The Biomass Site Assessment Tool (BioSAT) Integrated with Landscape Suitability

Timothy M. Young, James H. Perdue, Xia Huang

Abstract
A challenge in the development of renewable energy is the ability to spatially assess the risk of woody cellulosic feedstock supplies to conversion facilities. Policy makers and investors need improved methods to identify the interactions associated with landscape features, socio-economic conditions, ownership patterns, and the influence these variables have on supply curves and the marginal cost (MC) curves of woody cellulosic producers. This study estimates opportunity zones in a spatial context for woody cellulosic feedstocks based on landscape suitability and geo-referenced economic supply using the BioSAT model (www.biosat.net). The study covered 13 southeastern states in the U.S. Population density, farm income, road density, forest land area relative to crop land area, water area, slope, forest ecoregion type, annual net growth-to-removal ratio, and area of lands in public preserves were used to distinguish regions and the suitability for woody cellulosic feedstock supply. BioSAT was used to estimate the MC curves for these regions to further identify highly suitable zones. Highly suitable zones for woody cellulosic feedstocks were located in Central Mississippi, northwest and southeast Alabama, north Arkansas, west Georgia, southeast Oklahoma, Kentucky, Tennessee, and southwest Virginia. Softwood and hardwood logging residues MC in these regions ranged from $38 to $41/dry ton. Highly suitable regions for softwood pulpwood occurred in Alabama, Florida, southeast Oklahoma, South Carolina, and Virginia where MC ranged from $46 to $61/dry ton. In highly suitable regions that contained hardwood pulpwood, MC for hardwood pulpwood ranged from $34 to $56/dry ton.

Keywords: Biomass; site assessment; model; spatial analysis; landscape suitability

Introduction
Elbehri (2007) noted replacing petroleum products with cellulosic feedstocks presents several technical, economic, and research challenges, one of which is the availability of cellulosic feedstocks. Elbehri (2007) further noted that high relative costs of production, logistics, and transportation of cellulosic feedstocks are all potential constraints that need to be better understood. Elbehri’s thesis provides the rationale for this research, i.e., provide decision-makers with a better quantitative tool to accurately assess the costs of woody cellulosic supply. The objective of this study was to estimate the economic availability of woody cellulosic feedstocks in a geo-spatial context.


Methods
The methodology had three main components: 1) estimation of forest biomass availability; 2) measurement of landscape suitability for forest biomass; and 3) estimation of producers’ supply curves. All records were organized at the U.S. Census Bureau 5-digit ZIP Code Tabulation Area (ZCTA) level.
There were 10,016 ZCTAs in the 13-state study region which corresponded to 10,016 potential analytical polygons.

**BioSAT Model**

The BioSAT model ([www.biosat.net](http://www.biosat.net)) estimated the economic availability of woody cellulose for procurement zones with one-way haul distances ranging in size from 128.8 km to 321.9 km which were not always concentric, *i.e.*, the shape of such zones rely on the transportation network and corresponding physical biomass supply (Perdue et al. 2011). The supply chain of BioSAT has three main cost components: resource, harvesting, and transportation. Estimates of total biomass, and average annual growth and removals were obtained from the Forest Inventory and Analysis Database (FIADB) version 3.0.

Resource cost data (*e.g.*, stumpage, mill residue prices, etc.) were obtained from Timber Mart South ([http://www.tmart-south.com/tmart/](http://www.tmart-south.com/tmart/)). The Fuel Reduction Cost Simulator (FRCS) as modified for the Billion Ton Study (Perlack et al. 2005, U.S. Dept. of Energy 2011) was used to estimate the costs of harvesting logging residues. Merchantable wood harvesting costs were estimated from the Auburn Harvest Analyzer (Tufts et al. 1985) which was expanded for six ecoregions types, five forest types, and five harvesting systems by Baker and Greene (Center for Forest Business, Warnell School of Forestry and Natural Resources, University of Georgia). Transportation costs were based on travel times and distances adapting the truck transportation model of Berwick and Farooq (2003).

**Landscape Suitability**

The availability of woody cellulosic supply, as well as other forest resources, is physically constrained by a set of factors from the natural and socio-economic environment. Twelve variables were used in this study to determine the suitability of the forest landscape (Table 1). Suitability assumes the presence of harvestable forests, access to abundant forest resource supply, and minimal socio-economic restrictions from human activity (*e.g.*, urban development, suburban sprawl, national parks, etc.). Attributes of “forest land area ratio,” “slope,” as well as “suitable ecoregions for forests” determined the spatial degree of the presence of harvestable forests. The attribute “timberland annual growth-to-removal ratio” was an indicator of forest net growth. “Population density,” “farm net income,” “median income,” and “road density” were used to estimate socio-economic indicators.

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3 Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, Oklahoma, South Carolina, Tennessee, Texas, Virginia.

