

## Geospatial Economics of the Woody Biomass Supply in Kansas – A Case Study

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This research assessed the geospatial supply of cellulosic feedstocks for potential mill sites in Kansas (KS), with procurement zones extending to Arkansas (AR), Iowa (IA), Missouri (MO), Oklahoma (OK), and Nebraska (NE). A web-based modeling system, the Kansas Biomass Supply Assessment Tool, was developed to identify least-cost sourcing areas for logging residues and upland hardwood roundwood biomass feedstocks. Geospatial boundaries were used according to the 5-digit zip code tabulation area (ZCTA). This higher level of resolution advanced the understanding of the geospatial economics of modeling the supply chain for cellulosic feedstocks. The analyses were conducted for six sub-regions (Chanute, Effingham, El Dorado, Manhattan, Ottawa, and Pratt) within Kansas that were identified by the US Forest Service as suitable for forest habitat. Atchison County of Effingham region had the least marginal costs for upland hardwood roundwood, ranging from \$92.59 to \$108.68 per dry metric ton, with an available annual supply of approximately 72 thousand dry metric tons. The least favorable was the El Dorado region, where the marginal costs ranged from \$97.32 to \$108.05 per dry metric ton, with an annual supply of approximately 4.4 thousand dry metric tons.

*Keywords:* Cellulosic feedstocks; Woody biomass; Economic supply; Geospatial assessment; Kansas; BioSAT

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### INTRODUCTION

Approximately 60% of the global biomass supply in 2030 is predicted to originate from energy crops and forest products, including forest residues (Nakada *et al.* 2014). While the largest supply potential exists in Asia and Europe, the US has a potential of producing between 1.1 and 1.6 billion dry tons, which is equivalent to 1 to 1.5 billion metric tons of biomass annually (Perlack and Stokes 2011). The forest-type biomass would account for almost 20% of the US annual biomass production (US Department of Energy 2011).

As highlighted in the 2016 Billion-Ton Report (Langholtz *et al.* 2016), questions are raised on how the transportation costs of biomass feedstocks from the roadside to biorefineries may impact the prices of delivered supplies and therefore feedstock availability. Ongoing research and development efforts require a characterization of the economic availability of biomass resources delivered to biorefineries and not just to the roadside (US Department of Energy 2016). The adverse effects of climate change were not taken into consideration in this research.

Multiple studies addressed a variety of aspects concerning the forest-type or woody biomass. The research in North America was conducted on forecast for biomass ethanol production (DiPardo 2000), potential in utilization of residual biomass resources (Champagne 2007), economic impacts of increasing ethanol production (Ugarte *et al.* 2007), the geographic distribution of the feedstocks for certain assumed price levels (Walsh 2008), economic drivers of ethanol production and environmental applications (Biomass Research and Development Board 2010), potential use in bioenergy production taking into account the climate change policy (White 2010), and “potential” production of biomass (US Department of Energy 2011). The availability of the woody biomass is a subject of many research studies in Europe (De Wit and Faaij 2010; Verkerk *et al.* 2011; Zambelli *et al.* 2012; Welfle *et al.* 2014; Rytter *et al.* 2015), Asia (Koopmans 2005; Yoshioka *et al.* 2005; Sasaki *et al.* 2009; Joshi *et al.* 2016), Latin America (Houghton *et al.* 2001; Ferreira-Leitao *et al.* 2010), and Africa (Banks *et al.* 1996; Marrison and Larson 1996; Dasappa 2011). The availability of woody biomass in the Southern U.S. was studied by Munsell and Fox (2010), Eastern U.S. by Brown and Schroeder (1999), Southeastern U.S. by Young and Ostermeier (1989), Young *et al.* (1991), Galik *et al.* (2009), Perdue *et al.* (2011), and Huang *et al.* (2012), Western U.S. by Skog and Barbour (2006), Tennessee Valley by Downing and Graham (1996), and the state of Mississippi specifically by Perez-Verdin *et al.* (2009). However, a review of the literature did not indicate any previous studies focused at the state level on Kansas.

The modeling system BioSAT provides spatially explicit information on biomass supply. The model uses readily available geographic information system, GIS-based landscape characterization and socioeconomic inputs to derive and generate visual information on biomass supply/demand, risk potential, biomass accessibility and landscape suitability, opportunity zones, energy crop production potential, and ecological vulnerability (Zalesny *et al.* 2016).

The goal of this study was to develop georeferenced supply curves for cellulosic feedstocks on a web-based platform (that allows for periodic data updates) to assist practitioners in KS interested in procuring cellulosic feedstocks.

## **EXPERIMENTAL**

### **Methods**

About 5.5 million acres (2.2 million hectares) of Kansas is covered mostly by forestland, but also agroforestry (windbreaks and streamside forests), urban forests, and community forests (Kansas Forest Service 2015). Hardwood or deciduous species are the predominant forest type in the region (Kansas Forest Service 2015) and are the primary focus of the study. Wood manufacturers and urban tree care activities produce approximately 141,362 dry tons (128,215 metric tons) of woody biomass (wood processing by-products and urban tree waste) in Kansas annually (Enterprises 2009) supplying the existing and potential mills in the region.

There are 10 types of woody biomass and six agricultural-residue feedstocks available in the KS BioSAT (<http://www.biosat.net/Kansas/index.html>) model of the study. For conciseness, the supply and cost estimates were summarized for hardwood (oak/hickory, woodland hardwoods) logging residues (*e.g.*, the limbs and unmerchantable tops of the trees, whole trees that are harvested, but are too small or damaged to be used for conventional forest products) and merchantable trees. Hardwood logging residue

marginal cost (MC) curves (producer supply curves) were estimated for “chipping tops and limbs at the logging site landing” (referred to as at-landing logging residue costs) and for “second pass harvesting of sub-merchantable material in the forest” (referred to as in-woods logging residue costs). The MC curves for roundwood were estimated for upland hardwood pulpwood for six KS sub-regions (Chanute, Effingham, El Dorado, Manhattan, Ottawa, and Pratt) as defined by the US Forest Service Forest Inventory and Analysis group as suitable for forest habitat.

