Biomass Cofiring in Coal Power Plants and its Impact on Agriculture in the United States

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PRELIMINARY DRAFT

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Abstract

We analyze the effects on local biomass supply, demand, and prices of co-firing requirement for existing coal-fired power plants. The co-firing requirement is imposed on 398 existing power plants. The biomass feedstock can come from corn stover, wheat straw, switchgrass, and/or forest residues. Our model incorporates county-level biomass supply as well as national crop commodity demand. A solution to the model consists of county biomass prices and national crop prices.

Keywords: Biomass, co-firing, land-use, commodity prices

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1. Introduction

Growing concern about greenhouse gas emissions and energy security in the United States has lead to policy enactments or proposals to rely more on domestic renewable energy sources such as the Renewable Fuel Standard (RFS) passed with the 2005 Energy Bill requiring blending regular gasoline with corn ethanol. Proposals include the American Clean Energy and Security (ACES) Act of 2009 and the American Power Act (APA) of 2010 which would have establish cap-and-trade system. In addition to federal efforts, 29 U.S. states plus the District of Columbia and Puerto Rico have enacted a renewable portfolio standard (RPS) as of May 2012 (U.S. Department of Energy - Database of State Incentives for Renewables & Efficiency, 2012). All three federal policies affect the use of lignocellulosic biomass such as agricultural residues, energy crops, and forest residues.

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The RFS requires an increasing share of cellulosic ethanol to be blended with gasoline and the renewable energy standards in the cap-and-trade systems would result in dedicated biomass power plants and co-firing in existing coal power plants (EIA, 2009). In this paper, we focus on co-firing biomass in existing coal power plants and its impact on local biomass prices. However, our model can also be applied to dedicated biomass power plants and cellulosic ethanol plants given their location.

A RPS is comparable to the RFS as it demands from energy producers a predetermined level of renewable output. As an example, Minnesota requires 25% of the state's power to come from renewable energy sources, including biomass. Other states have similar standards in place. As aforementioned, efforts to establish a federal RPS are underway and in this paper, we analyze the effects of different RPS requirements (in percent of total electricity production) on the market for biomass and crops. Coal-fired power plants can cofire biomass with coal to achieve a reduction in greenhouse gas (GHG) emissions. Almost all coal-fired power plants can be easily retrofitted at low costs (Basu et al., 2011).

Cellulosic biomass feedstock from crop residues, energy crops, and forest residues have a low energy content compared to their density. Hence, the biomass market is local and not national. If biomass is produced from crop residues, then the effect on commodity prices should be minimal whereas a switch from field crops to energy crops should affect commodity prices much stronger. Many coal-fired power plants are located in the Midwest which coincides with the availability of crop residues. Our model examines two issues: the competition of power plants for limited biomass resources and the effect of landowners switching from field crops to energy crops and its effect on national commodity prices.

Our model focuses on existing coal power plants which are subject to an exogenously determined co-firing percentage. Previous studies mostly focus on the effects of a renewable portfolio standard on the demand side of fuels, i.e., the generating sector whereas this paper focuses on the impact on crop production and prices. Several studies analyze the impact of a renewable portfolio standard on biomass consumption in the United States. A 2007 study by the Energy Information

Administration projected a threefold increase in the electricity production from biomass given a 15% federal RPS (EIA, 2007). Other studies result in similar predictions for the biomass industry.

Three sources of biomass fuel types are considered in our model: agricultural residues, energy crops, and forest residues. Because we are interested in the effects on agriculture and land allocation, the fuel sources are endogenous to the model. Agriculture residues included in our model are corn stover and wheat straw. Switchgrass is used as the energy crops and can be planted on land currently used for crop production. For the moment, we do not include land which is enrolled in the Conservation Reserve Program. The last category of fuel sources is forest residues which is material left after timber harvest. The area of forest is assumed to be fixed and we rely on previous studies to assess the supply curve of forest residues.

There are two types of electricity production from biomass: dedicated power plants and co-firing plants. Cofiring plants work in conjecture with coal and have the advantage of requiring small modifications to existing power plants, lower costs, and more flexibility in the short-term input mix, i.e., shortages in biomass supply can be compensated easily by increasing the coal percentage. The spatial aspect plays an important role for two reasons: First, many power plants which would qualify for co-firing are already in place and second, the transportation from biomass from its production site to the plant is likely limited due to transportation cost and infrastructure.

