	200	25	100	200
All Biomass Sources	-----million metric tonnes per year-----					
Energy Crops	4.6	7.2	55.7	3.8	29.8	99.9
Crop Residues	1.8	8.6	0.4	6.8	20.3	18.6
Woody Crops	0.0	5.6	3.1	5.2	9.0	10.2
Logging Residues	0.0	1.7	0.0	0.0	1.7	1.2
Milling Residues	0.5	4.5	0.0	0.6	3.0	2.8
Roundwood	0.0	2.6	0.0	0.0	2.4	8.6
All Agricultural Sources						
Energy Crops	4.4	14.5	49.4	14.1	32.5	110.5
Crop Residues	1.1	2.8	9.9	2.0	11.0	20.6
Woody Crops	2.1	10.6	0.0	0.0	21.2	7.9
All Forestry Sources						
Logging Residues	3.4	14.0	16.7	5.8	17.6	21.9
Milling Residues	2.7	8.0	19.6	3.9	14.7	31.0
Roundwood	2.7	14.5	38.4	11.5	53.9	122.0
Energy Crop Only						
SwitchGrass	7.0	28.3	58.8	16.5	65.9	139.4
Crop Residues Only						
Barley	0.8	1.0	2.0	2.0	1.7	3.8
Corn	0.0	24.2	53.6	1.9	66.6	154.1
Oats	0.0	0.6	0.5	0.1	0.7	1.3
Rice	0.1	0.6	1.5	0.5	1.7	1.9
Sorghum	0.3	1.3	3.4	0.2	1.6	6.6
Wheat	5.4	8.1	15.0	11.3	16.3	22.1
Short Rotation Woody Crops						
HybrdPoplar	0.7	16.6	25.7	2.4	32.8	53.2
Willow	6.3	14.0	35.7	13.9	37.4	92.5

The values reported in this table represent averages over the specified periods for short-run and longer-run. Because the biopower generation levels used to specify each scenario are not reached until 2030 (as described earlier, biopower generation is assumed to increase linearly from 2010 through 2030, then remain at 2030 levels through the end of the model period), the average amount of biopower produced in the short-run for a given scenario is less than in the longer-run. That is the key reason for the differences in quantities of feedstock required between short- and longer-run for each scenario.

Land Use Change – “All Biomass Sources” Unrestricted Scenario

Table 3 details the baseline land allocation across the primary land uses in the FASOM model over three periods, followed by the difference in land allocation for three of the bioelectricity target levels. In general, permitting all sources of bioelectricity increases land allocation to cropland and pasture and decreases allocation to forestry and cropland pasture.² This is the result of the relative energy productivity across products and the relative value of the marginal product from these land types. Market responses lead to reallocation of land use. As energy crops are the most efficient feedstock to use for biopower production in FASOM, we observe net conversion of forest and cropland pasture land types into cropland for increased switchgrass production. There is also some net movement of land from forest to pasture to make up for the net loss of cropland pasture.

Table 3. Baseline Land Allocation and under the “All Biomass Sources” Scenario

Baseline Land Allocation	Initial (2010)	End of Short-term (2025)	End of Longer-term (2040)
	<i>----- base (mil acres) -----</i>		
Forest	346	346	349
Cropland	301	299	290
Pasture	84	74	70
Cropland pasture	54	51	44
Range	303	301	300
Bioelectricity Target Levels	25	100	200
End of Short-term (2025)	<i>----- difference from base (mil acres) -----</i>		
Forest	(0.45)	(4.88)	(4.47)
Cropland	3.89	6.29	7.69
Pasture	0.34	1.76	1.32
Cropland pasture	(3.79)	(3.17)	(4.54)
Range	0.00	0.00	0.00
End of Longer-term (2040)			
Forest	1.13	(3.07)	(5.71)
Cropland	1.39	6.65	12.44
Pasture	(1.00)	0.11	2.43
Cropland pasture	(1.51)	(3.69)	(9.15)
Range	0.00	0.00	0.00

² In FASOM, cropland pasture refers to land that is of sufficient quality to be considered cropland, but is being allocated to pasture. Pasture, on the other hand, cannot be used to grow crops in the model without additional expenditures to improve land quality prior to conversion to cropland.