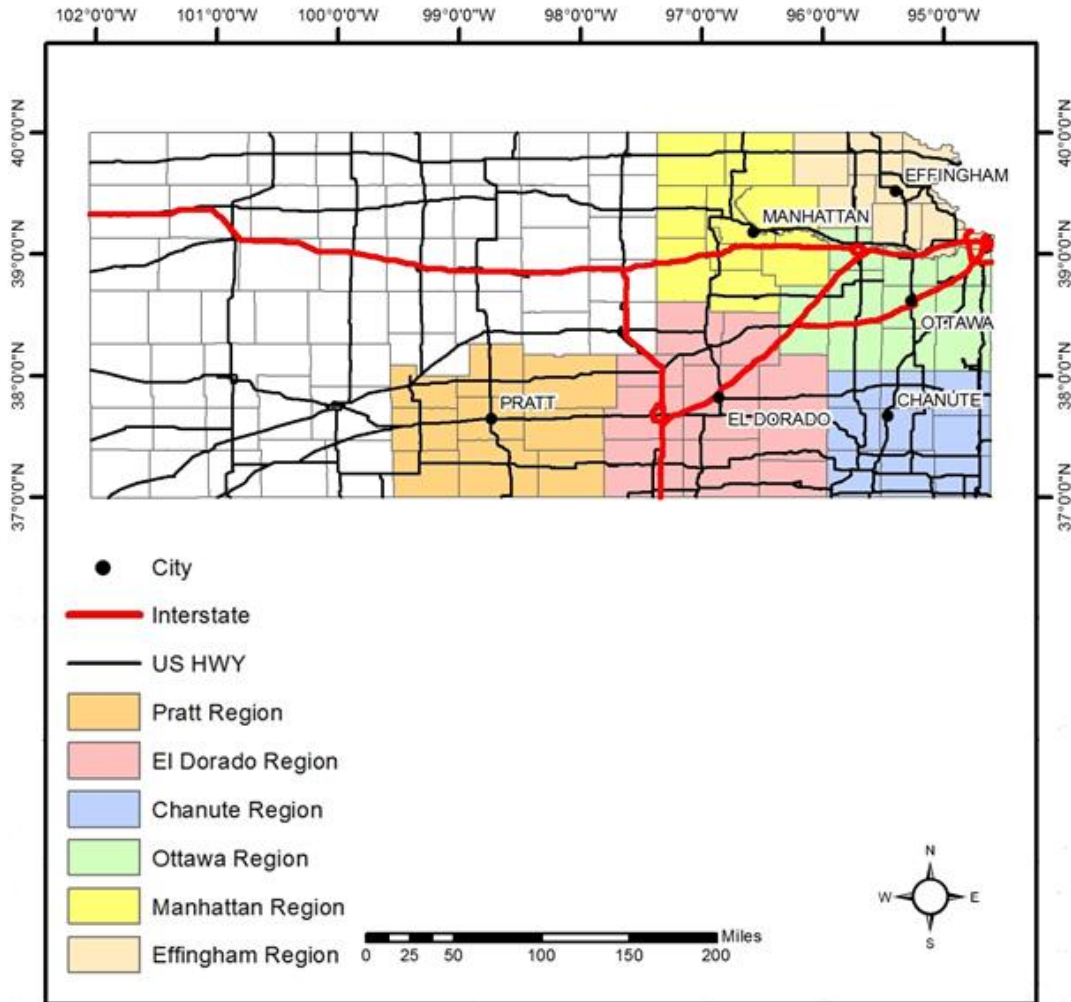
The sourcing areas for cellulosic feedstocks (the renewable resources that include crop residues, wood residues, dedicated energy crops, industrial, and other wastes (DOE 2016)) were estimated using the five-digit zip code tabulation area (ZCTA) which is a generalized areal representations of United States Postal Service ZIP Code service areas (US Census Bureau 2010). The data (*e.g.*, geographic information system (GIS), US Forest inventory, *etc.*) were allocated at this highest level of resolution to enhance the usefulness of the KS BioSAT model for practitioners. The road network was a key factor in determining the location of woody biomass, *i.e.*, the procurement zones were often non-concentric given the availability of roads relative to biomass supply. This spatial allocation of economic, social, and resource data at the five-digit zip code tabulation area is a key contribution of this work because a higher geospatial resolution may provide more realistic boundaries for a mill’s procurement zone and associated delivered “at-gate” cost estimates, being important for states that have large counties with rectilinear polygon shapes. Even with this higher level of geospatial boundaries, limitations associated with the sampling error associated with biomass inventory data exist, and this error decreases as the area increases. However, the area proportionality allocation to the 5-digit ZCTA of the biomass inventory data may provide a more realistic “edge-effect” of procurement boundaries.

The study accounted for the limitations of feedstock supply (later referred to as Exclusion Criteria) based on government ownership (*e.g.*, military bases, parks, reservations, *etc.*), large urban centers (*e.g.*, Kansas City, Wichita, *etc.*), and not suitable ecological regions or ecoregions (*e.g.*, The Flint Hills (the hilly region with rocky soil), *etc.*), the areas where the allocation of woody biomass is not feasible.

The KS BioSAT (Knoxville, TN, USA) model has three main cost components: resource (*e.g.*, stumpage for standing trees, biomass residues), harvesting, and transportation. The selection of six sub-regions within KS was suggested by the US Forest Service (USFS) Inventory and Analysis (FIA) Group that identified the area as regions of interest based on woody biomass concentration in the state. The sub-regions were defined as Chanute, Effingham, El Dorado, Manhattan, Ottawa, and Pratt, and were the basis of the analyses in this study (Fig. 1).

### Forest Resource Data

County-level estimates of all-live total biomass, as well as growth, removals, and volume were obtained from the USFS FIA Database (USDA 2015). The latest complete cycle of data for each state was used. The forest data were obtained for net growth (gross growth (average annual change in volume of merchantable size trees on timberland in dry tons) minus mortality, where mortality is the average annual death of merchantable size trees on timberland in dry tons), removals, gross volume, and volume of pulpwood in cubic feet and were converted to dry tons (see Biomass Energy Data Book (Oak Ridge National Laboratory (ORNL))). The county level data were allocated spatially to the 5-digit ZCTA using the ZCTA polygons.



**Fig. 1.** The US FS FIA regions of interest

The Subregional Timber Supply (SRTS) model was used to estimate logging residue supply with recovery rates set to 30% (Abt *et al.* 2000; Abt 2008). The SRTS model uses USDA FS FIA data to project timber supply trends based on current conditions and the economic responses in timber markets (Abt and Cubbage 2000; Abt 2008). The internal inventory module in SRTS is based on the Georgia Regional Timber Supply (GRITS) model (Cubbage *et al.* 1990). The GRITS extrapolates forest inventories based on USDA FS FIA estimates of timberland area, timber inventory, timber growth rates, and timber removal. The GRITS classifies data into 10-year age class groups by broad species group (softwoods and hardwoods) and forest management type (planted pine, natural pine, oak-pine, upland hardwood, and lowland hardwood).

County-level forest quantity estimates were allocated to ZCTAs based on area proportionality and the land cover GIS imagery. If a ZCTA with all forestland accounts for 10% of a county, 10% of the county's forest quantity was assigned to that ZCTA. The ArcGIS (Redlands, CA, USA) zonal histogram tool was used to determine the number of forest pixels in each county and ZCTA. The number of forest pixels in a given county, providing the forest quantity residing in each pixel, divided the county-level forest quantities. That ratio was then multiplied by the number of forest pixels in each ZCTA.

When a ZCTA boundary crossed multiple counties, proportions for each county were summed. The ZCTAs were based on the 2010 census definition and obtained from the US Census Bureau (US Census Bureau 2010). The forest pixels were derived from the National Land Cover Database (2011). There were 4,486 supply ZCTAs (679 demand ZCTAs in KS) in the six-state study region with approximately 30% of them classified as excluded areas that are Federal lands, highly populated areas, and unsuitable ecoregions.

### Forest Resource Costs

Resource cost data for woody cellulosic biomass was obtained from Timber Mart-South (2016). The average price data for Arkansas was used in the study, *i.e.*, that is the only state close to KS that has periodically reported stumpage. There are currently no estimates for logging residue resource costs reported in the public domain. While some works did not include stumpage value of logging residues (Kerstetter and Lyons 2001; Gan and Smith 2006; Gan 2007), Wu *et al.* (2010) assumed the logging residue stumpage price to be 0.91 \$ per green ton, Galik *et al.* (2009) gave a “rough approximation” of \$1 per green ton. The value of 1\$/green ton seemed underestimated, and therefore the logging residue stumpage price in this research was set to \$1 per dry ton.

### Harvesting Costs

#### *Logging residue harvesting costs*

The Fuel Reduction Cost Simulator (FRCS) as modified for the Billion Ton Study (Perlack *et al.* 2005; US Department of Energy 2011) by Dykstra (2008) was used to estimate the costs of harvesting logging residues (Stokes 1992; Fight *et al.* 2006). The revised FRCS (Dykstra 2008) was used to estimate logging residue costs for chipping tops and limbs at the landing, and in wood’s harvesting of sub-merchantable material.

#### *Merchantable tree or roundwood harvesting costs*

The Auburn Harvest Analyzer (AHA) (Auburn, AL, USA) was used to estimate harvesting costs for roundwood (Greene *et al.* 1987; Tufts *et al.* 1985; Tufts *et al.* 1988; Lanford and Stokes 1996). The AHA model was adapted for the six-state study region accounting for its ecoregions and forest stand types, and two available harvesting systems were assumed (*e.g.*, feller-buncher/grapple skidder and chainsaw/cable skidder). The primary drivers for the model were the quadratic mean diameter, tons per acre removed, trees per acre removed, tract size, and average height of dominant trees obtained from the FIA merchantable tree estimates. The harvesting cost model generated roundwood production costs on a per dry ton basis for the two harvesting systems for all forest stand types. To evaluate the maximum available quantity of upland hardwood pulpwood in the region the authors assumed the use of a chainsaw/cable skidder and clearcut (where 100% of trees are removed) harvesting practices.