As aforementioned, the spatial aspect plays an important role in the demand and supply side of biomass. To model the demand side for the biomass feedstock, we will use an Energy Information Administration dataset with the location of coal power plants in the United States to determine the type of power plant (e.g., name plate capacity, fuel type, heat rate, etc.). Given data about the size and location of the power plant, the feedstock demand function under a RPS requirement is calculated. The supply side of biomass is modeled at the county level for which we know the cropland characteristics (e.g., land allocation, yield potential) for biomass supply from agricultural residues and forest characteristics (e.g., area, type) for biomass supply from forest residues. We also include the possibility for farmers to switch from food to energy crops. Our model predicts crop price changes from a reallocation of land at the county level due to biomass demand. The supply function is determined by the cost of removing and collection residues or by the cost of growing a dedicated energy crop. The model then solves for the competitive equilibrium under different RPS mandates. To the best of our knowledge, this is the first paper to analyze the county level impacts of a federal renewable portfolio on biomass suppliers.

2. Coal-fired Power Plants

Data on the power plants were obtained from the 2010 Energy Information Administration 860 Annual Electric Generator Report. We include power plants with coal (i.e, anthracite, bituminous, lignite, refined, subbituminous) as the primary source of energy. We assume that the following sectors are required to co-fire: electric utilities, independent power producers (IPP), and independent power producers with combined heat and power (IPP CHP). We excluded power plants from the Western Electricity Coordinating Council (WECC) of the North American Electric Reliability Corporation (NERC) regions because of lack in biomass supply. In total, 398 coal power plants in the contiguous United States are included in our analysis. Basu et al. (2011) identifies three co-firing options: direct co-firing, indirect co-firing, and gasification co-firing. We assume that each those co-firing options can be used for all coal-fired power plants. In addition, we are interested in the equilibrium and assume that the investment decision and adjustments for co-firing has already been made. For each plant location, we determine the sum of the nameplate capacity of all the generators considered. The heat input of the power plant remains unchanged unaffected by the co-firing option used (Basu et al., 2011). We assume a uniform boiler efficiency η of 88% and 8000 hours of yearly operation. Based on the average heat input rate and the yearly energy output in MWh, the following amount of biomass feedstock (b) in mega joule (MJ) is necessary:

$$b = \rho \times E \times \varphi \tag{1}$$

where ρ is the co-firing fraction, E represents the annual energy output in megawatt hours (MWh), and φ expresses the heat rate in MJ per MWh. The heat rate was not available for some power plants and thus, we assumed a value of 10,325 MJ/MWh.

3. Feedstock Production

Our model considers agricultural residues (corn stover and wheat straw), energy crops (switchgrass), and forest residues as possible feedstock for co-firing.

3.1. Agricultural Residues

The landowner faces commodity demand functions $Q_j = D(\mathbf{p})$ for crop j which are functions of the price vector $\mathbf{p}$. We focus on three crops: corn, soybeans, and wheat. Corn and wheat can be used to produce corn straw and wheat straw. The demand elasticities are represented in table 1. The price of soybeans refers to soybean meal in the case of feed and to soybean oil in the case of food. The elasticities for food and feed demand are calculated using the Linear Approximation Almost Ideal Demand System (1). Some elasticities were adjusted because the estimates from the LA/AIDS were inconsistent with economic theory. The elasticities are corrected using the POLYSYS model (2), the Food and Agricultural Policy Research Institute (FARPI) model (3), and the Economic Research Service/Pennsylvania State trade model (4).

We include counties that were in crop production for at least five years after 2000. The base area in each county is calculated as the average crop area harvested between 2000 and 2010. In a second step, we use 1975-2010 yield data from the National Agricultural Statistical Service to fit a linear trend for each county and each commodity to determine the expected yield by crop and county in 2010. Based on the expected yield and the base area, we can calculate the crop production in each county. The total production forms the basis to calibrate the constant in the demand function.