Cropland Acreage Allocation and Agricultural Production – “All Biomass Sources” Unrestricted Scenario

In addition to changes in land allocation across types, increasing the demand for biopower is expected to cause reallocation in the crop mix that landowners choose to produce. Table 4 compares the average cropland acreage across the major crops in millions of acres. While we do see reallocation of crop production towards biopower feedstocks, especially switchgrass, this shifting between crops provides less of the area used for switchgrass than movement between land types. In all instances, we see a reallocation of acreage among crops, with net decreases in the area devoted to food crops, with wheat being particularly negatively impacted. Soybeans are most affected at lower levels of biopower, while impacts on wheat tend to rise with biopower generation. Adjustments in other crops are relatively small, with the exception of increases in the “other” crop category. As biopower requirements are increased, additional crops become increasingly impacted. For instance, in the 200 TWh scenario, there is a 0.5 million acre decrease in corn acreage. In the long-run, crop acreage has increased enough to mitigate many of these declines however wheat production remains most heavily affected. This cropland shift results in a transfer from the production of food to the production of energy. However, the large reliance on agricultural energy crops greatly reduces the land required from the forest sector due to the high yields provided, mitigating the deforestation and associated GHG impacts expected to result from the use of lower-yielding feedstocks.

Table 4. Cropland Acreage Allocation

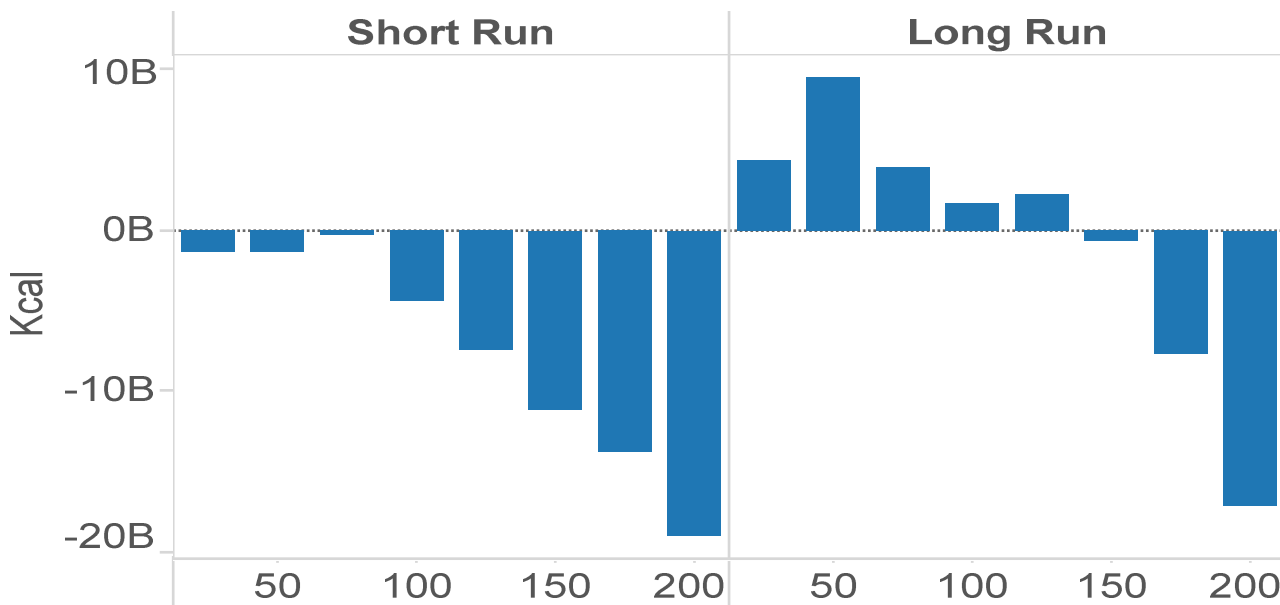
	Crop	Barley	Corn	Cotton	Hay	Oats	Other	Rice	Silage	Sorghum	Soybeans	SRWC	Switchgrass	Wheat	Total
Biopower generation TWh / year	----- average cropland allocation over the short-term (2010-2025) in million acres -----														
	0	7.5	75.7	9.0	51.0	4.3	4.6	2.9	5.9	11.1	66.1	1.0	0.6	61.9	301.4
	----- change from base cropland allocation over the short-term (2010-2025) in million acres -----														
	25	(0.05)	0.10	0.03	0.25	0.03	0.83	(0.01)	0.03	(0.27)	1.18	(0.08)	0.88	(0.93)	2.01
	100	(0.14)	0.17	(0.01)	0.36	(0.00)	3.13	(0.06)	0.07	(0.14)	0.63	1.06	1.23	(0.39)	5.89
	200	0.03	(0.56)	0.12	(0.05)	0.01	2.48	(0.04)	0.09	(0.48)	(2.81)	0.42	8.42	(1.89)	5.73
	----- average cropland allocation over the longer-term (2025-2040) in million acres -----														
	0	7.0	72.3	8.0	50.3	3.9	5.9	2.7	5.4	10.9	63.3	0.7	3.3	60.6	294.3
	----- change from base cropland allocation over the longer-term (2025-2040) in million acres -----														
	25	0.03	0.48	0.14	(0.07)	(0.11)	0.70	0.02	(0.04)	(0.23)	0.21	1.09	0.69	(0.91)	1.99
	100	0.00	0.88	0.39	0.41	(0.05)	3.66	(0.14)	0.15	(0.53)	2.62	1.44	4.17	(2.33)	10.66
	200	(0)	(0)	0	(0)	(0)	3	(0)	0	(0)	(1)	2	13	(4)	14