### Transportation Costs

#### *Transportation network*

The shortest travel time routes between the demand and supply ZCTAs were estimated with Microsoft MapPoint 2011 (Redmond, WA, USA). The road networks in MapPoint are a combination of the Geographic Data Technology, Inc. (GDT) and Navteq (Chicago, IL, USA) data (Huang *et al.* 2012). The GDT data were used for rural areas and small to medium size cities, while the Navteq data were used for major metropolitan areas. The GDT data are based on “Tele Atlas Dynamap Streets,” which are address level

geocoding. When an address level geocode is not available, the GDT data set uses cascading accuracy at the ZIP+4, ZIP+2, and ZIP code centroid to return the highest level of geocode for the address. The ZIP code boundary data are based on the Dynamap/5-Digit ZIP code Boundary data from Tele Atlas North America. The Navteq maps provide a highly accurate representation of the detailed road network, including up to 260 attributes, such as turn restrictions, physical barriers and gates, one-way streets, restricted access, and relative road heights.

### *Trucking costs*

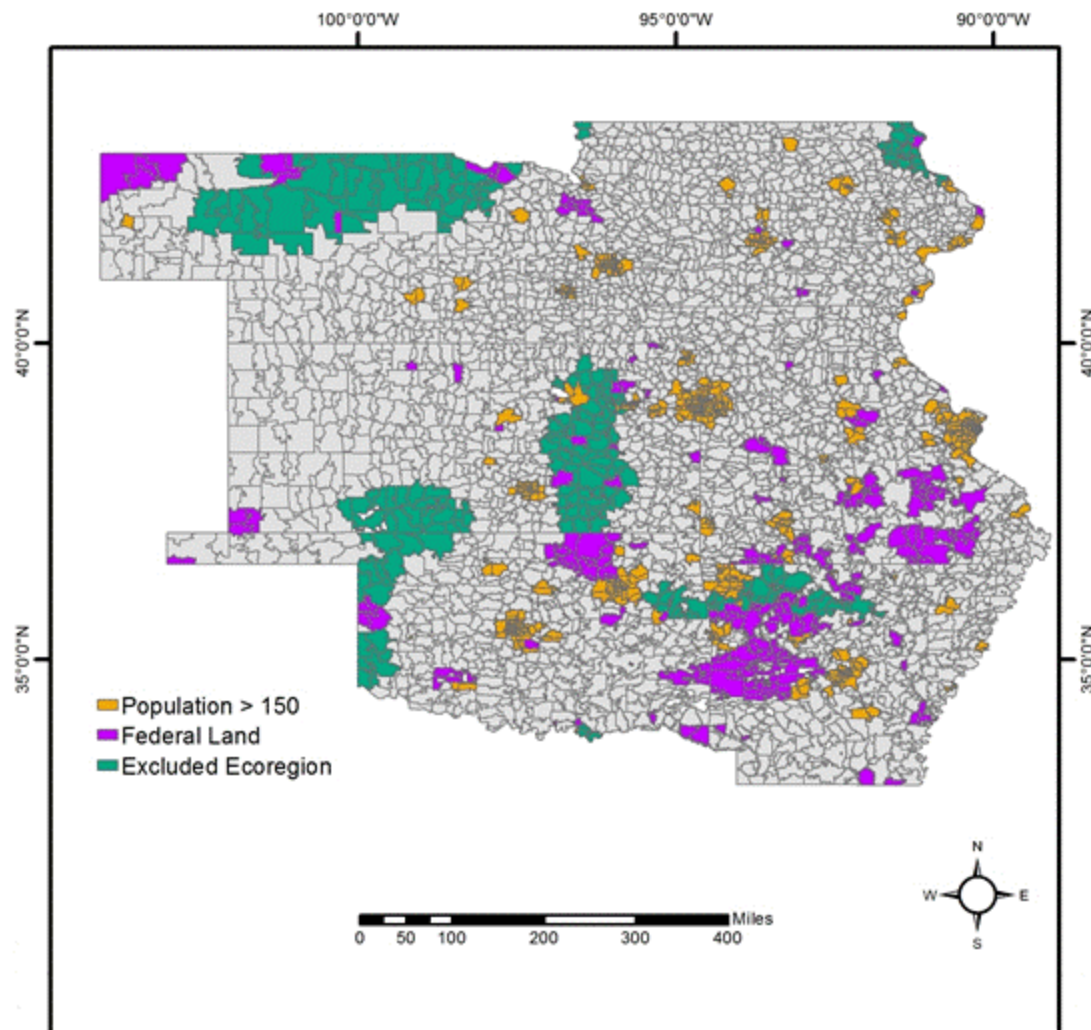
The transportation cost model estimated the fixed and variable trucking costs, based on the shortest travel time and distance from the MapPoint road network of a sourcing area, and the maximum annual mileage for tractor-trailers (the travel distance, which influences fixed costs, was allocated over the tractor-trailer's estimated annual miles, which was 100,000 miles for the tractor and dry van and flatbed trailers; 80,000 miles for the long-log trailers). Single-driver day cabs were assumed with a maximum one-day legal round-trip time of 11 h. As supported in the research by Perez-Verdin (2009), fleet carriers contracted by a manufacturer were also assumed in this study. The choice of the trailer-type in the trucking cost model depended on the type of feedstock and was either dry-van storage for logging residues or full length for roundwood.

The trucking cost model was an adaptation of the truck transportation model by Berwick and Farooq (2003). The trucking variable costs were a function of travel time between the supply and demand ZCTAs, while the trucking fixed costs were a function of travel distance. The least-cost solutions for a set of supply ZCTAs to meet a specified demand quantity (*i.e.*, 250,000 dry tons [226,750 metric tons] of logging residue) within a specified distance of 80 miles (128.7 km) were generally dependent on the shortest travel time between the supply and demand ZCTAs.

The trucking fixed costs included the equipment depreciation cost, average value of investment, interest, insurance, and taxes. Variable costs consisted of maintenance and repairs, diesel fuel and lubricants, and labor costs. The diesel fuel costs were obtained from the Energy Information Administration 2016 (Ferreira-Leitao *et al.* 2010) and are updated on monthly basis in the KS BioSAT model. Only ZCTAs able to supply at least one full truckload of biomass were considered for the analyses. The gross truck weight in the model was the 80,000-pound legal limit for KS (40 dry tons or 36.3 metric tons) (K.S.A. 8-1912).

