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GIS-based Approach of Identification of the Optimal Pulpwood-to-Biofuel Facility Location in Michigan's Upper Peninsula

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Abstract

One of the critical elements for promoting ethanol production from woody biomass is defining the optimal ethanol plant location. The woody biomass feedstock and transportation costs are geographically dependent. A Geographic Information System (GIS) based approach was applied to identify potential pulpwood-to-biofuel facility locations. The approach uses a county-based

pulpwood distribution, a population census, and railroad and state/federal road transportation networks. The preferred location will be selected using a weighted-average transportation cost.

Keywords: GIS, biomass, biofuel, transportation cost, optimal facility location

Introduction

To reduce dependence on imported fossil fuels and to mitigate greenhouse gas (GHG) emissions, the United States (U.S.) is pursuing several efforts to exploit renewable biomass to produce biofuels as an alternative for transportation fuel. This is one of several possible options. The U.S. Department of Agriculture (USDA) and the U.S. Department of Energy (DOE) Biomass Research and Development Technical Advisory Committee members envisioned the potential of a 30% replacement of the present consumption level of petroleum products with biofuels in the U.S. by 2030 (Perlack et al., 2005). A joint biofuels systems analysis project, “90-Billion Gallon Biofuel Deployment Study”, conducted by Sandia National Laboratories and General Motors’ Research and Development Center between March and November 2008, assessed the feasibility, implication, limitations, and enablers of large-scale production of biofuels in the U.S. Based on a series of analyses, the research teams concluded that producing 90 billion gallons of biofuels from biomass each year in the U.S. is feasible. The sensitivity analyses also demonstrated that cellulosic biofuels can compete with oil at a reasonable price based on specific assumptions

(West et al., 2009). Forest biomass is geographically dependent and the location of a biofuel facility significantly influences the delivery cost. Selection of the best location for a processing facility becomes a critical element for cost-effective biofuel production.

A methodology using two-phases for identifying the optimal facility location for biofuel production from forest biomass was developed. Phase I used Geographic Information System (GIS) to identify potential pulpwood-to-biofuel facility locations in a study area. The GIS analysis considers such factors as a county-based pulpwood distribution, a population census, and railroad and state/federal road transportation networks. In phase II, the Public Land Survey System (PLSS) was used to generate a one-square-mile grid system as the minimum analysis unit. A weighted-average transportation cost model that utilized a transportation cost model was developed. The optimal site for biofuel production will be identified through the use of the two-phase methodology.

The literature review summarizes some of the key research findings regarding the selection of the optimal plant location. Gaps in the current research have been identified and serve as the basis for the development of the proposed two-phase selection methodology.

Literature Review

GIS is considered an effective tool to address issues related to biomass availability and cost, and issues related to bioenergy facility locations (Graham et al., 2000). Graham et al. (2000) applied GIS using a state-level modeling system for estimating regional geographic variations on energy crop feedstock costs and supplies (farmgate and delivered), and environmental effects of switching from conventional crops to energy crops. Haddad and Anderson (2008) applied GIS to identify potential supply locations of corn stover for bioenergy production. Voivontas et al. (2001) estimated the biomass potential for power production from agriculture scraps based on GIS.

Selected components of GIS have been employed to optimize biofuel production. Noon et al. (2002) proposed an algorithm for generating a marginal price (maximum delivered cost) surface and applied this methodology to identifying potential ethanol production plant locations. Panichelli and Gnansounou (2008) took into account site competition for biomass resources and developed a methodology for farmgate price calculation.

In previous research, different biomass feedstocks were used to produce biofuels and bioproducts. The most commonly used biomass feedstocks are agricultural residues (e.g., corn stover and wheat straw), energy crops (e.g., short rotation woody crops (SRWC) and

switchgrass), and forest residues. In this study, pulpwood, which has been primarily used by paper mills, was the feedstock for biofuel production. Because of the declining demand for pulpwood by the paper products industry (Ince, 2001), this is an alternative use for a readily available woody biomass feedstock. Based on the gaps identified in the literature review, a two-phase methodology was developed and will be described in the next section.