Agricultural Production, Net Exports, and Domestic Demands – “All Biomass Sources” Unrestricted Scenario

One of the key issues to consider is the change in food markets resulting from a reallocation of land and changing crop mix. The net reallocation of land from food to energy production will reduce the total food calories produced in the U.S. and could potentially have implications for food security. Based on our simulated changes in production of each crop and data on average caloric content of major agricultural products modeled within FASOM (see Table 2), we calculated the change in calorie production across scenarios as a proxy for calorie availability.

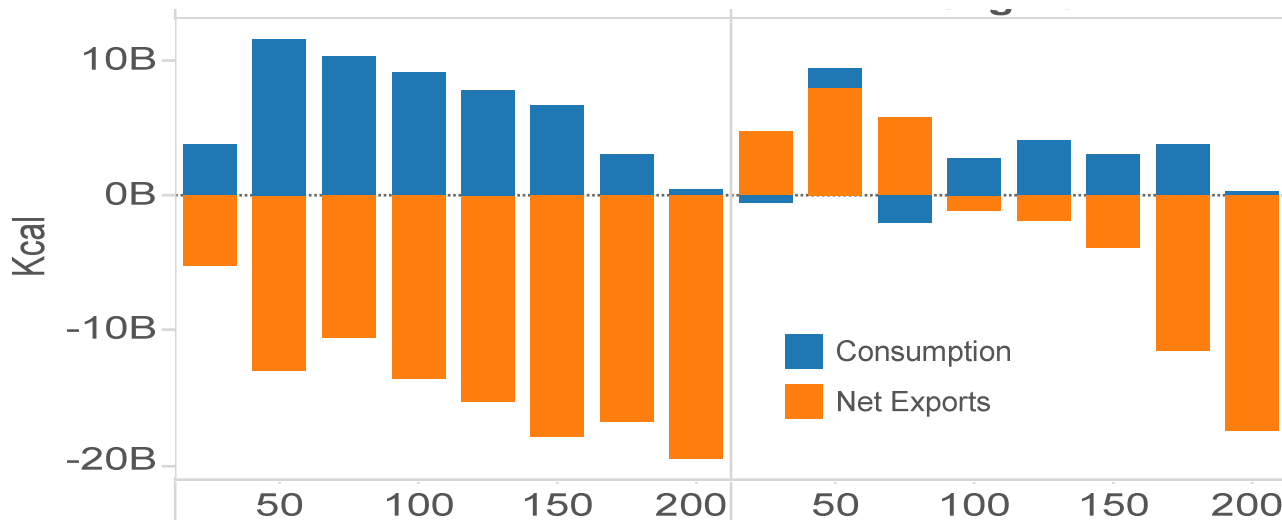
The change in total Annual Calorie Availability for the unrestricted biomass scenario is shown in Figure 4 for each of the biopower generation levels in TWh /year. This figure shows a clear negative relationship between the level of biopower generation and calorie availability in the short run (2010-2025). Our results for the long run (2025-2040) reveal a more complex relationship between biopower feedstock production and food production when there is more time for market responses. With long run adjustments in forest management, yield improvements taking place over time, and biopower feedstock demand stabilizing after 2030, there is less pressure on the land resource and the lower quantities of biopower production actually result in increasing calorie production. Competition from biopower feedstock production is driving up prices of other crops, leading landowners to convert their land to crop production from other uses and actually inducing greater food production in the long run period of our model simulation for biopower generation up to 125 Twh/year. As biopower requirements continue to increase beyond that level, however, larger areas of land are converted to switchgrass and this effect begins to reverse as the expansion of food crops observed at lower biopower requirements becomes smaller or even negative. .