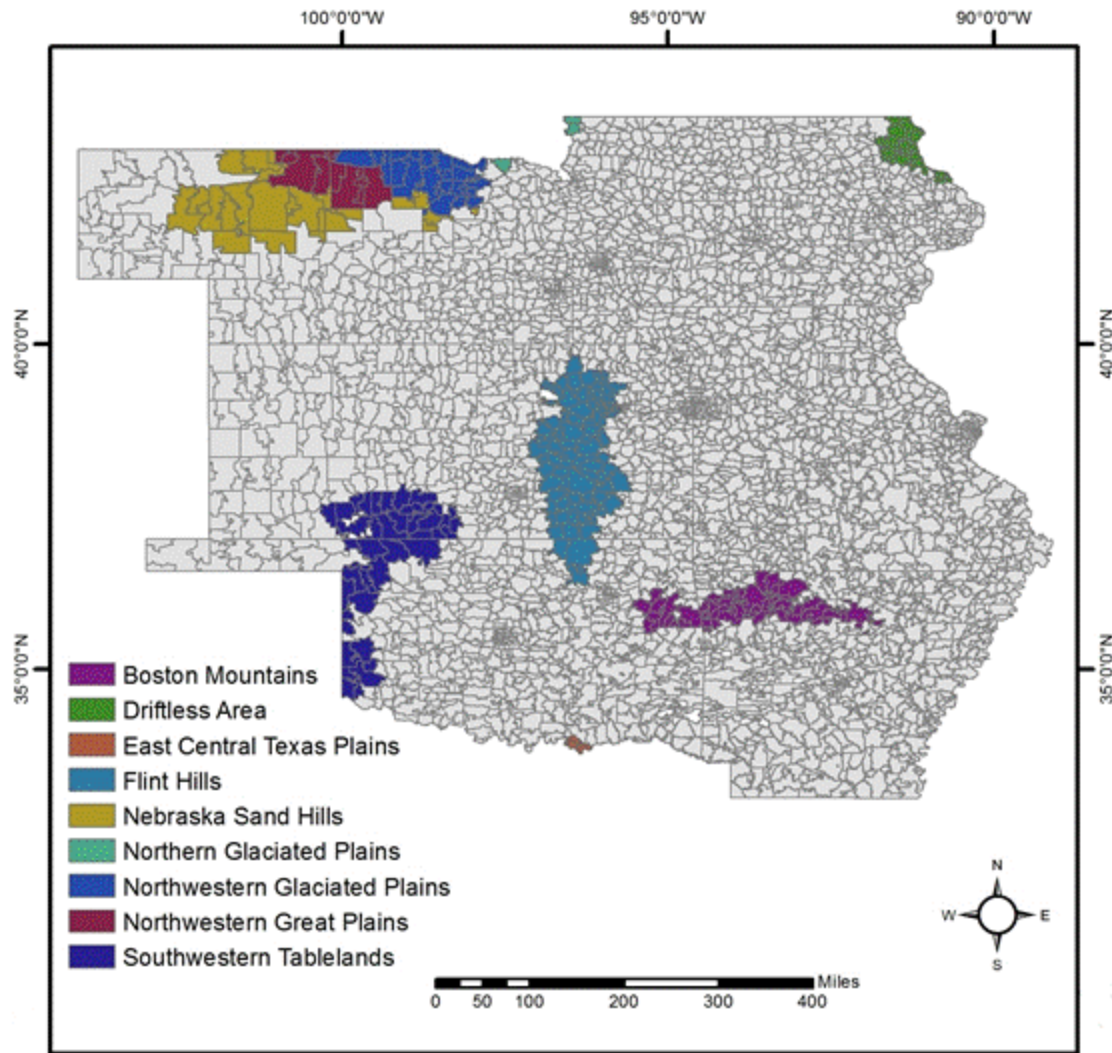
### **Exclusion Criteria**

The exclusion criteria were developed as a refinement of the available supply given legal, political, and social constraints for procuring sustainable woody biomass supply. For example, the production of commercial timberland is improbable in heavily populated areas (Wear *et al.* 1999); ZCTAs with a population density higher than 150 people per mi<sup>2</sup> (58 people per km<sup>2</sup>) were excluded from the analyses (Fig. 2). The ZCTAs within the US Environmental Protection Agency (EPA) Level III ecoregions (Fig. 3) that are not ecologically suitable for forest production (*i.e.*, Nebraska Sand Hills, Northern Glaciated Plains, *etc.*) (US Environmental Protection Agency 2013) were excluded. Certain types of federal ownership were also excluded (*i.e.*, Air Force Department of Defense (DOD), Bureau of Reclamation (BOR), National Grassland, Indian Reservations, *etc.*), as shown in Fig. 4.



**Fig. 2.** Excluded zones due to population density, federal land, and EPA Level III ecoregions







**Fig. 3.** Excluded US EPA Level III Ecoregions

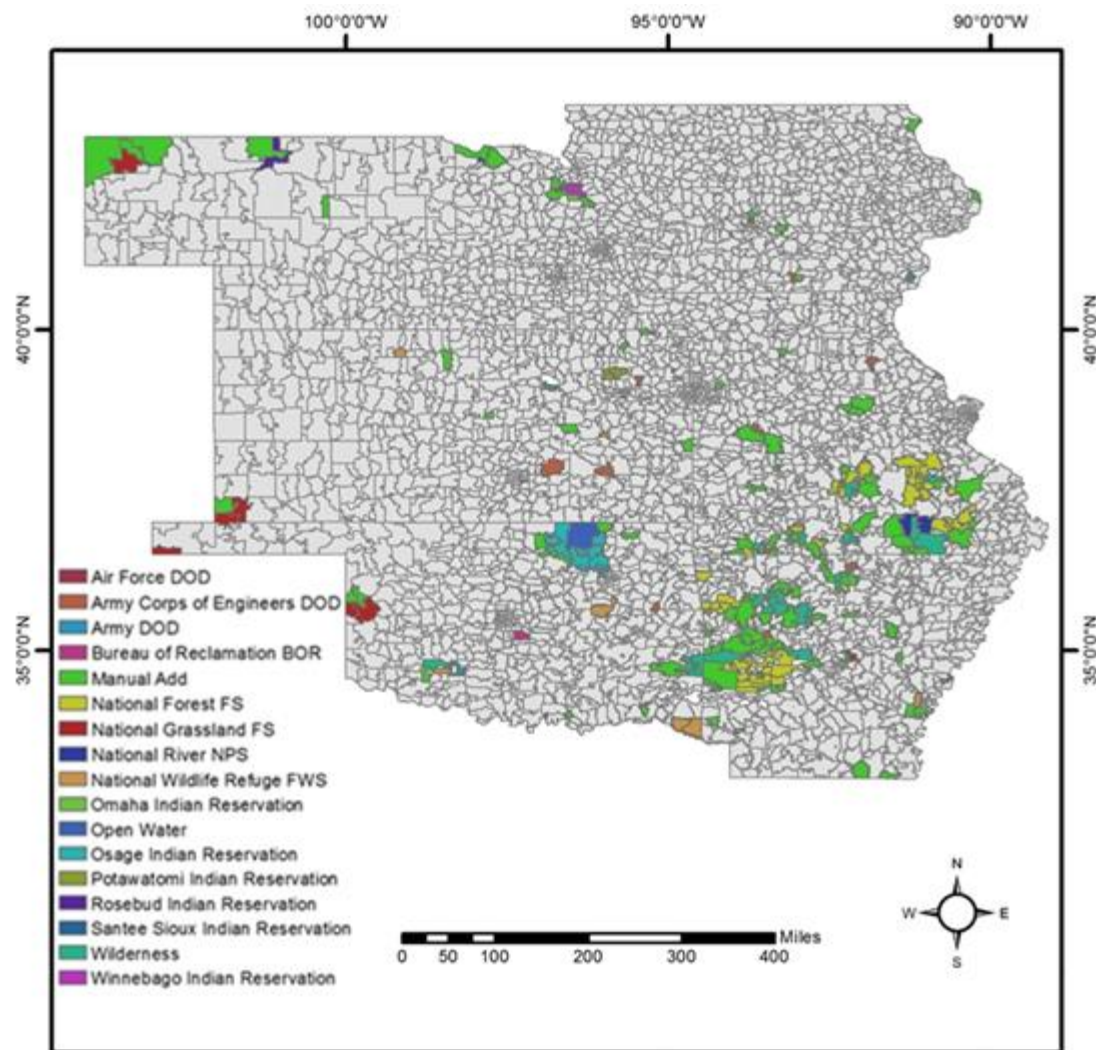


Fig. 4. Federal land excluded by type of federal ownership

## RESULTS AND DISCUSSION

### Logging Residues

The maximum quantity available in a sourcing area and the associated total cost, average total cost per dry ton (ATC), and median MC in dollars per dry ton were estimated for hardwood logging residues (at-landing and in-woods). Approximately 23 million dry tons (21 million metric tons) of hardwood logging residues were available in the six-state region, with only 0.9% located in KS (USDA 2015). The maximum annual quantity of hardwood logging residues available across all regions, within an 80-mile (128.7 km) one-way truck haul distance in KS, was a quarter of a million dry tons with the procurement areas predominately located in Missouri (Fig. 5).

The top ten ZCTAs (Figs. 5 and 6) were located in southeast Kansas for both of the hardwood logging residue types (at-landing and in-woods). The ATC per dry ton in the least-cost sourcing areas ranged from \$22.86 to \$24.72 per dry ton (\$25.20 to \$27.25 per metric ton) for at-landing, and from \$146.88 to \$147.36 per dry ton (\$161.94 to \$162.47 per metric ton) for in-woods logging residue. The median MC ranged from \$23.41 to \$26.92 per dry ton (\$25.81 to \$29.68 per metric ton) (Table 1, Fig. 7) for at-landing, and from \$146.47 to \$148.46 per dry ton (\$161.49 to \$163.68 per metric ton) for in-woods logging residue (Table 1, Fig. 7).

