Co-firing in coal power plants and its impact on biomass feedstock availability

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Legislation Affecting Biomass Production in the U.S.

Federal legislation to address greenhouse gas emissions in the United States

- 2005 Energy Bill
  - Renewable Fuel Standard (RFS)
  - Increasing amount of cellulosic biofuel in gasoline
- Proposals for a U.S. cap-and-trade system
  - American Clean Energy and Security Act of 2009
  - American Power Act of 2010

State legislation

- Renewable Portfolio Standards (RPS) in 29 U.S. states
  - E.g., 25% of renewable energy in Minnesota by 2025
  - Biomass as part of the renewable options in all states
Biomass Demand and Agriculture

Two demand sources for biomass:

1. Biofuel plants (corn and cellulosic)
2. Electric power plants
   - Dedicated power plants
   - Co-firing power plants

Research questions:

- What is the potential for spatial competition among biomass users?
- What is the effect of co-firing existing coal power plants with biomass on agriculture?

Influence of federal and state policy on lignocellulosic biomass such as agricultural residues, energy crops, and forest residues
Biomass Co-firing

Advantage of co-firing

- (Almost) ready to use for co-firing
- Lower greenhouse gas emissions when compared to biofuels
- Existing infrastructure and location

Co-firing coal power plants

- Relatively easy retrofitting of existing coal-fired power plants
- Small and low cost modification to existing power plants

Biomass feedstock:

- Crop residues
- Energy crop
- Forest residues

Competition of power plants for limited biomass resources
Figure: Number of power plants within 200 km of county’s centroid
Energy Information Administration (EIA): 25% RFS (sales) and 25% RPS by 2025

- Rise of biomass consumption from 30 million tons to 571 million tons (2007-2030)
- Price increase of biomass from $30 to $88 per ton

Biomass analysis in the context of lignocellulosic ethanol production or co-firing

- Biomass availability for ethanol (Mabee et al. 2011)
- Transportation cost analysis for parts of Michigan (Egbendewe-Mondzozo et al., 2011) or Spain (Panichelli and Gnansounou, 2008)
- Co-firing and transportation in Illinois (Khanna et al., 2011)

Co-firing forest residue
Model Components

Agricultural sector
- Field crops: corn, soybean, and wheat
- Energy crop: switchgrass
- County-level allocation of cropland given prices

Electricity sector
- 398 Coal-fired power plants

Transportation cost
- Availability of all biomass at the centroid of the county
- Cheapest biomass based on distance and available quantity $\Rightarrow$ Lowest marginal cost

Forest sector
Agricultural Sector

Calibration of demand and net revenue functions:
- Corn, soybeans, and wheat
- Four demand sectors: food/domestic, feed, exports, and biofuel
- Cost by region from the USDA/ERS Commodity Costs and Returns

Expectations are rational in the sense that:
- Price taking behavior of all landowners
- Area allocation matches expectations about aggregate production and prices

Profit maximization for field crops

\[ B^f_i(a) = \sum_j p_j \left( a^{f}_{ij} + a^b_{ij} \right) y_{ij} + \alpha_{ij} \left( a^{f}_{ij} + a^b_{ij} \right) + \frac{1}{2} \beta_{ij} \left( a^{f}_{ij} + a^b_{ij} \right)^2 \]

Profit maximization for biomass crops

\[ B^b(a) = p_{bm} \sum \delta_{ij} y_{ij} a^b_{ij} - \eta_{ij} a^b_{ij} \]
Electricity Sector

Data on 398 coal fired power plants (2010 Energy Information Administration)

- Type of coal (i.e., anthracite, bituminous, lignite, sub-bituminous)
- Sectors: electric utilities, independent power producers (IPP), and independent power producers with combined heat and power (IPP CHP)
- All North American Electric Reliability Corporation (NERC) regions except Western part of the country (i.e., WECC)

Assumptions:

- No investment decision of co-firing
- Unaffected heat input of the power plant
- Uniform boiler efficiency of 88% and 8000h of yearly operation
Table: Summary of key scenario parameters

<table>
<thead>
<tr>
<th>Scenario</th>
<th>RPS</th>
<th>$p_{bm}$</th>
<th>Switchgrass Cost</th>
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</thead>
<tbody>
<tr>
<td>RPS 15: Low Incentive</td>
<td>15%</td>
<td>$3</td>
<td>High</td>
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Simulation Procedure

Exogenous variables:

- Price of biomass
- RPS requirement

Simulation steps:

1. Set $p_{bm}$ and RPS
2. Land allocation by the farmer and production of agricultural residues and/or switchgrass
3. Demand of coal-fired powerplants to individual counties based on transportation cost and biomass price
4. Calculate excess supply and demand of biomass
Figure: RPS = 15%, \( p_{bm} = $3 \), High Switchgrass Production Cost
Figure: RPS = 15%, $p_{bm} =$ $4$, Low Switchgrass Production Cost
Figure: RPS = 25%, $p_{bm} = $3, High Switchgrass Production Cost
Figure: RPS = 25%, $p_{bm} = $4, Low Switchgrass Production Cost
Conclusion

Political perspective

- Legislation leading to the potential use of biomass for co-firing purposes due to state renewable portfolio standards

Coal-fired power plant perspective

- Possibility to mitigate greenhouse gas emissions by co-firing with biomass

Agricultural sector

- Possibility of additional revenue from selling to the power plant

Competition of power plants for limited supply of biomass