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Research paper

Factors affecting utilization of woody residues for bioenergy production in the southern United States

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ABSTRACT

Biomass is the renewable resource with the potential to serve as a substitute for fossil fuels. A form of biomass, woody residues, includes woody byproducts such as mill residues, logging residues, and other wood waste. This study estimated the impact of woody residue processing capacity, mill willingness to utilize additional logging residues for electricity production, mill equipment upgrades to facilitate electricity production, and different factors limiting the utilization of logging residues on the utilization of woody residues by mills. Data on the utilization of woody residues were collected via a census mail survey of mills in the southern United States. Data were analyzed using a two-stage least square (2SLS) regression model. Results indicated that average utilization was 91% of available woody residue processing capacity for bioenergy. Woody residue utilization increased with an increase in the processing capacity of woody residues, equipment upgrades, and lower transportation costs. In addition, the study found that there were only a few mills with a large enough processing capacity to utilize woody residues for bioenergy production. Thus, an increased utilization of woody residues will be highly dependent on mills' ability to increase woody residues processing capacity, implement necessary equipment upgrades, and lower transportation and processing costs. Logging residue utilization was relatively limited and had less of an impact on overall woody residue utilization. Findings will assist policy makers and mill managers in making informed decisions about woody residue utilization and identify specific mill factors that might help improve the economic feasibility of using woody biomass for bioenergy purposes.

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1. Introduction

In 2012, the United States produced 8% of its energy from renewable sources and approximately 50% of renewable energy was produced from biomass [1]. Biomass is utilized to produce energy through direct combustion and gasification processes to produce heat and electricity, and extraction of liquid fuels and chemicals [2–4]. A study done by U.S. Department of Energy (DOE) called the Billion-Ton Update of 2011 estimated that 907 million tonnes (Mt) [one billion U.S. tons] of dry biomass was available in the United States from forest and agricultural lands, and could potentially replace 30% of the national petroleum consumption [5]. Therefore, utilization of woody biomass for bioenergy purposes can help lower fossil fuel usage and reduce carbon dioxide (CO_2) emissions.

Depending on its source, woody residues utilized for bioenergy purposes are categorized into mill residues, logging residues, and other woody wastes such as construction wood waste, urban wood waste, and solid waste. Mill residues are residues produced as a byproduct during manufacturing activities at a mill such as the production of lumber, pulp, veneer, and plywood [6]. Mills include primary forest products manufacturers representing processing facilities classified under codes 312 and 322 of the North American Industry Classification System (NAICS) and they manufacture their products using raw material from forests [7]. Primary forest products manufacturers differ from secondary forest products manufacturers, classified under NAICS code 337, that produce their final products, such as furniture, by remanufacturing products obtained from primary manufacturers [7]. Logging residues are the commercially unwanted woody materials left at the logging site and include forest residues, coarse woody debris (down wood and standing snags), and fine woody debris (snags, cut limbs, and

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leaves) [8]. Other woody wastes such as construction wood waste, urban wood waste, and solid waste are byproducts of construction activities and human consumption [9]. Urban wood wastes were not available in sufficiently large quantities to serve as a single feedstock for producing bioenergy although they were identified as a potential source [9].

According to the Billion-Ton Update study, 117 Mt of dry forest biomass and 77 Mt of dry agricultural biomass were utilized in 2010, and these quantities were projected to increase to 205 and 93 Mt by 2030, respectively [5]. Skog et al. [10] estimated that from 75 to 115 Mt of dry forest biomass could be supplied from all forest lands in the United States. Approximately 50% (87 Mt) of biomass energy consumption was contributed by woody residues and pulping liquors from the mills in the United States [11]. By 2031, utilization of woody residues is expected to account for 18–36% of the inputs for bioenergy production [12]. Therefore, a substantially large quantity of woody biomass is potentially available in the United States as a source of renewable energy and forest products industry can play an important role in increasing bioenergy production.

Among all types of woody residues, mill residues are the least costly fiber residues that can be utilized to produce bioenergy at a mill because they are generated at the site or obtained from nearby wood processing facilities, thus avoiding transportation costs or lowering them substantially [13]. It is logistically more efficient and financially less costly to trade or give away mill residues to nearby facilities as compared to procuring logging residues or urban wood wastes [13]. However, the Billion-Ton Update study reported that 98% of mill residues were already utilized for bioenergy and non-bioenergy purposes such as animal bedding and mulch [5]. On the other hand, some studies indicated that a substantial quantity of mill residues was sold or used for purposes other than bioenergy, and this quantity could potentially be diverted to bioenergy production if there was a cost advantage [14] and a market for bioenergy [9]. Therefore, it is possible that mills will first utilize mill residues currently used for purposes other than bioenergy before considering other forms of residues as alternative feedstocks.