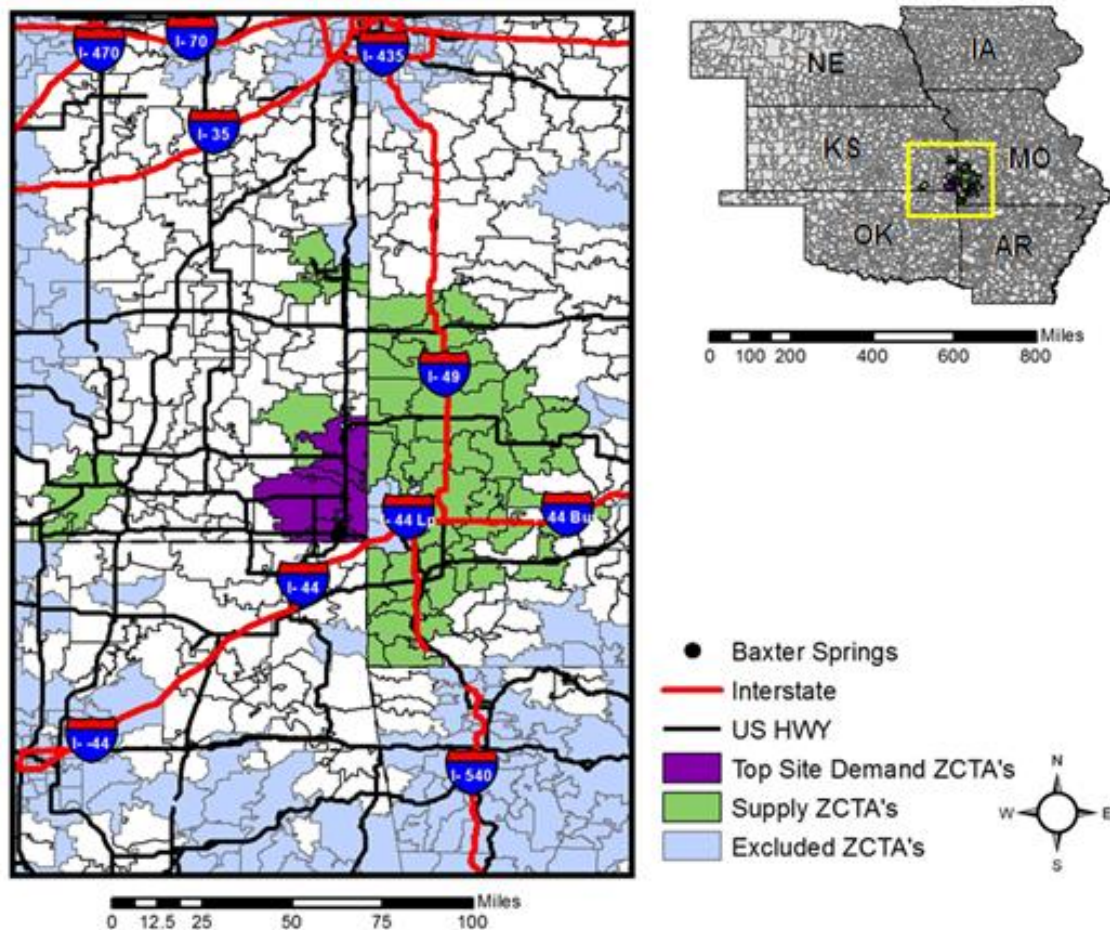


Fig. 5. Least-cost sourcing areas for at-landing hardwood logging residues in KS

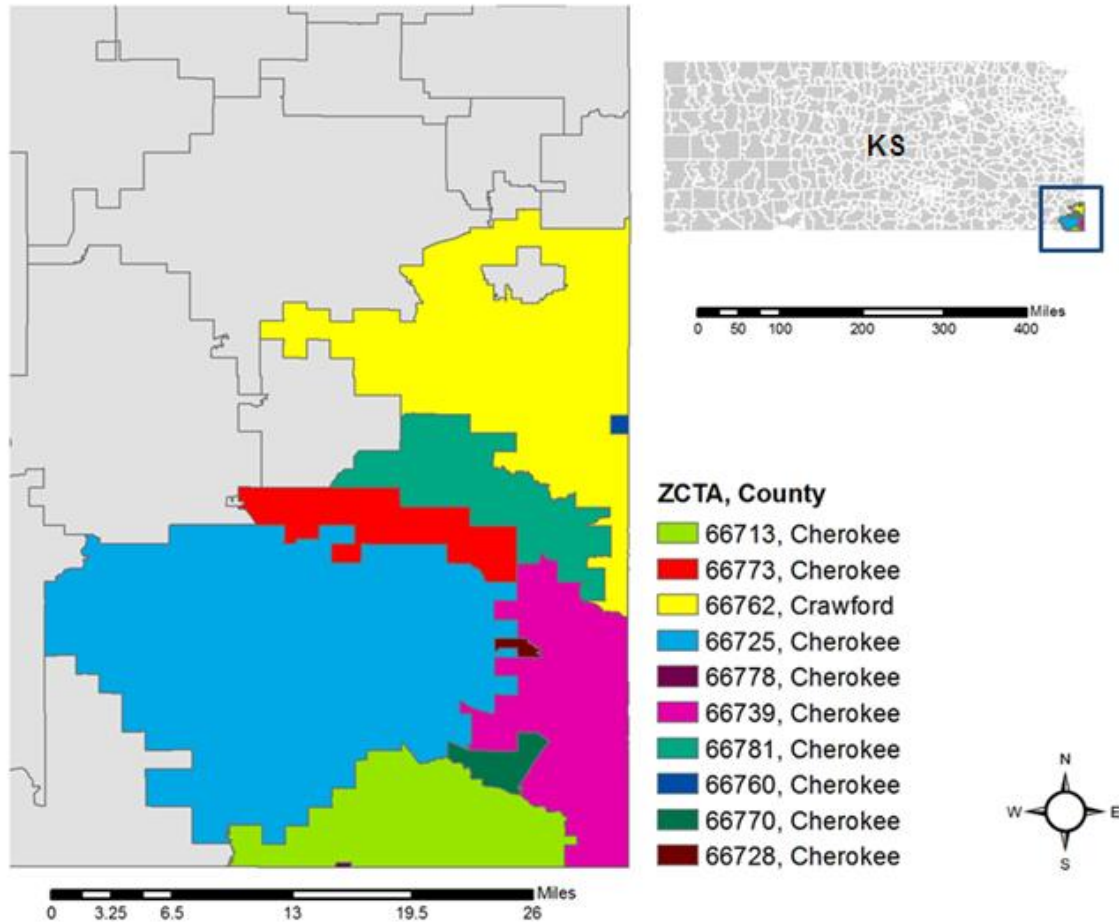


Fig. 6. Top ten demand ZCTAs for at-landing hardwood logging residues in KS

Table 1. Top Ten Locations in KS for At-Landing Hardwood Logging Residues, Based on Average Total Cost per Dry Ton

Demand ZCTA	County	Total Quantity (dt)	Total Cost (\$)	Truck Loads	Number of Supply ZCTA	Average Cost (\$/dt)	Median Marginal Cost (\$/dt)
66728	Cherokee	268,813	6,145,276	21,505	25	22.86	24.14
66770	Cherokee	254,513	5,827,871	20,361	24	22.90	23.41
66760	Cherokee	276,038	6,390,339	22,083	33	23.15	24.15
66781	Cherokee	260,663	6,193,965	20,853	33	23.76	25.48
66739	Cherokee	250,350	5,997,178	20,028	34	23.96	25.52
66778	Cherokee	253,813	6,105,754	20,305	23	24.06	24.68
66725	Labette	250,913	6,041,939	20,073	23	24.08	25.01
66762	Cherokee	278,425	6,726,349	22,274	42	24.16	25.95
66773	Cherokee	269,750	6,619,318	21,580	35	24.54	26.92
66713	Cherokee	253,738	6,272,658	20,299	30	24.72	25.50