Methodology

The methodology consists of two phases of analysis: (1) identify potential pulpwood-to-biofuel facility locations based on a GIS approach (phase I), and (2) selection of the optimal biofuel facility location based on a weighted-average transportation cost model (phase II). Figure 1 outlines the steps in each phase and shows the relationship between the two phases.

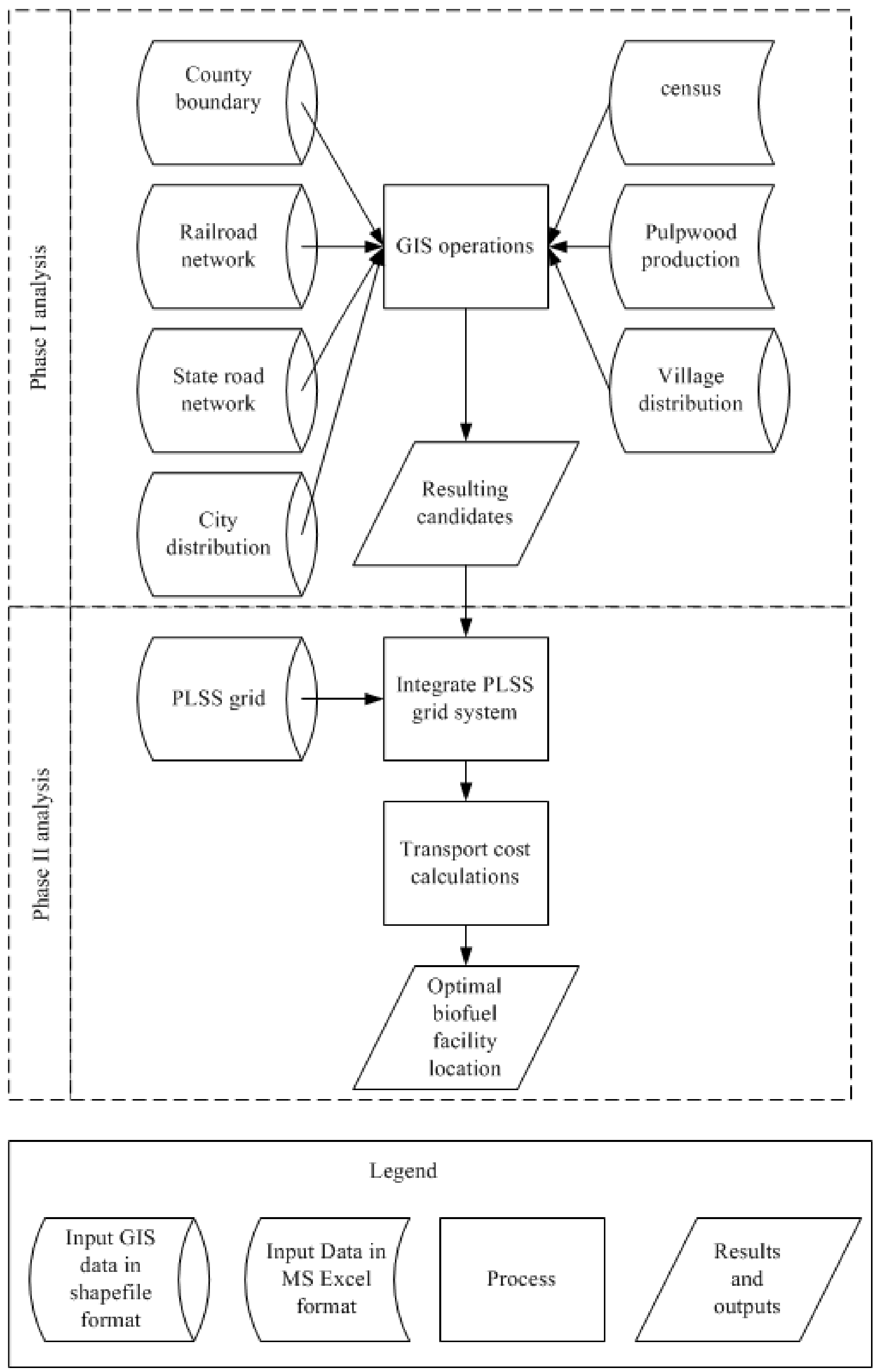

Figure 1 Overview of methodology

GIS Identification of Potential Locations for Pulpwood-to-Biofuel Facilities

In phase I (Figure 1), GIS is used to identify potential pulpwood-to-biofuel facility locations. The required data for the GIS analysis included seven categories: county boundary, railroad transportation network, state/federal road transportation network, city distribution, village distribution, population census, and pulpwood production.

Prior to analysis, it is necessary to make several assumptions regarding the application of GIS:

- The unit of measure of pulpwood is commonly in million cubic feet. A conversion factor of 30 lb per cubic feet is used.
- Only one percent of pulpwood production is available for biofuel production. The one percent assumption of pulpwood used for biofuel production is based on the consideration of sustainable harvesting of forest resources and competition for the raw material from other biofuel and bioproducts industries and the pulp and paper industries.
- Because the pulpwood production information is county-based, a uniform distribution was used to describe pulpwood production within each county.
- The biomass conversion plant has a medium capacity production of 50 million gallons of biofuel per year (Tembo et al., 2003).

- Based on a conversion yield of 80 gallons/dry ton of biomass (Aden et al., 2002), the biofuel facility will have a demand for approximately 700,000 dry tons of feedstock per year.
- The trucking distance (haul radius) is 50 miles or less, with the biofuel facility location at the center of the biomass harvesting area.
- The biofuel facility is accessible to state/federal road or railroad transportation networks (i.e., the facility is within one mile of a network). This guarantees the input (pulpwood feedstock) and output (biofuel products) can be easily transported.