Cost and return data are obtained from the USDA's Economic Research Service[1]. The total cost in our model is represented as $K_i(a_{ij}) = \alpha_{1i}a_{ij} + (1/2)\alpha_{2i}a_{ij}^2$ where $K_i(a_{ij})$ represents the operating cost. The increasing marginal cost captures either the decrease of yields because marginal land with lower average yields is brought into production if cropland is expanded or the requirement of more fertilizer use for the same reason. The increasing marginal cost is also necessary to obtain

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[1] www.ers.usda.gov/Data/CostsAndReturns accessed January 15th, 2012

Table 1: Food, feed, and export demand elasticities

	p_{CO}	p_{SB}	p_{WH}
Food Demand			
Corn	-0.389[1]	0.002[4]	0.003[4]
Soybeans	-	-0.604[1]	-
Wheat	0.004[4]	0.001[4]	-0.137[1]
Feed Demand			
Corn	-0.883[1]	0.090[3]	-
Soybeans	0.081[4]	-0.513[1]	-
Exports			
Corn	0.420[2]		-
Soybeans	-	-0.570[2]	-
Wheat	-	-	-0.380[2]

a solution to the profit maximization problem of the landowner. County specific cost data are not available and hence the direct estimation of the county specific parameters α_{1i} and α_{2i} is not possible. To obtain county specific parameters, we proceed in two steps. First, we obtain data from the USDA/ERS cost and return database on operating cost by crop and farm resource region between 2005 and 2010 and set the parameter α_{1i} equal to the total of operating cost but exclude fertilizer and chemical costs. We assume that all counties in a particular farm resource region have the same α_{1i}. The values are represented in table 2. Second, assuming profit maximizing but price taking behavior allows the calculation of the county specific parameters α_{2i} because the landowner sets marginal revenue equal to marginal cost, i.e., $p_j \cdot y_{ij} = \alpha_{1i} + \alpha_{2i} a_{ij}$. Given p_j, y_{ij}, α_{1i}, and a_{ij} enables us to obtain α_{2i} for the base year.

Agriculture is a perfectly competitive market and hence, all agents are price takers and do not take the effect of their acreage decision on output prices into account. In aggregate however, the net revenue in each county is endogenous to the model.

Table 2: Average operating cost except fertilizer and chemicals

Region	Corn	Soybeans	Wheat
Basin and Range	-	-	55
Eastern Uplands	100	78	-
Fruitful Rim	-	-	100
Heartland	109	76	52
Mississippi Portal	-	107	-
Northern Crescent	121	84	64
Northern Great Plains	118	80	53
Prairie Gateway	168	103	53
Southern Seaboard	110	72	
United States	119	83	52

3.2. Energy Crops

The yield map of switchgrass is obtained from Baskaran et al. (2010). The fixed costs are based on Huang et al. (2009).

	Corn Stover	Wheat Straw	Switchgrass
Farmer's Cost ($/t)	44.73		72.01
Heating Value (MJ/kg)	17.45	17.63	18.51

3.3. Farmer's Profit Maximization Problem

The six decision variables in our model are the area of corn (co), soybean (sb), wheat (wh), corn stover (cs), wheat straw (ws), and switchgrass (gr). Note that corn straw refers to corn area harvested for stover. The same is true for wheat and wheat straw. The profit maximization problem for the farmer in county *i* is written as follows:

$$
\begin{aligned}
\pi_i = {} & p_{co}(a_{co} + a_{CS})y_{co} - \alpha_{co}(a_{co} + a_{CS}) - \frac{1}{2}\beta_{co}(a_{co} + a_{CS})^2 \\
& + p_{sb}a_{sb}y_{sb} - \alpha_{sb}a_{sb} - \frac{1}{2}\beta_{sb}a_{sb}^2 \\
& + p_{wh}(a_{wh} + a_{ws})y_{wh} - \alpha_{wh}(a_{wh} + a_{ws}) - \frac{1}{2}\beta_{wh}(a_{wh} + a_{ws})^2 \\
& + p_{bm}a_{cs}y_{cs} - \alpha_{cs} \\
& + p_{bm}a_{ws}y_{ws} - \alpha_{ws} \\
& + p_{bm}a_{gr}y_{gr} - \alpha_{gr}
\end{aligned}
$$

where a_j and y_j are the crop yield and area allocated to (biomass) crop j, respectively. The landowner solves this problem subject to the land constraint. Note that the price for the commodity crops is determined at the national level whereas the price for biomass is county-specific. In addition, we assume that the price of biomass is in \$/GJ, i.e., we do not differentiate between the biomass source.