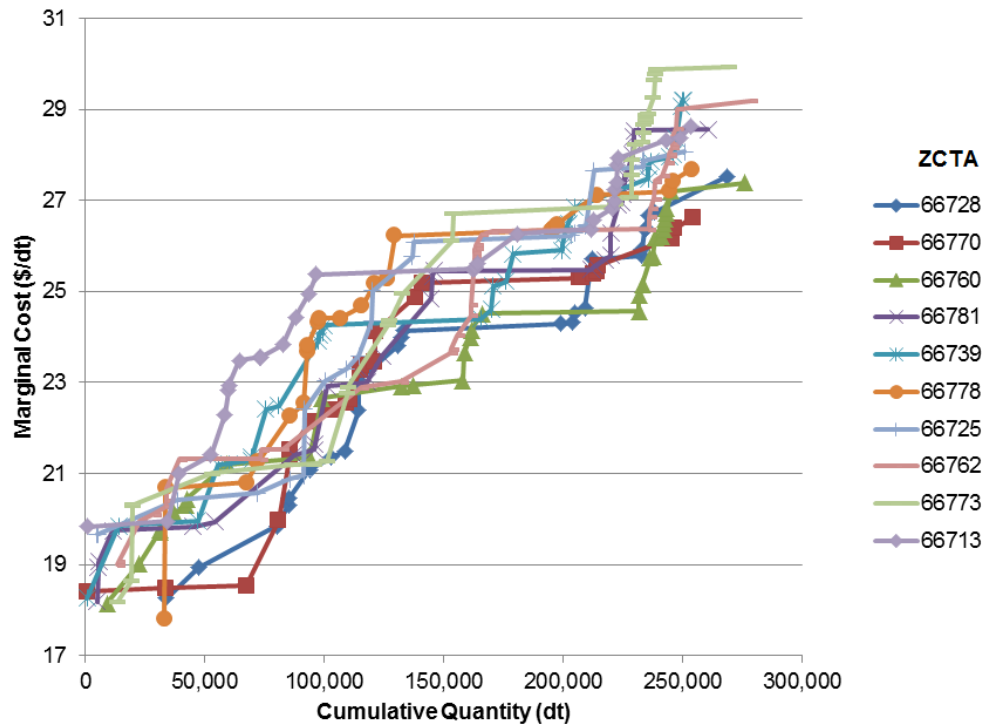


Fig. 7. Marginal cost curves for top ten locations for at-landing hardwood logging residues in KS

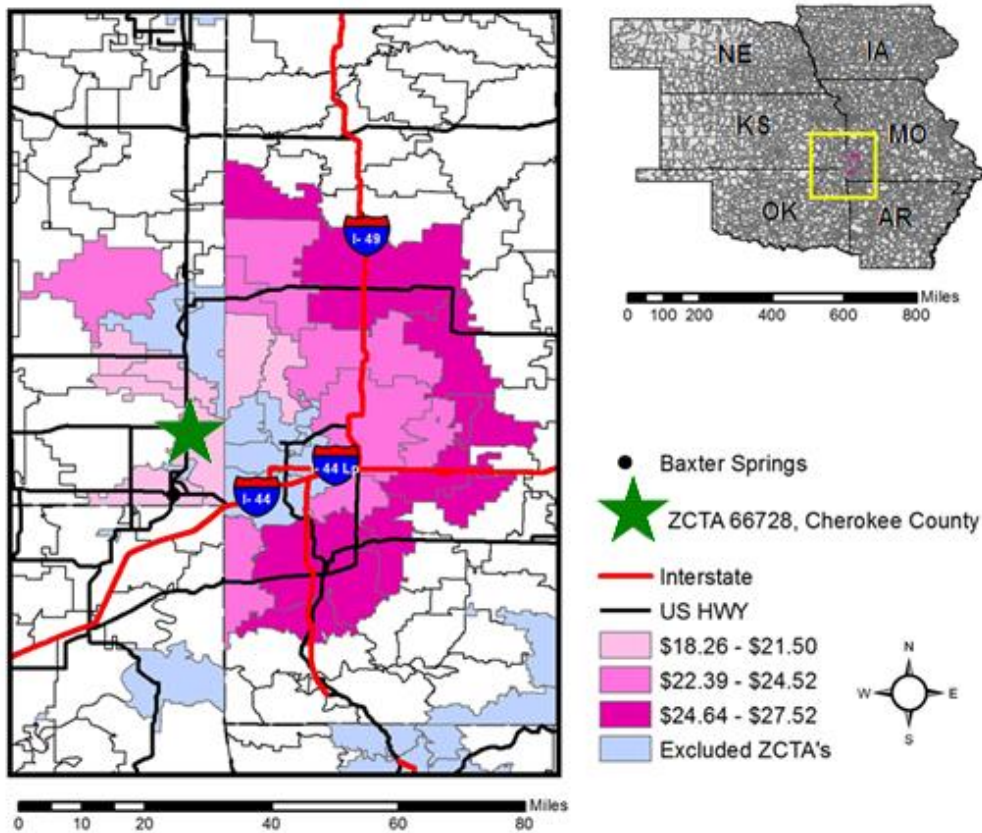
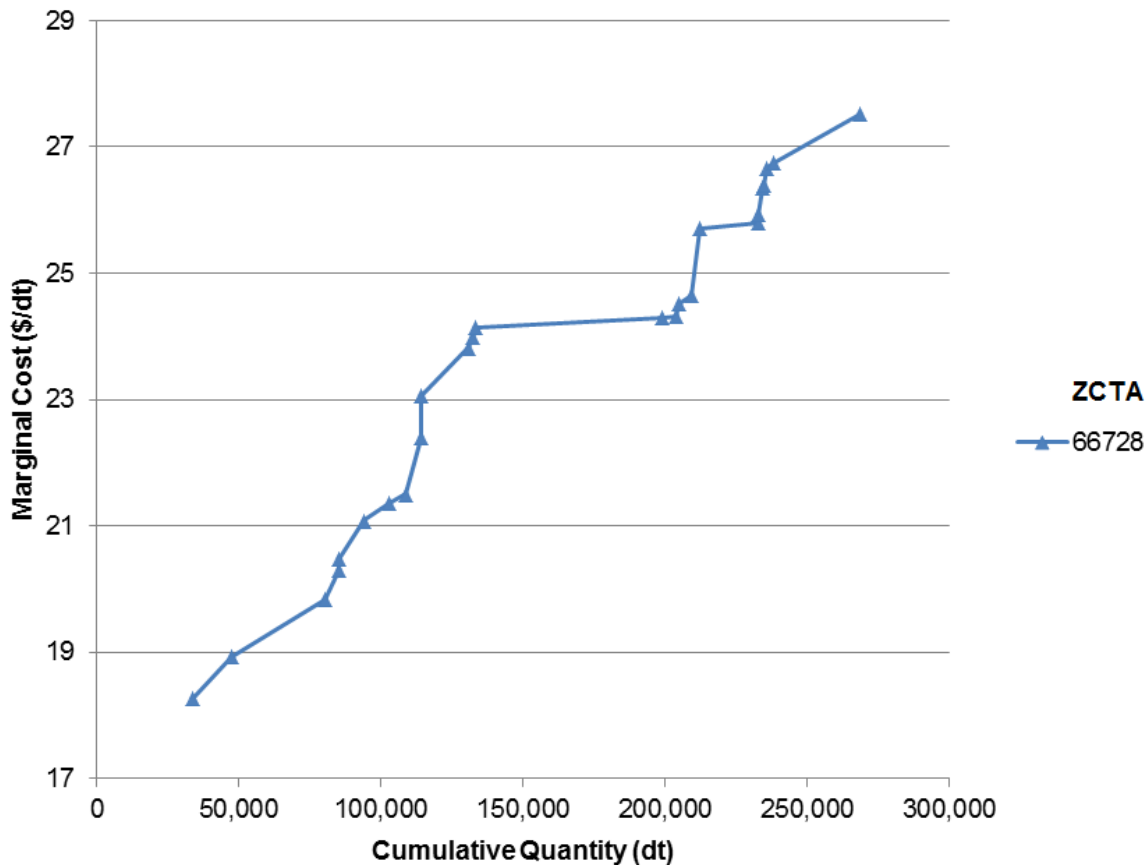


Fig. 8. Least-cost sourcing area for at-landing hardwood logging residues (ZCTA 66728, Cherokee County, KS)

*Least-cost demand ZCTA for at-landing hardwood logging residues*

The demand ZCTA 66728 (Cherokee County, KS) had the least ATC per dry ton of at-landing hardwood logging residues (Table 1). A quarter of a million dry tons of at-landing hardwood logging residues were available within an 80-mile (128.7 km) radius from ZCTA 66728 (Fig. 8). The MC ranged from \$18.26 per dry ton to \$27.52 per dry ton (\$20.13 per metric ton to \$ 30.41 per metric ton) (Fig. 9 and Table 2).