4 The average area for 5-digit ZCTAs in the 13-state study region was 209.84 km².
Table 1. Geographical landscape and socio-economic factors used in study.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Resolution</th>
<th>Unit</th>
<th>Data Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population Density</td>
<td>5-digit ZCTA</td>
<td>People/mile²</td>
<td>U.S. Census Bureau (2010) population density in each 5-digit ZCTA.</td>
</tr>
<tr>
<td>Farm Net Income</td>
<td>County</td>
<td>Dollar</td>
<td>USDA NASS Census Agriculture (2007) farm net income in each county.</td>
</tr>
<tr>
<td>Road Density</td>
<td>5-digit ZCTA</td>
<td>km/km²</td>
<td>U.S. Census Bureau (2010) road length</td>
</tr>
<tr>
<td>Crop Cultivated Land Area Ratio</td>
<td>5-digit ZCTA</td>
<td>percent</td>
<td>U.S. National Land Cover Database (2006)</td>
</tr>
<tr>
<td>Forest Land Area Ratio</td>
<td>5-digit ZCTA</td>
<td>percent</td>
<td>U.S. National Land Cover Database (2006)</td>
</tr>
<tr>
<td>Water Area Ratio</td>
<td>5-digit ZCTA</td>
<td>percent</td>
<td>U.S. National Land Cover Database (2006)</td>
</tr>
<tr>
<td>Slope</td>
<td>5-digit ZCTA</td>
<td>percent</td>
<td>U.S. National Elevation Dataset (1999) NED 1arc second</td>
</tr>
<tr>
<td>Ecoregions Level III</td>
<td>Ecoregions</td>
<td>-</td>
<td>U.S. EPA (2011)</td>
</tr>
<tr>
<td>Lands in Public Preserves</td>
<td>5-digit ZCTA</td>
<td>-</td>
<td>U.S. Forest Service (2009)</td>
</tr>
</tbody>
</table>

Forest biomass annual growth and removal quantity data were collected at the county level from Forest Inventory and Analysis Database (FIADB) version 3.0 (Figure 1a), and allocation was done for each of the 10,016, 5-digit ZCTAs using geographic information system (GIS) technology. National land cover and digital raster map data were used to identify forestland. In the digital raster map, each pixel represents one particular land cover class, e.g., water, urban, forest, or cropland, etc. (Figure 1b). Forest biomass annual growth and removal quantities were proportionally allocated to each 5-digit ZCTA using the county boundary, 5-digit ZCTA, and the land cover image data with GIS spatial overlay techniques. Due to errors between county and 5-digit ZCTA boundaries (i.e., some 5-digit ZCTAs cross county boundaries), each forest biomass county was split into multiple area parts via the 5-digit ZCTA area shape, and assigned a unique 5-digit ZCTA identifier. By overlaying each area part with the land cover image layer, the numbers of pixels in all land cover classes within each area were estimated (Figure 1c). By summing up the pixels of deciduous forests, coniferous forests and mixed forests, which together represented forestland in the unit of a county, a forestland pixel ratio for each area part to its belonging county was calculated and the forest biomass quantity in every area part was derived for this pixel ratio (Figure 1d). A summed quantity value for all area parts belonging to the same 5-digit ZCTA were then calculated as the forest biomass quantity in this 5-digit ZCTA.
Results

Landscape Suitability
Regions that had forest area ratio greater than 30%, timberland annual growth-to-removal ratios greater than 1.5, ecoregions defined as mostly forestland, slopes less than 10%, and less than 39 people/km² were considered areas for highly suitable forest production. Based on these criteria, high suitable opportunity zones for woody cellulosic feedstocks were located along the Central Mississippi, northwest and southeast Alabama, southeast Oklahoma, west Georgia, Kentucky, Tennessee and southwest Virginia (Figure 2). This research supports the conclusions of Butler et al. (2010) in identifying forest biomass that is physically constrained by a set of factors from the natural and socio-economic environment. This study also expands the scope of the research by Butler et al. (2010) in analyzing the southeastern region of the U.S.
Figure 2. ZCTAs excluded in the 13-state study region (left figure) and opportunity zones for woody biomass identified by landscape suitability (right figure).

Geo-Referenced Supply Curves from BioSAT
As an illustration, the BioSAT model was used to derive detailed economic information for southern pine pulpwood (*pinus spp.*) for one of the high suitability opportunity zones located in central Mississippi (ZCTA 39090, Kosciusko MS). A 193.1 km haul distance was assumed and the associated supply or marginal cost (MC) curve is displayed in Figure 3. MC increases from approximately $48 to $66/dry ton over a maximum supply of 773,096 dry tons of southern pine pulpwood. The estimates for this illustration in MS and other BioSAT estimates for the southeast are consistent with the results of U.S. Dept. of Energy (2011) but expand upon the research by including geo-referencing and forest suitability at a finer resolution (*i.e.*, the 5-digit ZCTA).

Figure 3. Spatial representation of biobasin for ZCTA 39090 (Kosciusko MS) and associated marginal cost curve for pine pulpwood (*pinus spp.*) from the BioSAT model.
References