While mill residues were already being used for bioenergy and other purposes, logging residues are being advocated as a potential alternative feedstock that can be utilized for bioenergy production [15]. Substantial quantities of logging residues are typically left unused on harvest sites after logging operations, increasing the likelihood of fire, pest outbreaks, and diseases [16]. On the other hand, logging residues offer many benefits such as maintaining soil productivity [16–18] and mitigating soil compaction as well as providing habitat for small mammals, birds, and arthropods, while maintaining soil hydrology through regulated evaporation, transpiration, and runoff control [19]. Although discussion on the impacts related to removal of logging residues is still unsettled, some studies have shown that a certain portion of logging residues (from 30 to 70%) can be removed for bioenergy purposes without affecting the soil productivity [5,16,20]. Forest certification standards can be used to ensure that best forest management practices include leaving a sufficient quantity of logging residues on a harvest site to maintain soil productivity and provide these other benefits [3].

Nationwide, the quantity of recoverable logging residues was approximately 36.2 Mt (dry weight) and this amount of residues has a potential of producing 67.5 TW h^{-1} of electricity [21]. Additionally, Gan and Smith [21] estimated that recoverable logging residues could displace 17.6 Mt of CO_2 in the United States. Similarly, Hall [22] reported that 6 Mkm^2 of biomass plantations having an average yield of 1200 t km^{-2} could offset 50% of CO_2 emissions annually by 2050. Based on these studies, it seems that utilization of additional logging residues might play an important role, both in bioenergy expansion based on woody biomass and lowering CO_2 emissions.

It should be noted that utilization of logging residues as a bioenergy feedstock is restricted by high delivery costs that include price paid to the owner, transportation costs, and logger charges [6]. Although, logging residues are widely available and have been promoted as an energy feedstock, mills have utilized logging residues in small quantities because their recovery and transportation costs were not feasible [23,24]. Furthermore, recovery of higher-value products might be more cost-effective to many logging operators rather than collecting logging residues. Logging residues require more space compared to logs and chips for the same weight to be transported and stored [25,26]. Thus, infrastructure is necessary to maintain a supply of logging residues and accommodate additional space and costs [27]. Lack of equipment to handle logging residues is another factor limiting their utilization [28]. Most equipment was designed for processing saw logs and pulpwood chips rather than small-diameter trees and logging residues. Purchasing specialized equipment to extract, transport, and process logging residues increases costs and reduces its economic feasibility [29].

The delivery cost of logging residues can be reduced and energy content improved if these residues are dried for 4–8 weeks as demonstrated after harvests of southern pine stands [30,31]. However, it is not a common practice to dry logging residues and deliver them to mills in the southern United States, because logging operators in the region are paid per unit of green weight [30,31]. Similarly, examples from other countries (e.g. Finland) indicated that most logging residues produced after harvesting were not used because of drying and storage problems [32]. Therefore, the necessity to dry logging residues and limited storage space at the mill increase the cost of logging residue utilization. While it might be easier to dry residues in warmer climates, such as in the southern United States, storage limitation remains a concern for many mill owners. However, some of these limitations might be easier to overcome in the southern United States, because the region has established logging, timber, and pulpwood supply chains [2,33]; has half of its land under forests [34,35]; and hosts large clusters of forest product manufacturers which might facilitate more efficient residue recovery [7,36].

This study determined the relationship between mill's bioenergy production characteristics, different factors limiting utilization of logging residues, and the quantity of woody residues utilized at mills in the southern United States. Although Gan and Smith [21] and the Billion-Ton Update study of DOE [5] indicated the availability of logging residues for bioenergy production, their utilization has been limited. A better understanding of bioenergy production potential based on woody biomass, consisting of mill and logging residues, will be useful in developing more effective programs and policies facilitating bioenergy production, and determining potential implications of proposed bioenergy policies.

2. Material and methods

2.1. Study area

This study was conducted in 12 states in the southern United States, which includes Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, Oklahoma, South Carolina, Tennessee, and Virginia (Fig. 1). The southern region is considered a wood basket of the United States because forests cover about 33% (3.3 Mkm^2) of the United States land area and in the southern region of the country they cover approximately 50% (1.08 Mkm^2) [34,37]. The majority of forests in the region are classified as timberlands, which are forests capable of producing at least

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