Figure 4. Change in Total Annual Calorie Availability for Unrestricted Biomass Scenario



A decomposition of this effect is shown in Figure 5, which breaks out the changes to both the US domestic consumption calories and the changes to net exports. This shows that in the short run, export markets are quick to adjust to production shifts and resulting changes in the competitive position of the U.S. in international markets. Exports were found to decline significantly for all biopower scenarios in the short run as well as long run scenarios of 100 Twh/year or greater, particularly in the soybean product market. The net impacts on domestic calorie availability are generally positive, with the brunt of the reduction in calorie production impacting consumers outside the U.S. in our trading partners.

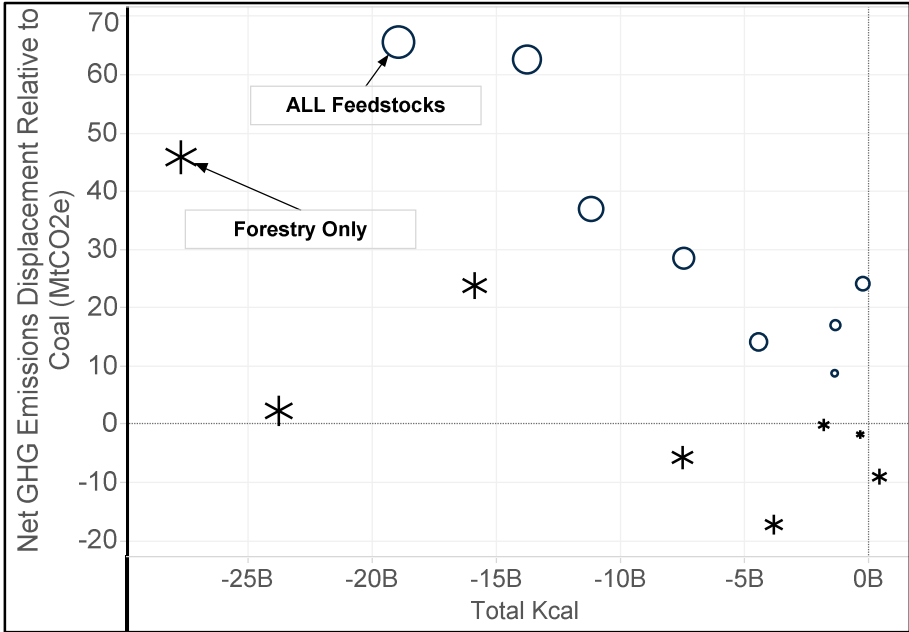
Figure 5. Change in Annual Consumption and Net Export Calories for Unrestricted Biomass Scenario



Calorie availability and GHGs – All Scenarios

Constraining feedstock eligibility generally leads to worse GHG impacts. The research conducted in Latta et al. (2013) highlighted the importance of agricultural and forestry sector interactions when considering the GHG implications of expanding bioenergy. Figure 6 illustrates this tradeoff for the unrestricted feedstock case and the forestry only scenario along with the food security implications generated from the current analysis in the short run. The size of the symbol in this figure represents the biomass scenario, with the smallest depicting the +25 TWh scenario, and the largest, the +200 TWh scenario. Both the unrestricted and forestry only scenarios show a negative relationship between GHG mitigation and availability of calories. However, the unrestricted case generates greater total GHG emissions displacement as well as more GHG mitigation per calorie reduced. On the measure of GHG mitigation and calorie availability, the unrestricted feedstock case outperformed most other scenarios with the exception of crop residues.

