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The moderating role of biomass availability in biopower co-firing — A sensitivity analysis

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ABSTRACT

Of the various types of renewable energy technologies being promoted in response to concerns about climate change and energy security, co-firing biomass for electricity is one that is potentially feasible in many states and regions of the USA. This study contributes to our understanding of the factors that influence the economic feasibility of this technology. Using a recently developed spatial evaluation tool we perform sensitivity analyses to investigate how the cost of co-firing biomass is affected by power plant scale, level of biomass used as feedstock, local feedstock availability, transportation costs, and resource and harvesting costs. Specifically, we demonstrate the use of this tool by exploring the cost of co-firing biomass in existing qualified coal-fired power plants in Missouri.

We find that the cost of electricity generated is higher when biomass is cofired under all assumption. However, it finds significant and interesting interaction among the cost-related features. We are able to conclude that abundant and reasonably-priced biomass feedstocks can dramatically increase the feasibility of biopower by reducing transportation costs. Also, the scale of the technology must be right—large enough to exploit economies of scale but small enough to avoid high transportation costs incurred to procure large volumes of feedstocks.

1. Introduction

Two days before the United Nations summit on climate change on September 21st 2014, one of the largest ever climate-change demonstrations, estimated to involve more than 300,000 people, took place in the streets of New York City (USA Today, 2014). Large protests were held in other locations as well. These demonstrations sent a strong message that more and more people are concerned about climate change. On the other hand, given the world's overwhelming dependence on low-cost fossil fuels, there are also concerns about the possible damage to the economy that switching from fossil fuels to renewable energy could cause. In early September 2014, a report entitled “Better Growth, Better Climate: The New Climate Economy Report”, was released by the Global Commission on the Economy and Climate. The Commission included more than 100 politicians, leaders, economists and other scientists from seven countries. The report argued that it is possible to reduce the risk of climate change while achieving economic growth (GCEC, 2014).

Despite recent dramatic increases in the production of domestic oil and natural gas, concerns about energy sustainability and security continue to be raised (WEC, 2007; EIA, 2013). In June 2014, the U.S. Environmental Protection Agency (EPA) proposed guidelines designed to reduce the national level of CO_2 emissions from power plants by 30% from 2005 levels by 2030. Strategies to reach this goal will be developed and executed at the state level, and each state is required to submit CO_2-reduction plan by 2016 (EPA, 2014). A study by the University of Massachusetts Political Economy Research Institute (PERI) and Center for American Progress in September 2014 declared that 40% of 2005 levels of carbon pollution could be eliminated, and 2.7 million jobs related to clean energy could be created at the same time (Pollin et al., 2014).

In response to these findings, more and more research is being undertaken to find clean, safe and renewable energy sources to complement or even replace fossil fuels. Biomass-based energy (bioenergy) has significant appeal as a partial replacement for fossil fuels because it is renewable, emits less carbon into the

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atmosphere, is potentially more environmentally benign, is easier to procure and store, and is almost ubiquitous. Biopower is one popular use of biomass with better energy utilization than biofuels (Mizsey and Racz, 2010). Biopower technology offers local benefits as a way of disposing residues and wastes, and global benefits by reducing greenhouse emissions (Yusoff, 2006). A great deal of research has focused on the technical aspects of biopower production such as optimum oxygen factors, air temperature, air-fuel ratio, operating pressure, biomass particle size, pressure, etc. Bioenergy research and practitioners have confirmed that co-firing biomass in existing plants, especially coal-powered plants, is a technically feasible option (Ponton, 2009). While biomass residues can replace more than 50% of coal in coal-fired plants with large capital investments (English et al., 1981), up to 20% biomass can be co-fired with coal without significant modification to current equipment (Grabowski, 2004; Haq, 2002). Biomass use must to be managed very carefully to avoid decreased boiler efficiency (English et al., 2007; English, 2010) and boiler corrosion. In this article, we focus on 10% and 15% biomass co-firing levels and analyze the impacts of non-technical factors such as fuel availability and transportation costs on the feasibility of biopower generation in the Midwestern U.S. state of Missouri. Specifically, we conduct sensitivity analyses of varying levels of biomass availability, transportation costs and biomass resource and harvesting costs on the economic feasibility of co-firing in existing coal-powered plants in Missouri.