**Fig. 9.** Marginal cost curve for at-landing hardwood logging residues (ZCTA 66728, Cherokee County, KS)

*Least-cost demand ZCTA for in-woods hardwood logging residues*

The same top ten ZCTAs were selected for in-woods, as well as for the at-landing hardwood logging residues, because the analyses were based on the same resource data with the distinct difference in cost components. A quarter of a million dry tons of in-woods hardwood logging residues were available within an 80-mile (128.7 km) radius from ZCTA 66728 (Cherokee County, KS). The MC in the selected least-cost sourcing area ranged from \$136.87 to \$148.85 per dry ton (\$150.90 to \$164.11 per metric ton).

**Upland Hardwood Pulpwood**

The analyses of the six sub-regions of the state of Kansas for upland hardwood pulpwood net growth revealed that the Effingham, Ottawa, and Chanute in the more eastern regions of KS have a larger amount of woody biomass supply available within an 80-mile (128.7 km) one-way truck haul distance, relative to the other three regions (Table 3, Fig. 10).



**Table 2.** Supply ZCTAs for at-landing Hardwood Logging Residues in KS (Demand ZCTA 66728, Cherokee County)

Supply ZCTA	Total Quantity (dt)	Number of Truck Loads	Round Trip (miles)	Harvesting Cost (\$/dt)	Trucking Cost (\$/dt)	Total Cost (\$)	Cumulative Quantity (dt)	Marginal Cost (\$/dt)
74369	33,763	2,701	10.1	12.67	4.59	616,563	33,763	18.26
67351	13,438	1,075	20.4	12.67	5.26	254,379	47,200	18.93
67342	33,038	2,643	30.2	12.67	6.17	655,373	80,238	19.84
67344	4,750	380	33.4	12.67	6.63	96,446	84,988	20.30
67357	263	21	36.1	12.67	6.80	5,373	85,250	20.47
74367	8,575	686	40.9	12.68	7.40	180,788	93,825	21.08
67354	9,075	726	44.7	12.68	7.67	193,753	102,900	21.35
67356	5,813	465	45.3	12.67	7.83	124,974	108,713	21.50
66776	5,438	435	53.7	12.68	8.71	121,733	114,150	22.39
66779	175	14	58.2	12.68	9.38	4,035	114,325	23.06
65723	16,725	1,338	70.1	12.68	10.14	398,343	131,050	23.82
66775	1,413	113	71.6	12.68	10.30	33,869	132,463	23.98
67337	638	51	72.7	12.68	10.46	15,390	133,100	24.14
67341	65,725	5,258	73.7	12.68	10.61	1,596,164	198,825	24.29
67335	5,325	426	75.4	12.67	10.65	129,490	204,150	24.32
67336	700	56	75.6	12.68	10.84	17,161	204,850	24.52
65654	4,375	350	79.5	12.68	10.96	107,799	209,225	24.64
74331	3,063	245	88.8	12.68	12.03	78,749	212,288	25.71
74332	20,575	1,646	91.8	12.68	12.11	530,619	232,863	25.79
64752	250	20	89.4	12.68	12.25	6,482	233,113	25.93
65756	1,113	89	96.1	12.68	12.67	29,313	234,225	26.35
65707	638	51	99.7	12.68	12.71	16,825	234,863	26.39
74330	813	65	101.2	12.68	12.98	21,662	235,675	26.66
74301	2,438	195	100.5	12.68	13.06	65,168	238,113	26.74
74360	30,700	2,456	109.2	12.68	13.84	844,826	268,813	27.52

**Table 3.** Summary of Six US Forest Service FIA Sub-Regions in the State of Kansas

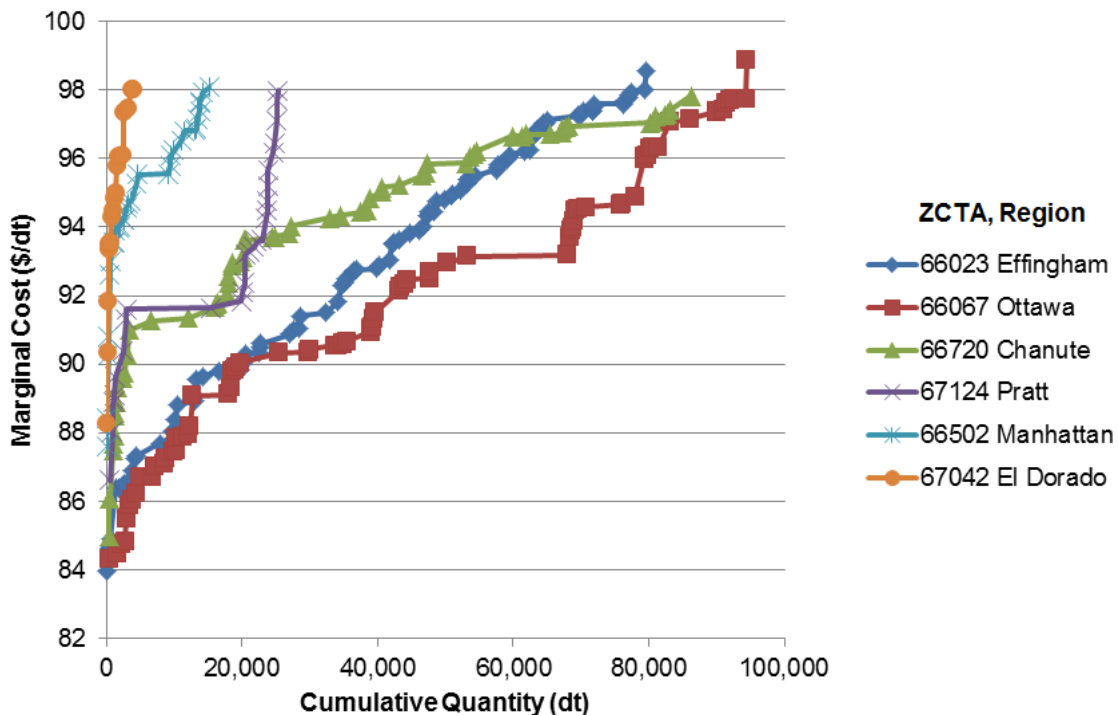
Region	ZCTA	Total Quantity (dt)	Number of Supply ZCTA	Minimum Marginal Cost (\$/dt)	Maximum Marginal Cost (\$/dt)	Range	Average Cost (\$/dt)
Effingham	66023	79,650	93	83.98	98.57	14.59	92.79
Ottawa	66067	94,425	75	84.31	98.85	14.54	91.71
Chanute	66720	86,213	66	84.97	97.81	12.84	93.35
Pratt	67124	25,325	28	86.62	97.97	11.35	92.83
Manhattan	66502	15,188	32	87.59	98.08	10.49	94.73
El Dorado	67042	4,000	17	88.27	98.00	9.73	94.60

The Effingham region has the least MC per dry ton for upland hardwood pulpwood net growth, with procurement areas extending to Kansas, Missouri, and Nebraska. The ZCTA 66023 (Atchison County, KS) was the least-cost demand ZCTA in the Effingham region.