Figure 6. Representation of GHG and Calorie Impacts for 2010-2025 across Biomass Scenarios



This point is further represented in the Table 5 summary figure where the 100 TWh bioenergy scenario has large negative impacts on available calories for the majority of scenarios. Also, the timescale is an important factor as markets need to adjust to large increases in bioenergy demand.

Table 5. Comparing the Annual GHG and Calorie Impacts Across Biomass Sourcing Scenarios

Time Period	Shock		All Biomass	Agriculture Only	Forestry Only	Crop Residues	Forest Residues	Pulp and Logging Residues	Short Rotation Trees
Short Run (2010-2025)	25	Net GHG Emissions Displacement Relative to Coal (MtCO2e)	8.7	3.0	-1.7	2.8	-0.8	11.1	9.5
		Bil Kcal Change from Baseline	-1.4	-6.4	-0.3	-1.3	5.3	-0.3	1.9
	100	Net GHG Emissions Displacement Relative to Coal (MtCO2e)	14.0	26.3	-17.5	28.9	38.5	-9.2	-6.2
		Bil Kcal Change from Baseline	-4.4	-11.9	-3.8	1.6	-14.9	-9.9	-4.4
Long Run (2025-2035)	25	Net GHG Emissions Displacement Relative to Coal (MtCO2e)	19.0	20.6	12.5	25.8	28.0	-7.5	6.6
		Bil Kcal Change from Baseline	4.4	-0.2	-1.3	-1.8	-4.9	-9.0	-7.7
	100	Net GHG Emissions Displacement Relative to Coal (MtCO2e)	75.1	96.6	21.7	94.9	36.4	39.8	55.0
		Bil Kcal Change from Baseline	1.7	-16.9	-19.4	7.2	-27.1	-29.6	-8.0

Discussion

This research extended the analysis in Latta et al. (2013) to provide insights into the potential impacts of biopower expansion on the agricultural sector and food security. Through this lens we are able to assess the tradeoffs between GHG mitigation, impacts on agricultural production, and a rough measure of food security under alternative policy scenarios. Adequately capturing linkages between agriculture and forestry is vital for assessment of policies influencing the use of biomass because these sectors compete for land. Thus, any major initiative that changes the demand for biomass feedstocks is likely to influence the relative returns to using land in forestry vs. agricultural production and lead to changes in land allocation. Because of the large amounts of carbon sequestered in forests, changes in forestland and forest management tend to dominate calculations of GHG impacts.

In addition, there are interactions between agricultural land uses that can have important implications for both net GHG mitigation and food production. Designing a policy to restrict the set of eligible feedstocks does not mean that impacts will be restricted to the markets for those feedstocks. For instance, a policy requiring the use of forest biomass with a stated aim of avoiding food security impacts is likely to result in unintended impacts on food security larger than those that would result from a less restrictive policy allowing the use of agricultural biomass, particularly in the long run. The reason is that agricultural energy crops offer the highest yield of biopower generation per unit of area and therefore require far less land to produce a given quantity of biopower than forest biomass feedstocks, requiring less conversion of cropland used for food commodities.

Overall, as shown in Latta et al. (2013), biopower is found to provide GHG reduction benefits relative to coal power generation with greater benefits provided as the quantity of biopower generation rises. Scenarios with greater feedstock flexibility tend to result in greater GHG reductions, but also a large proportion of the feedstocks being drawn from agricultural sources. The primary question examined in this paper is whether there is a relationship between the level of GHG mitigation achieved and food security. Our findings in this study are supportive of there being a relationship exists between food security and climate change mitigation. In general, there does appear to be a tradeoff between the mitigation achieved and food production. Thus, diverting

agricultural lands for energy feedstock production potentially raises food security concerns, particularly at high levels of production and when biomass options are constrained to specific feedstock categories. Based on our results, those impacts are likely to take place largely outside the U.S. as food commodity exports fall much faster than domestic production. In the long run, a biopower policy with moderate targets falling around the midpoint of our range of scenarios and allowing feedstock flexibility could potentially result in sizable GHG mitigation without negative effects on food security.

References