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Research paper

A comparison of methodologies for estimating delivered forest residue volume and cost to a wood-based biorefinery

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A B S T R A C T

Plant location can be a major factor in the financial success of a company when feedstock transport costs are high, such as for wood-based biorefineries. Biorefineries sited near large amounts of forest residue can better mitigate against the risk of reduced feedstock availability due to exogenous market constraints. Two methodologies for estimating the volume and cost of delivered forest residues to a biorefinery are presented. Both methodologies are based on data provided by the U.S. Forest Service Forest Inventory and Analysis (FIA) program. The first methodology is past-predictive in that it uses individual state Timber Product Output (TPO) datasets, while the second methodology is future-predictive in that it uses a spatially explicit economic optimization model of the U.S. forestry sector coupled with stand data at FIA plot locations to project near- and medium-term residue volumes. A Total Delivered Feedstock Cost Model is used with both biomass estimation methods to enable comparison of facility supply curves. A case study assesses four pulp mills, considered as candidate repurposed biorefinery locations, for their ability to procure sufficient biomass under average- and low-yield scenarios utilizing both methods. The facility that procures sufficient feedstock to meet annual biorefinery demand at the least cost under both yield scenarios theoretically provides the least risk to investors in terms of insufficient feedstock availability. The past-predictive methodology was found to be best-suited for refining a list of candidate facilities for further analysis. The future-predictive methodology is best-suited for a robust analysis of facilities using multiple economic and policy scenarios.

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1. Introduction

Forest residues are a byproduct of timber harvests performed primarily to supply raw material to satisfy lumber and paper demand, and can exist in sufficient quantity to be evaluated as a biofuel feedstock [1]. For industries with high raw material transport costs, such as wood-based biorefineries, the location of a plant can be a major factor in the financial success of a company [2]. Biorefineries sited near large amounts of forest residue feedstock can better mitigate against the risk of reduced supply due to exogenous physical constraints such as forest fires and insect infestations, and market constraints such as low demand for forest products. In contrast to agricultural feedstocks where annual production is planted in direct response to demand, forest residues are recovered over a 20- to 50-year timber harvest rotation. This difference in planting and planning cycles can lead to a more spatially dispersed supply area for forest-based materials compared to agricultural residues of energy crops. Therefore, methods to quantify forest residues available to a biorefinery should account for both the spatial distribution of the biomass and future timber demand.

For a biorefinery to obtain a reliable annual feedstock supply, the plant should have access to low-cost feedstock at volumes in excess of the minimum annual demand in average- and low-supply years. We present two biomass estimation methodologies, one past-predictive and one future-predictive, for determining annual forest residue volumes[1] that would theoretically be available at a

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[1] Forest products include measurements in both volume and mass for different products, and can also be reported for the same products in the case of pulpwood and residues. We refer to both mass and volume as volume for simplicity.

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range of marginal delivered feedstock prices. In addition, we evaluate each method's relevance for use in facility siting. These methods only predict likely availability based upon a number of market assumptions and do not guarantee any buyer-seller relations that would inform tactical supply decisions.

Both methodologies rely on public data supplied by the U.S. Forest Service (USFS) Forest Inventory and Analysis (FIA) Program. The past-predictive methodology uses FIA Timber Product Output (TPO) datasets [3], which provide county-level volumes of timber harvested in a single year. Each state is assessed in five-year increments. The volumes are reported by land-ownership type and present a historical accounting of timber harvest over time. The future-predictive methodology uses a spatially explicit economic optimization model of the U.S. forestry sector coupled with forest stand data at FIA plot locations. The model projects near- and medium-term residue volumes through forest growth and harvest regimes for public and private timber lands across the U.S. The output from this model is a forest residue volume estimate at each FIA plot over a projected time span of 20 years in one-year increments. An average volume is derived from the yearly increments. The two methodologies use the same transportation cost model to enable a comparison of facility supply curves generated by the different biomass estimation methodologies.

The goal of this research is to develop and compare methods for estimating forest residue availability to a facility. The objectives are to: 1) create a total delivered feedstock cost model that combines fixed and variable harvest and hauling biomass costs with a networked road dataset to estimate the marginal delivered feedstock cost to the biorefinery gate; 2) develop algorithms for the two methodologies that integrate the spatial variability of forested biomass with the total delivered feedstock cost model to determine feedstock supply curves; and 3) assess the risk in feedstock supply to a biorefinery using each methodology. We define risk as the failure to procure the minimum annual feedstock demand at a maximum delivered cost, and assess this risk through facility feedstock supply curves under low-yield scenarios.