There are 93 supply ZCTAs within an 80-mile (128.7 km) radius from the ZCTA 66023 (Fig. 11) with an available cumulative annual quantity supply of 79,650 dry tons (72,242 dry metric tons) for upland hardwood pulpwood net growth. The MC for upland hardwood pulpwood net growth in the Effingham region ranged from \$83.98 to \$98.57 per dry ton (\$92.59 to \$108.68 per dry metric ton), while it ranged from \$86.62 to \$97.97 per dry ton (\$95.50 to \$108.02 per dry metric ton) in the Pratt region. It ranged from \$84.31 to \$98.85 per dry ton (\$92.95 to \$108.99 per dry metric ton) in the Ottawa region, and from \$87.59 to \$98.08 per dry ton (\$96.57 to \$108.14 per dry metric ton) in the Manhattan region.

The MC ranged from \$88.27 to \$98.00 per dry ton (\$97.32 to \$108.05 per dry metric ton) in the El Dorado region, and from \$84.97 to \$97.81 per dry ton (\$93.68 to \$107.84 per dry metric ton) in the Chanute region (Table 3, Fig. 12).

The cost estimates of this study were slightly higher in nominal dollars than those (\$72.10 per dry ton [\$79.49 per dry metric ton] with a maximum cost of \$78.76 per dry ton [\$86.84 per metric ton]) reported for Arkansas by Stokes (1992). However, this study had lower cost estimates by approximately 25%, when compared in real dollars to the study by Stokes (1992). This study also had a much more detailed transportation model than that of Stokes (1992).



**Fig. 10.** The marginal cost curves for upland hardwood pulpwood net growth, analyses for six US Forest Service FIA sub-regions in the state of Kansas

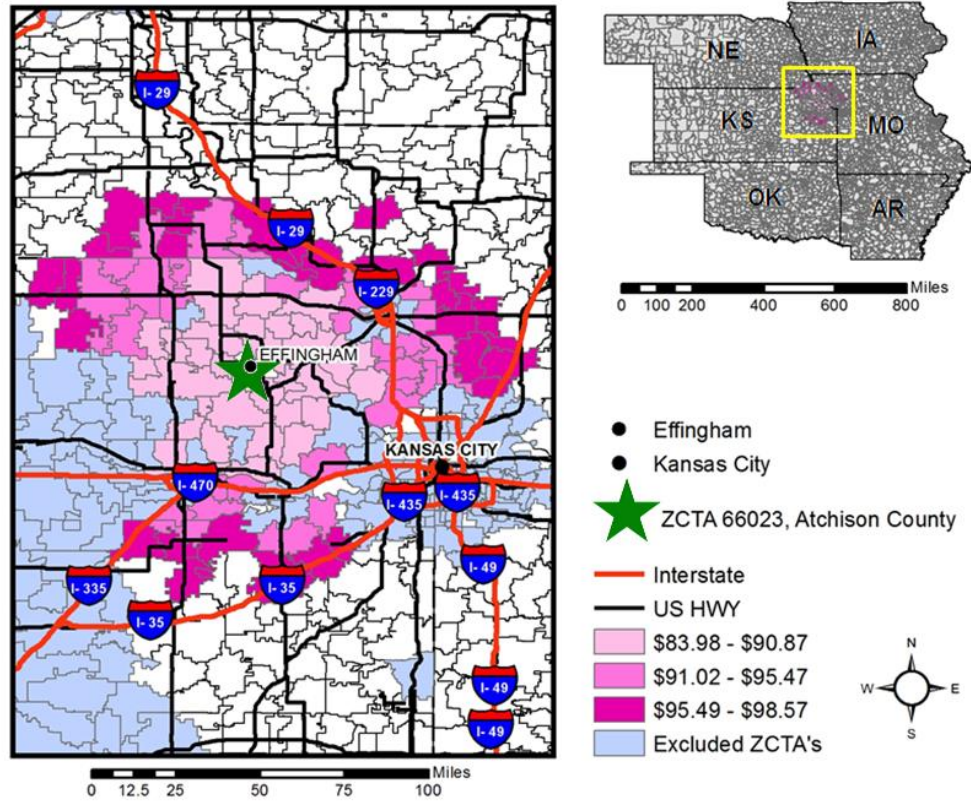


Fig. 11. The least-cost sourcing area for upland hardwood pulpwood net growth (ZCTA 66023, Atchison County, KS), relating to the Effingham region

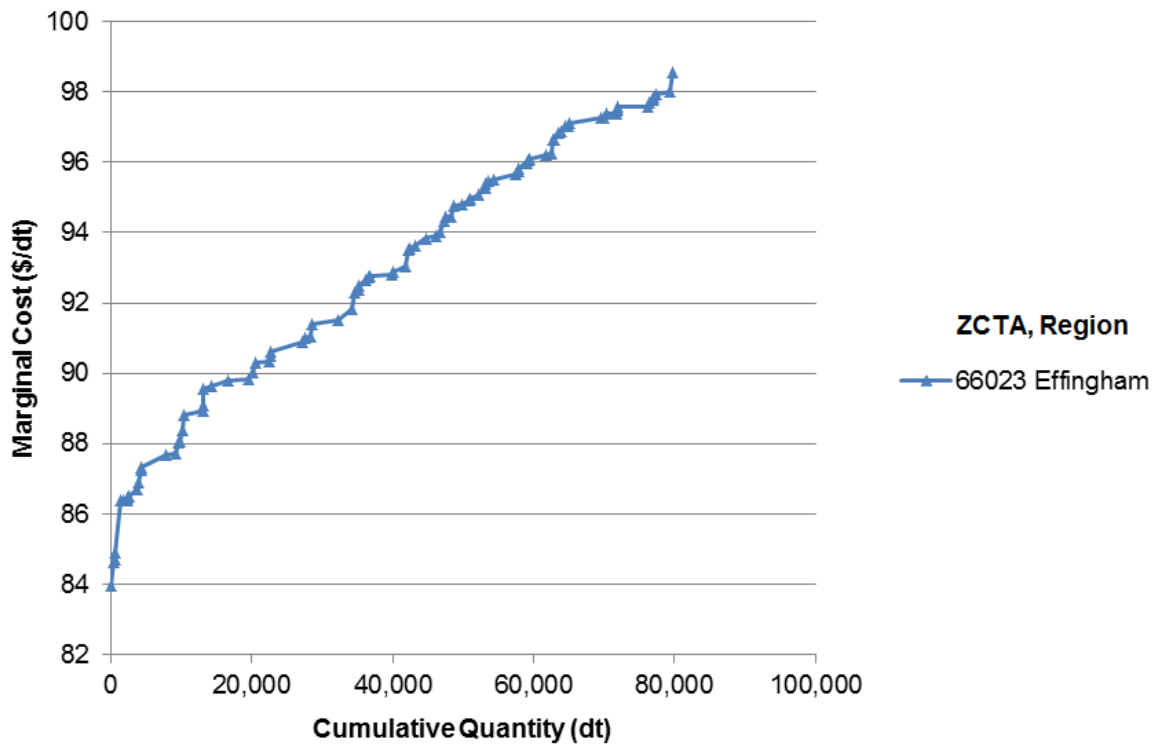


Fig. 12. Effingham Region. Marginal cost curve for upland hardwood pulpwood net growth (ZCTA 66023, Atchison County, KS)

## CONCLUSIONS

1. This study improves the overall understanding of the economic costs of cellulosic feedstocks for potential manufacturers wishing to invest in the state of Kansas.
2. It provides decision-makers in the cellulosic feedstock-using industries with a better geospatial economic web-based tool that allows them to assess the economic comparative advantages of cellulosic supply from procurement zones within KS and from five surrounding states.
3. The KS BioSAT model may provide a useful template for other research conducted on the economic supply of woody biomass.
4. Least cost ZCTAs for at-landing and in-woods hardwood logging residue types were found in Southeastern Kansas. The average total costs in the areas were very similar with minimum of \$22.86 per dry ton and maximum of \$24.72 per dry ton for at-landing hardwood logging residue. The costs for in-woods logging residue were much higher, as was expected, and ranged from \$146.88 to \$147.36 per dry ton. Least cost ZCTA for upland hardwood pulpwood in the six KS sub-regions was found in Effingham region, Northeastern Kansas. Marginal costs in the region ranged from \$83.98 to \$98.57 per dry ton of upland hardwood pulpwood and were slightly higher in nominal dollars than those (\$72.10 to \$78.76 per dry ton) reported for Arkansas by Stokes (1992).

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