- The biofuel facility will be located in a city or village with a population greater than 1,000 to ensure that enough workers are available for the plant.

After the assumptions were made, the GIS operations involved in identification of potential locations for pulpwood-to-biofuel facilities are detailed. GIS operations are the central part of the methodology of the first phase of the analysis. The operations consist of the 7 steps described below.

1) Create a geodatabase to include all input features used for analysis;
2) Join pulpwood information to counties;
3) Calculate tons per square mile within each county;

4) Join population census information to cities and villages;

5) Build a one-mile buffer around state/federal roads and railroads;

6) Select cities and villages within the state/federal roads and railroads buffer;

7) Select cities and villages with a census population greater than 1,000.

After completing the phase I analysis, additional information is available to complete phase II of analysis.

Determining the Optimal Biofuel Facility Location

The objective of phase II (Figure 1) of analysis is to identify the best location for biofuel production from forest biomass. A preliminary selection of potential sites was performed in phase I based on the GIS approach by examining a series of decision factors. Potential sites identified from phase I, including cities and villages, were transferred into point geometry that represent demand points. The PLSS[1] grid system (1 mile x 1 mile) was used as the minimum information unit over the study area. A weighted-average transportation cost model was

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[1] PLSS was developed by the Land Ordinance of 1785 and is a method used in U.S. to survey and identify land. Its basic units of area are the township and section. The PLSS typically divides land into 6-mile-square townships. Townships are subdivided into 36 one-mile-square sections.

developed. The optimal site for biofuel production from forest biomass was identified to be the one with the minimum weighted-average transportation cost.