The two methodologies are applied in the Pacific Northwest region of the United States, as this region has abundant forest residues that may serve as a sustainable biofuel feedstock [1,4,5]. While pulpwood may be considered as a feedstock in areas where a local pulpwood market is absent or weak, this paper focuses solely on the use of residues as a biofuel feedstock. In recent years, a two-fold emphasis has been placed on utilizing this resource: 1) valorize unmerchantable biomass that is typically left onsite to decompose or is burned [1,6,7], and 2) gain carbon dioxide emission reductions through not burning the forest residue piles [8]. The latter helps achieve a mandated 60% reduction in lifecycle greenhouse gas emissions for cellulosic biofuels from a baseline as stated in the U.S. government's Renewable Fuel Standard [9].

2. Literature review

Researchers have taken many approaches to estimating forest residues and delivered feedstock costs to a facility. Many use historical biomass data, such as TPO datasets, applied equally over a county or grid to estimate feedstock volumes and transportation costs [10–13]. As harvest volumes change year to year, using a single year of data may significantly over- or under-estimate potential future biomass availability. Assigning biomass volumes to the centroid of a county or to equally distributed grid points does not reflect the spatial heterogeneity of forest residues. Similarly, using approximate transportation distances may introduce significant variability in the resulting delivered feedstock costs and thus biomass availability to a facility.

Yoshioka et al. [14] estimated forest residue volumes from data similar to FIA plots, yet used a rasterized road network (50 m cell size) to determine least cost paths from forest landings to a bioenergy plant. Unless the raster cell size is set to an average approximate road width, error may be introduced in travel time estimation as the sinuosity of the road network is lost in the larger cell size [15]. Although, smaller cell sizes may create excessively long computer processing times [15]. Using a vector-based approach can provide more accurate transportation costs in a reasonable amount of processing time. However, running network analyses using vector road layers requires “clean” topology, where all segments of the road network are snapped together and all traffic flow directions are correct. If a road layer does not have clean topology, ample upfront time may be necessary to prepare the layer for analysis. Additionally, both vector- and raster-based network analyses rely on accurately digitized road layers to estimate travel times and transportation costs effectively.

A selection of studies combine refined feedstock estimates with a networked road dataset to estimate total delivered feedstock cost and volume [16–18]. Two studies use methodologies similar to those presented in this paper. Chung and Anderson [19] average three separate years of TPO datasets, and disaggregate the county-level roundwood and residue volumes by land ownership and land cover data. Thiessen polygons are created around evenly spaced nodes on a road network and are assigned the biomass volumes for routing to a bioenergy facility. Noon and Daly [20] use FIA plot locations and stand data to determine residue volumes based on stand characteristics and the likelihood of a stand being harvested, assuming that regional harvesting characteristics and levels would be similar to those occurring in the prior decade.

The methods presented below assess projections from two biomass estimation methodologies; one based on the TPO approach of Chung and Anderson [19] and one based on the FIA plot inventories of Noon and Daly [20]. We present an alternative approach to TPO-based biomass estimation using GIS-generated service areas rather than Thiessen polygons. Service areas represent the area potentially accessible within a specified maximum transportation cost while Thiessen polygons distribute land area based on point locations of biomass. We utilize FIA plot inventories to simulate forest growth and future forest products demand through time to project likely logging and forest residues availability as opposed to focusing on past harvest data. By accounting for potential market changes, the use of a coupled biological-economic model to estimate average feedstock volume over a longer time horizon may provide an estimate of annual biomass availability that is more representative of possible future conditions.

3. Methodology

Because residues are byproducts of timber production, the process of determining forest residue supply to a facility is provided in two distinct steps: biomass availability followed by biomass supply. Availability is determined by the level of other forest harvesting activities, and supply is determined by the delivery of biomass to a facility at a given marginal cost. In both models, forest residue volumes from private, state, and tribal-owned lands are included in the analysis while forest residue from federal lands is not. The U.S. government's Renewable Fuel Standard states that only slash and pre-commercial thinnings from non-ecologically sensitive and non-federal forestland may be considered as renewable biomass for the production of renewable fuel [9]. The Methodology begin with a description of the Total Delivered Feedstock Cost model, followed by a discussion of biomass availability and supply for the TPO and LURA methodologies.

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