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Resource potential for renewable energy generation from co-firing of woody biomass with coal in the Northern U.S.

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ARTICLE INFO

Article history:
Received 10 April 2013
Received in revised form
23 August 2013
Accepted 26 August 2013
Available online 16 September 2013

Keywords:
Integrated harvest
Wood
Woody biomass procurement
Marginal cost
Logging residue

ABSTRACT

Past studies have established measures of co-firing potential at varying spatial scales to assess opportunities for renewable energy generation from woody biomass. This study estimated physical availability, within ecological and public policy constraints, and associated harvesting and delivery costs of woody biomass for co-firing in selected power plants of the Northern U.S. Procurement regimes were assessed for direct sources of woody biomass from timberland including logging residues (slash, by-products), small-diameter trees, and integrated harvest (logging residues and small-diameter trees). Concentric woody biomass procurement areas were estimated for each power plant using county-level estimates and varying procurement radii. Delivered fuel cost estimates were calculated for each power plant and procurement regime based on incremental maximum transport distances. Procurement regimes focused on small-diameter trees can potentially produce the most electric power, but are constrained by lower economical transport distances than logging residues. These estimates enabled us to assess which power plants in the Northern U.S. had the highest electricity generation potential. For most procurement regimes, an average power plant co-firing had the potential to replace greater than 30% of coal electricity generation if there was no competition for the feedstock. However, woody biomass resource competition from adjacent co-firing plants could reduce this generation potential to less than 10%.

1. Introduction

Increasing interest in utilizing wood for bioenergy in the U.S. has been motivated by environmental concerns, costs of fossil fuels, and public opinion regarding renewable energy. Among different biomass feedstocks, wood and wood waste currently account for the greatest share of bioenergy generation in the U.S. at about 53% according to the U.S. Energy Information Administration [1]. Renewable energy markets can help provide incentives to remove small-diameter trees (i.e. trees <25 cm in diameter measured at 140 cm from the ground) and other non-timber woody material during compatible silvicultural treatments such as pre-commercial thinning, hazardous fuel reduction, woodland restoration, and certain types of wildlife habitat improvement. Forests and waste wood sources on a dry

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0961-9534/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.biombioe.2013.08.032

basis in the contiguous U.S. could have provided about 88 Tg of energy feedstock if priced at 66 $ Mg^{-1} at roadside or mill gate in 2012 [2].

Wood used for bioenergy generation can be currently obtained from several sources, including directly from forest (e.g. residues from timber harvesting operations, and forest-derived biomass from removal or thinning of trees), indirectly from primary and secondary wood product manufacturing (e.g. chips, briquettes, mill residues, pellets) and recovered from post-consumption (e.g. urban residues from demolition, packaging materials) [3]. In the U.S., indirect sources supply 78.9%, direct sources 19.3%, and recovered sources 1.8% of all wood energy consumed in the country [4]. Indirect sources are highly dependent on output from the wood products industry [5] and large amounts of this material are already utilized or under contract. Recovered wood is a component of potentially available wood for energy, but this source is mainly limited to urban areas [2]. Direct sources have the greatest potential for future growth for bioenergy at various price levels [2] and their production can be complementary to other forest management objectives [6]. Wood sourced directly from a forest, woodland, or rangeland environment may be broadly defined as woody biomass, encompassing by-products of forest management including trees and woody plants (limbs, tops, needles, leaves, and other woody parts) [7].

Prominent technological platforms that convert wood to energy include: (1) direct firing or co-firing biomass with coal for electricity, heating and cooling, (2) production of liquid biofuels [8], and (3) gasification [9–12]. Co-firing refers to the practice of introducing biofuels as a supplementary energy source in high efficiency utility boilers [13,14]. There are currently 89 coal-fired power plants in the U.S. that utilize some quantity of biomass [1,15]. Compared to alternatives such as liquid biofuels or gasification, co-firing facilities (coal-fired electric plants) can often incorporate biomass into the existing fuel storage and handling systems with relatively minor modifications [6,16–19]. Also, unlike wind and solar energy, wood energy can be readily stored (e.g., as chips or on the stump) and utilized when needed [20]. In a survey conducted by Aguilar and Garrett [6], various wood energy stakeholders ranked the perceived practical potential of woody biomass co-firing higher than other energy conversion methods including cellulosic ethanol, gasification and pyrolysis.

Many studies have focused on woody biomass resource assessments at varying spatial scales to determine the broad-scale feasibility of co-firing across the U.S. [20,21]. Nevertheless, there has been considerably less research assessing the localized resource availability and coinciding costs for specific areas identified as having high potential for biomass co-firing. Aguilar et al. [22] used an array of information to estimate woody biomass resource availability and elicit the likelihood of co-firing in counties of the Northern U.S. This methodology served as a “coarse screen” for identifying counties with the highest probability of co-firing based on several internal, external, and location specific physical factors. However, Aguilar et al. [22] did not estimate localized biomass supply potential for the areas identified as having a high probability of co-firing based on transport distance, source of feedstocks, and alternative woody biomass procurement regimes. These are important factors nonetheless, as they will all have an effect on delivered costs of different biomass feedstocks, as well as limitations to annual net generation in co-firing facilities.

The purpose of this study was to estimate the supply potential and costs of harvesting, processing and transporting woody biomass and unused mill by-products for co-firing in selected coal-fired power plants. For each power plant, woody biomass procurement areas, maximum transport distances, and resulting delivered fuel costs were estimated for four different forest procurement regimes including: (1) removal of small-diameter trees based on stand density, (2) removal of small-diameter trees using a biological maximum, (3) removal of logging residues (slash), and (4) integrated removal of logging residues and small-diameter trees. For each power plant and procurement regime, supply potential and delivered costs were estimated using concentric circles to represent woody biomass procurement area and to calculate maximum transport distance to the plant. Results from these analyses identified power plants best poised to co-fire based on cost and electricity generation potential. The first section of this paper describes the study area and background information for the selection of power plants and woody biomass availability assessments. The next section describes the methods used to estimate woody biomass availability and production costs. This is followed by results, discussion and conclusions.

2. Theoretical background and study area

Recent studies have shown that past placement of co-firing facilities is highly correlated with power plant physical (e.g. feeding systems), external (energy markets) and location-specific (e.g. transportation infrastructure) factors [22,23]. Aguilar et al. [22] developed econometric models to estimate the likelihood of co-firing at the county-level using explanatory variables such as electricity demand, technical feasibility, coal price, availability of wood mill by-products, renewable portfolio standards (RPS), and transportation infrastructure.

For this study, we focused on coal-fired power plants residing within selected counties in the Northern U.S. that have been identified with a high likelihood of co-firing based on the econometric models developed by Aguilar et al. [22]. Specifically, the counties of interest were identified as being in the top 25% of all counties in terms of estimated probability of co-firing. We restricted this study to applicable counties in the U.S. Northeastern and North-central states – hereafter referred to simply as the Northern U.S. The Northern U.S. is comprised of the 20 following states: Connecticut, Delaware, Illinois, Indiana, Iowa, Maine, Maryland, Massachusetts, Michigan, Minnesota, Missouri, New Hampshire, New Jersey, New York, Ohio, Pennsylvania, Rhode Island, Vermont, West Virginia, and Wisconsin. This region was chosen for this assessment due to lack of necessary data at the county-level for the entire U.S., as well as large fluctuations and uncertainty in production costs amongst major U.S. regions. Aside from data restrictions, there were two other important reasons for focusing on this region. First, woody biomass has been identified as a major potential source of renewable energy in the region [6,15]. Second, this region