Biomass Co-Firing Potential and Land Use Changes:
A General Equilibrium Study in the United States

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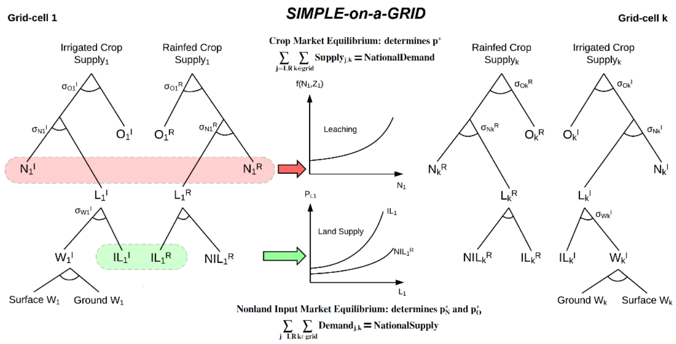
Electricity generation in coal-fired power plants results in one quarter of US GHG emissions and is the single largest sources of GHG emissions in the United States (US EPA GHG Inventory 2014). Co-firing biomass in the existing coal-fired power plants has been considered as an effective and efficient way to reduce emissions (McGlynn et al. 2014); many policies are also implemented or proposed to stimulate biomass co-firing both in the U.S. and in other countries, especially Europe. Due to the high transportation cost associated with biomass feedstock, the potential for co-firing at a given coal-fired power plant depends very much on the local availability of biomass. For large-scale co-firing, a stable supply of biomass is required, and for this, the planting of dedicated energy crops is essential (Evans et al. 2010, IRENA 2013). This, in turn results in land use change, which itself can have undesirable emissions impacts and causes concern in term of food security throughout the world. The main objective of this study is to explore the potential for co-firing and associated land use changes in the United States. Specifically, we investigate: (1) the total potential of co-firing and the associated land use changes in the United States; (2) heterogeneity in the potential for co-firing across different existing power plants and heterogeneity in the induced land use changes in different areas; (3) the co-firing threshold that requires dedicated energy crops involved as feedstock beyond residues from forest and agriculture; and (4) heterogeneity in these thresholds for different power plants in different areas.

Compared to electricity produced from 100% biomass power plants, the co-firing of biomass in the existing coal-fired power plants requires a lower investment cost and is able to achieve higher efficiency (IRENA 2013). Therefore, co-firing is considered to be a more promising and efficient way to reduce greenhouse gas emissions from electricity generation. Biomass available for co-firing in the United States mainly includes forestry residue, agricultural residue, and dedicated energy crops. Forestry residue and to some extent agricultural residue, is usually the preferred option because it is less expensive and does not cause changes in land use. However, the availability of residue, especially at a local level, is limited and unstable; for large-scale co-firing and a stable feedstock supply, dedicated energy crops (e.g., short rotation coppices) are essential.

Feedstocks represent the most important cost of biomass co-firing. And transportation costs comprise about half of the total feedstock cost because of the low density of biomass. Therefore the local supply of biomass plays an important role in the potential of co-firing of power plants. In the United States, the distribution of forest, agriculture, and land available for energy crop production differs substantially across areas. These differences lead to differences in the supply cost of biomass at a local level and further creates heterogeneity in the potential of co-firing across coal-fired power plants and heterogeneity in the changes of land use across different areas. Exploring these heterogeneities is important for identifying the power plants and areas where the reduction of greenhouse gas emissions can be achieved with the lowest abatement cost. These heterogeneities in land use also result in differential environmental and food impacts of the resulting land use change. In locations where energy crops displace food crops, there will be larger impacts on food prices with potential intensification of production ensuing. Where pasture and forest lands are displaced, there will be potentially larger environmental costs.

The objectives of this study require analysis at a local level, however, the consequences of extensive co-firing of power plants will be felt at the regional, national, and potentially even international level. Therefore, we employ a cross-scale analysis using the continental-US gridded version of SIMPLE (a Simplified International Model of Prices Land-use and the Environment). SIMPLE breaks the world into 15 geographic regions with the US and Canada combined into a single region. Unlike the other regions in SIMPLE, which rely on an aggregate specification of supply behavior, supply response in the US will be built up from the grid cell level, which is able to model the local supply of biomass feedstock. The figure below outlines the structure of the gridded model of the US crop sector. In the spirit of SIMPLE, the gridded model is as parsimonious as possible, while still capturing all of the conceptual features of the problem. This figure shows two representative grid cells labeled 1 (the first grid cell) and another representative grid cell with subscript k. In each grid cell, there are two production systems: rainfed and irrigated crops. Expansion of energy crop production competes with food crops and results in an inward shift of land supplies in that grid cell.



While farmers' decisions at the grid cell level are made taking the prices of crops, nonland, and water inputs as given, these are, in fact, endogenously determined in the context of the SIMPLE model. At global scale, demand in each region of SIMPLE is driven by growth in population, as well as per capita food demands which are disaggregated into direct consumption of crops and indirect consumption through purchases of livestock products and processed foods. While first generation biofuels also play a role in boosting global demand for the composite crop commodity, biomass co-firing in electricity generation creates further demand. In order to reflect the incomplete integration of global markets, consumer purchases of crops fall into two categories: domestic and international crops. The elasticity of substitution between these two types of crops determines how tightly integrated the regional economy is within the global economy. This, has implications for the local and global environmental impacts of regional policies and technology (Hertel, Ramankutty, and Baldos 2014). This feature of SIMPLE is essential for the investigation of the local supply of biomass in the US because the international trade of biomass (i.e., wood pellet) has increased dramatically in recent years and the environmental policies in Europe have significant impacts on US biomass market. The global SIMPLE model has been extensively validated against historical data (Baldos and Hertel 2013; Hertel and Baldos 2016). For non-US regions, the supply-side of SIMPLE will remain unchanged since the continental US is the focal point for this analysis.

Co-firing means replacing coal with biomass for a certain proportion in electricity generation. IEA (2012) estimates that the proportion of biomass in current co-firing coal-fired power plants is below 5% in most cases, but current co-firing technology is mature enough to support co-firing with 20% of biomass, and 50% is technically achievable. Based on the current situation and the feasibility of co-firing, we conduct our analysis with four scenarios. For the total electricity generated by coal-power plants in the U.S.: (1) no biomass co-firing electricity; (2) 5% electricity generated by biomass co-firing; (3) 10% electricity generated by biomass co-firing; and (4) 20% electricity generated by biomass co-firing. Because of the spatial heterogeneity of local supply of biomass, biomass co-firing capacity is not distributed evenly across power plants. Each of these scenarios is also accompanied by a specific pattern of energy crop land use and hence competition for land with food crops. Results focus on the consequences of co-firing for gridded land use, nitrogen fertilizer applications, groundwater withdrawal, food crop production and prices.

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