BIOMASS AND BIOENERGY 55 (2013) 339–349

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GIS-BASED location optimization of a biomass conversion plant on contaminated willow in the Campine region (Belgium)

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ARTICLE INFO

Article history:
Received 3 February 2012
Received in revised form
22 February 2013
Accepted 23 February 2013
Available online 13 March 2013

Keywords:
Willow
Phytoremediation
Biomass transport
Euclidian distance
Tractor-trailer
Location optimization

ABSTRACT

The Campine region is diffusely contaminated with heavy metals like cadmium. Since traditional excavation techniques are too expensive, phytoremediation is preferred as a remediation technique. In a previous study, the biomass potential from phytoremediation of contaminated agricultural land in the Campine region in Belgium was assessed. Based on recently upgraded figures of willow potential from phytoremediation on agricultural land in the seven most contaminated municipalities of the Belgian Campine region, the current paper uses GIS-knowledge to investigate which of three previously identified locations is most suitable for a biomass plant, taking into account the spatial distribution of the contaminated willow supply and the total cost of willow transport.

Biomass transport distance from the centroid of each contaminated agricultural parcel to each of the three potential biomass plant locations was determined following Euclidian distance calculations and distance calculations over the existing road network. A transport cost model consisting of distance fixed and distance dependent biomass transport costs was developed.

Of the locations identified, the Overpelt Fabriek site results in the lowest biomass transport distance and costs. When willow allocation for each parcel occurs based on the nearest potential plant location, transport costs are on average 23% lower than when all biomass is transported to the single Overpelt Fabriek site location. Therefore, when only considering transport costs, installing a smaller plant at each of the three potential plant locations would be less expensive than when installing a single biomass plant at the Overpelt Fabriek site.

1. Introduction

Phytoremediation uses biomass crops to clean up moderately contaminated soils by removing pollutants from the environment or by rendering them harmless [1]. The application of phytoremediation has two purposes. First of all, the soil is decontaminated by the plants. Concurrently, the crops cultivated during the remediation period can be used as a

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http://dx.doi.org/10.1016/j.biombioe.2013.02.037

biomass resource for the production of bioenergy [2]. Following [3,4], it is expected that a significant contribution to reaching the EU 20-20-20 targets will come from biomass, which is the most abundant and versatile form of renewable energy in the world.

Numerous studies have assessed the optimal location of a biomass plant at a regional [5–12] and a national scale [13–15]. Irrespective of scale and methods applied, the location optimization process is usually performed by means of a Geographic Information System (GIS). GIS can be considered as a useful tool to combine spatial information with statistical data in order to attain an integrated visual representation of different kinds of information. For example, GIS allows displaying simple statistical summaries and data plots in map format to illustrate the results more effectively than the traditional way of reporting [16].

Viana et al. [14] used GIS-data to calculate, by determining the optimal biomass collecting area radius, and map the forest biomass potential in order to identify the optimal location of 13 new biomass power plants in Portugal. A different approach was followed by Herrera-Seara et al. [6] who conducted a multi-criteria analysis to determine the optimal location of a biomass power plant in the Spanish province of Granada by using a GIS-system according to the analytic hierarchy process. Freppaz et al. [7] combined GIS techniques with mathematical programming methods to optimize the location and size of biomass plants. A similar combination was made by Velazquez-Marti and Fernandez-Gonzalez [10] to determine optimal biomass plant locations. Schmidt et al. [15] assessed combined heat and power (CHP) potential of biomass in Austria by considering a mixed integer programming (MIP) model that optimizes locations of bioenergy plants. Wu et al. [9] developed a MIP model to identify eleven possible biomass plant locations in the central Appalachian hardwood region.

In literature different factors influencing the location optimization process are considered. Leduc et al. [13] considered biomass cost, biomass availability and the district heating price as crucial factors for the optimal positioning of lignocellulosic ethanol refineries in Sweden. Velazquez-Marti and Fernandez Gonzalez [10] identified the amount of consumption of the energy produced and the cost of biomass transport as the most important criteria to determine the optimal sites for biomass plants. Herrera-Seara et al. [6] considered energy potential, biomass availability, highway knots accessibility and natural areas protection as the four main criteria to identify the optimal location of a biomass power plant in the Spanish Province of Granada. Perpina et al. [8] located a network of bioenergy plants around the community of Valencia depending on technical, economic, environmental, legal and social constraints. To perform the bioenergy plant location optimization in Austria, Schmidt et al. [15] regarded the spatial distribution of biomass supply and the cost of biomass transport as two key factors. In this paper spatial biomass distribution and biomass transport costs are the two factors considered in the location optimization process.

To assess the feasibility of biomass plants, the geographic distribution of biomass is an important factor. Since biomass is spatially distributed [17–20], the associated collection and transport costs are major bottlenecks for the success of biomass energy conversion [17]. Perpina et al. [8] consider the poor geographic distribution of biomass for retrieval and transport as a major drawback of the use of biomass for energy production. Singh et al. [17] suggest properly planning and the development of a proper methodology as key activities to reduce collection and transport costs resulting from geographically scattered biomass. To implement a successful bioenergy programme, a precise estimation of the scattered biomass at both spatial and temporal level is required [20].

The cost of moving biomass is a key component of the overall cost of recovering energy from biomass [18,21]. This statement was confirmed by Möller and Nielsen [19] who found out that biomass transport costs compromise on average 20% of the delivered biomass costs, making them an important contributor to the cost chain. In a study of Spinelli et al. [22], transport was the most extensive work task of the delivery of root biomass from poplar. It accounted for 40% of the total poplar recovery cost. Transport costs can even be up to 76% of total system operational costs [23].

An important framework for biomass transport cost calculation was given by Börjesson and Gustavsson [24] in 1996. The model treated transport costs as a function of transport distance for various types of biomass including willow and various transport modes including tractor-trailer. Tractors and trucks were found to be most cost efficient for shorter distances, and trains and boats for longer distances. The model did not take into account any discounts or special agreements. Furthermore, it was quite unclear which activities were assumed to be a part of the transport process.

More recent literature agrees on the division of transport costs in distance fixed and distance dependent costs [11,18,21]. According to Alfonso et al. [11] distance fixed costs, which are independent of the distance traveled, consist of costs due to loading, unloading and compaction activities. Following Searcy et al. [21] distance fixed costs equal loading and unloading costs. Distance fixed costs depend on the type of biomass being transported and the equipment and contractual arrangements involved which both are case specific. Distance variable costs, which vary with the distance traveled, are fuel costs and operation and maintenance costs [11]. Distance variable costs depend on the transport mode and the specific location [21]. An extensive biomass transport cost model was developed by Singh et al. [18]. In this model transport costs per load are divided into distance variable fuel and lubricant costs, with a different fuel consumption between the loaded outward journey and the empty return trip, distance fixed costs, operational and maintenance costs and labor costs.

In order to determine biomass transport distance some literature appeals to Euclidian distance calculation [13,15,25] while other literature [8,12] appeals to transport distance calculation over the existing road network. In this paper, both Euclidian biomass transport distance and biomass transport distance over the existing road network in the study area is calculated using the 'Network Analyst' extension of ArcGIS 10.0. This extension is a powerful tool to perform a network-based spatial analysis.

To summarize, this paper aims to identify which of three previously identified potential locations is the most suitable for a biomass plant provided by contaminated willow