4. Feedstock Delivery

Feedstock delivery involves the transportation cost and the choice of the power plant from which county to buy the feedstock. The average transportation cost of corn stover, forest residues, and switchgrass were estimated between \$0.11 and \$0.12 per dry ton per kilometer. In our model, the transportation cost are calculated as follows. We assume that all the biomass is available at the centroid of the county (Egbendewe-Mondzozo et al., 2011) and the transportation distance is between the centroid and the power plant. Because this assumption is likely to underestimate the transportation cost, we assume the upper cost value of \$0.12 dry t^{-1} km^{-1}.

We use the approach developed by Noon et al. (2002). Given the transportation cost, the biomass price from each county, and the biomass supply from each county, the power plant can construct a supply curve ranking the counties from lowest to highest price. The cost associated with the most expensive county supplying to the power plant is the marginal cost of biomass.

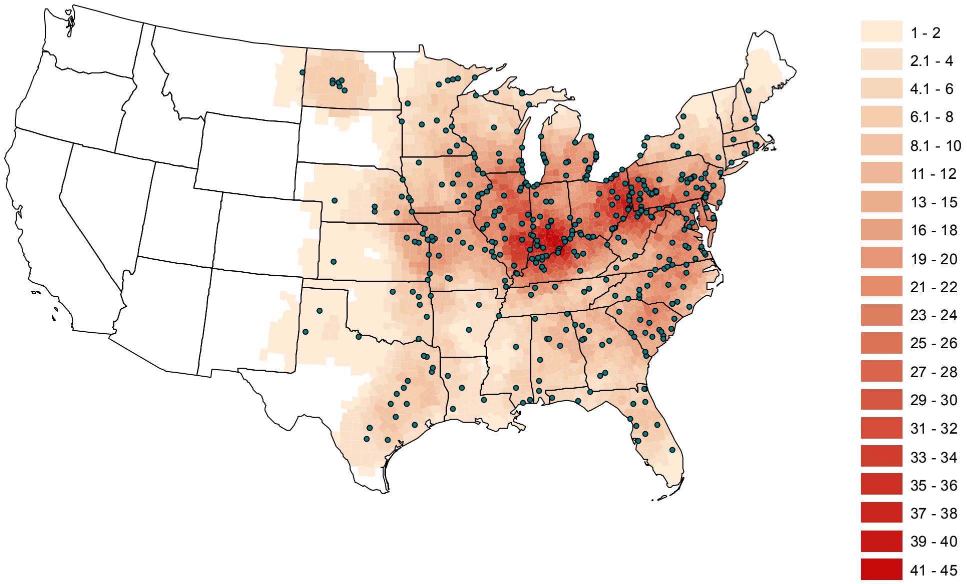
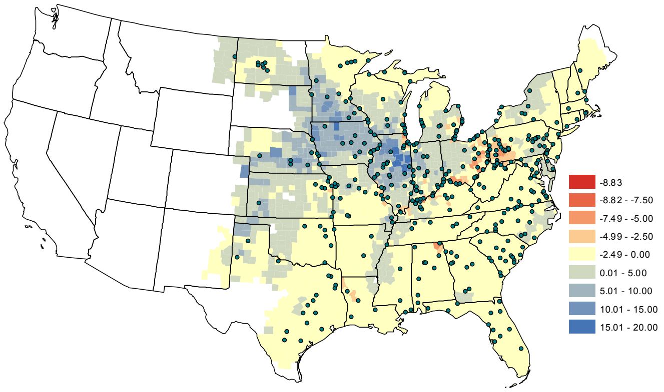