In Missouri, about 90% of the total electricity supply comes from investor-owned plants. Based on data from the U.S. Energy Information Administration (EIA, 2014), in 2013, 83% of Missouri's electricity generation came from coal compared to the national average of about 45%. Another 9% of electricity was supplied by nuclear power, mainly from the Callaway Nuclear Generating Station, and about 3% of electricity generation came from renewable energy resources, with about 95% of that from conventional hydroelectric power and wind. Only a small portion of electricity was generated from biomass, mainly at two low-capacity biopower plants, the University of Missouri (18 Megawatts or MW) and Anheuser Busch St. Louis (26 MW) (EIA, 2014). However, given Missouri's abundant biomass resources from agriculture and forestry sectors, there is significant potential for more biopower production. As a major agricultural state, with large quantities of crop residues and promising prospects for energy crops, as well as large areas of productive forests, Missouri produces vast amounts of biomass each year, some of which could be used for biopower generation. The Missouri Department of Natural Resources has estimated that 172,550,603 megawatt hours (MWh) could be produced annually. This is almost twice the total electricity produced in Missouri in 2009 (Fink and Ross, 2006). Although biomass feedstocks can only be partially collected and used, they nevertheless offer great potential for increased renewable energy generation and reductions in carbon emissions within the state.

In 2008, Missouri adopted a renewable portfolio standard (RPS), requiring investor owned electric utilities to increase their use of renewable energy sources to 15% by 2021. With proposed guidelines from the U.S. EPA in 2014 to reduce the national level of CO_2 emissions from power plants 30% by 2030, it is imperative for the power plants in the state to diversify their fuel mix by including more renewable energy resources. Co-firing biomass in existing coal-powered plants can help the owners meet the RPS requirements and can be an incremental way of reducing the emission of greenhouse gas and other pollutants. It is in this context that this study investigates the role of several factors in shaping the economic feasibility of biomass co-firing in Missouri, with the aim of identifying the most critical factors determining the ideal locations, scales, and feedstocks for power generation in Missouri. The tool and method employed in this analysis can be adapted to any state or region contemplating an increase in biopower capacity.

2. Literature review

Compared with traditional fossil fuels, the supply fluctuations and low energy density features of biomass feedstocks are major deterrents for large-scale biopower generation (Akhtari et al., 2014). Biopower plants usually have small capacities, typically one-tenth the size of coal-fired plants, due to the limited availability of local feedstocks (IEA , 2007). Due to region-specific variations in feedstock, transportation costs and many other economic parameters in biopower generation are not known with certainty, and the cost of this process varies across regions (Schneider and McCarl, 2003). So conducting a sensitivity analysis over a wide range of cost assumptions has important practical implications.

Detailed information regarding the forces that impact the feasibility of biopower production is useful for industry strategists, policy makers, and bioenergy entrepreneurs. As a result, many national and regional level studies have been conducted to assess the economic feasibility and/or environmental consequences involved in using bioenergy. Given the inevitable uncertainty involved in locating a new facility, sensitivity analysis is a useful tool for identifying the most critical factors to consider.

Sensitivity analysis has been widely employed in environmental and biomass related fields. Mathieu and Dubuisson (2002) simulated the process of wood gasification in the ASPEN PLUS process simulator based on the Gibbs free energy minimization, and conducted a sensitivity analysis on various factors regarding their effects on process efficiency, such as oxygen factors, air temperature, oxygen content in air, operating pressure and the injection of steam. Bettagli et al. (1995) calculated the gas composition under alternative operating conditions using a model to simulate the chemical kinetics of gasification and combustion processes. In their study, they performed a sensitivity analysis to evaluate the influence of the major parameters involved, such as temperature, pressure, and air-fuel ratio on the composition of the exit gas. Schuster et al. (2001) used thermodynamic equilibrium calculations to simulate a dual fluidized-bed steam gasifier with a decentralized system that combined heat and power. They conducted a sensitivity analysis of the process for a wide range of fuel composition levels and various operating parameters, and found that the most significant factors that determine the chemical efficiency of the gasification are gasification temperature and fuel oxygen content. Another study regarding biomass gasification in a fluidized bed by Lv et al. (2004) involved a sensitivity analysis to investigate how the gas quality is influenced by many technical factors including temperature, steam to biomass ratio, biomass particle size, gas yield, steam decomposition, heating value, etc. Their results indicate that a tradeoff exists between hydrogen production and gas heating value as temperature changes, and that optimal steam level and small size of particles can improve gas quality. Sadaka et al. (2002) built a two-phase biomass gasification model and conducted sensitivity analysis to test the model's response to alternative operating parameters (fluidization velocity, steam flow rate and biomass to steam ratio). The analysis showed that all operating parameters impact the model performance, and that the steam flow rate has a larger impact on the reactor's temperatures than the other two parameters.

Although there are many biomass-related sensitivity analyses, most focused on the impacts of various technical factors, such as air temperature, oxygen content, operating pressure, etc. There are very few studies that investigate how the performance of biopower is related to non-technical, economic factors, such as input costs and electricity prices involved in biopower generation. Dornburg