Transportation Cost Model

The transportation cost model used for the analysis was developed by Hicks et al. (2009). Three companies from Michigan were investigated for their tariff rate structures and used to develop the model for the Upper Peninsula (U.P.) of Michigan. All of the U.P. tariff rates were converted to dollars per ton and plotted against transportation distance. Linear regression was used to fit a line to the U.P. tariff rate data. Equation **Error! Reference source not found.** provides the transportation cost $C_{T,}$ in dollars per mile per ton:

$$C_T = 3.89 + 0.067 * d + 0.0114 * (C_F - 2.67) * d \quad (1)$$

where C_T is the one-way transportation cost ($/ton) from a supply point to a demand point, d is the one-way transportation distance (miles) from a supply point to a demand point, and C_F is the fuel price ($/gallon). The coefficient of determination for the fitted line was $R^2 = 0.9703$. The equation consists of three components: base cost, mileage cost, and fuel cost differential. The base cost rate of $3.89/ton covers the cost of loading and unloading.

The fuel cost differential term arises because the average fuel cost of $2.67/gal, as was the case in Oct 2009, will not be the case in general. If the fuel cost rate is indeed $2.67/gal, the one-way transportation cost, C_T, simplifies to:

$$C_T = 3.89 + 0.067 * d \qquad (2)$$

The transportation cost model was used in the section below to build the weighted-average transportation cost model.

Weighted-Average Transportation Cost Model

Candidate facility locations are referred as demand points (j = 1, 2, 3, …, m). Take one demand point for example, the 50-mile biomass harvesting area for the demand point is divided into n cells (the area of each cell is one square mile). A pixel is placed at the centroid of each cell, and this pixel serves as the supply point for the cell. Associated with each supply point i (i = 1, 2, …, N) is the quantity (Q_i) of pulpwood available. The quantity of pulpwood Q_i is calculated as:

$$Q_i = \frac{Q_c * A_i}{A_c} \qquad (1)$$

where Q_c is the total quantity of pulpwood available in a county, A_i is the area of cell or pixel i, and A_c is the area of a county.

The Euclidean distance is calculated between any pair of supply and demand points and used as the distance in the transportation cost model. A per unit transportation cost C_{ij} is calculated using

the transportation cost equations. The transportation costs are sorted from the lowest to the highest. The available quantity of biomass Q_i at each supply point is summed (S_j) beginning with the lowest transportation cost until the sum meets or exceeds 700,000 tons. When this condition is met, D_j is set equal to S_j (Equation (2)).

$$D_j = S_j = \sum_{i=1}^{n} Q_i \tag{2}$$

where Q_i is the available quantity of biomass at each supply point, S_j is the total quantity biomass available from the n supply points, and D_j is of the amount of biomass feedstock required at each demand point. The weighted-average transportation cost $C_{avg}(j)$ is calculated in Equation **Error! Reference source not found.**, i.e., the transportation cost is weighted by the available biomass at each supply point.

$$C_{avg}(j) = \frac{\sum_{i=1}^{n} \left(C_{ij} * Q_i\right)}{D_j} \tag{3}$$

where C_{ij} is per unit transportation cost ($/ton) and $C_{avg}(j)$ is weighted-average transportation cost ($/ton).

The weighted-average transportation distance, $L_{avg}(j)$, is calculated in Equation (4):

$$L_{avg}(j) = \frac{\sum_{i=1}^{n} \left(L_{ij} * Q_i\right)}{D_j} \tag{4}$$

where L_{ij} is the Euclidean distance between any supply point i and any candidate facility location j.

Summary and Conclusions

A two-phase methodology to identify the optimal facility location for biofuel production from forest biomass was developed. Phase I used GIS to identify potential pulpwood-to-biofuel facility locations in a study area. The GIS analysis considers such factors as a county-based pulpwood distribution, a population census, and railroad and state/federal road transportation networks. In phase II, the PLSS was used to generate the one-square-mile grid system as the minimum analysis unit. A weighted-average transportation cost model was developed. The optimal site for biofuel production will be identified as the one with the minimum weighted-average transportation cost.

Further Research

The methodology developed in this study will be applied in a case study: Michigan's Upper Peninsula, to identify the best location for biofuel production from forest biomass. Different types of sensitivity analysis will be conducted to identify the impacts of different parameters on the results, especially to identify the parameters that most influence the decision.

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