Figure 1: Number of powerplants within 200 kilometer of a county's centroid

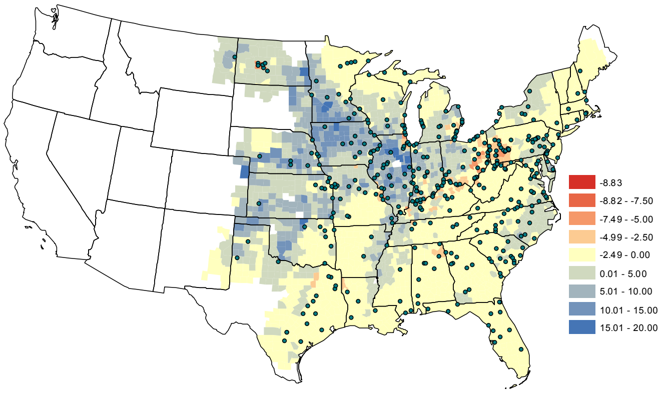
5. Preliminary Analysis and Results

In a preliminary run of the model, we focus on a uniform biomass price and show that at a uniform price, some counties might produce to much feedstock while other counties undersupply. Figure 1 represents for each county the number of coal fired power plants within 200 kilometer of the county's centroid. We see that the border of Ohio and Pennsylvania as well as the border of Illinois, Indiana, and Kentucky represent areas with a high density of coal-fired power plants.

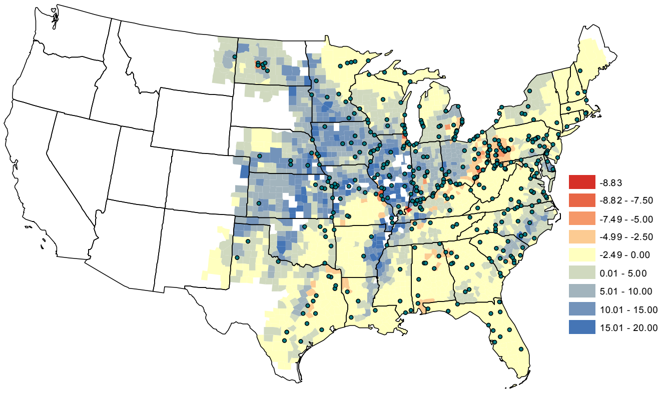
Figure 2 shows the excess supply in petajoules at different biomass prices ($/GJ) for a co-firing requirement of 5%. For the three prices of $3, $5, and $7 per GJ, excess supply exists in most parts of the Midwest. Areas with excess demand area at the border of Ohio, Pennsylvania, and West Virginia. Although the area of southern Illinois and Indiana has a high density of coal power plants, the supply in terms of corn stover, wheat straw, and switchgrass is sufficient to cover the demand from the coal-fired power plants.



(a) p_{bm} = \$3



(b) p_{bm} = \$5



(c) p_{bm} = \$7

Figure 2: Number of powerplants within 200 kilometer of a county's centroid

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Bibliography

Baskaran, L., Jager, H. I., Schweizer, P. E., Srinivasan, R., 2010. Progess toward evaluating the sustainability of switchgrass as a bioenergy crop using the SWAT model. Transactions of the American Society of Agricultural and Biological Engineers 53 (5), 1547–1556.

Basu, P., Butler, J., Leon, M. A., 2011. Biomass co-firing options on the emission reduction and electricity generation costs in coal-fired power plants. Renewable Energy 36, 282–288.

Egbendewe-Mondzozo, A., Swinton, S. M., Izaurralde, C. R., Manowitz, D. H., Zhang, X., 2011. Biomass supply from alternative cellulosic crops and crop residues: A spatially explicit bioeconomic modeling approach. Biomass and Bionenergy 35.

EIA, April 2009. Impacts of a 25-Percent Renewable Electricity Standard as Proposed in the American Clean Energy and Security Act Discussion Draft. Tech. rep., Energy Information Administration.

Huang, H.-J., Ramaswamy, S., Al-Dajani, W., Tschirner, U., Cairncross, R. A., 2009. Effect of biomass species and plant size on cellulosic ethanol: A comparative process and economic analysis. Biomass & Bionenergy 33, 234–246.

Noon, C. E., Zhan, F. B., Graham, R. L., 2002. Gis-based analysis of marginal price variation with an application in the identification of candidate ethanol conversion plant locations. Networks and Spatial Economics 2 (1), 79–93.

U.S. Department of Energy - Database of State Incentives for Renewables & Efficiency, 2012. RPS Policies May 2012.
URL `http://www.dsireusa.org/summarymaps/`