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BIOMASS & BIOENERGY

Using spatial information technologies to select sites for biomass power plants: A case study in Guangdong Province, China

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ARTICLE INFO

Article history:
Received 8 September 2006
Received in revised form
5 June 2007
Accepted 6 June 2007
Available online 15 August 2007

Keywords:
Biomass estimation
Site selection
Transportation cost
Remote sensing
Geographical information systems
Supply area

ABSTRACT

Biomass is distributed over extensive areas. Therefore, transportation cost is a critical factor in planning new biomass power plants. This paper presents a case study of using remote sensing and geographical information systems (GIS) to evaluate the feasibility of setting up new biomass power plants and optimizing the locations of plants in Guangdong, China. In this study, the biologically available biomass was estimated from MODIS/Terra remote sensing data. The amount of biomass that is usable for energy production was then derived using a model incorporating factors including vegetation type, ecological retaining, economical competition, and harvest cost. GIS was employed to define the supply area of each candidate site based on transportation distance along roads. The amount of usable biomass within the supply area was calculated and optimal sites were identified accordingly. This study presents a procedural framework for taking advantage of spatial information technologies to achieve more scientific planning in bioenergy power plant construction.

1. Introduction

Biomass energy has been considered a successful alternative to fossil fuels [1,2]. Unlike fossil fuels, however, biomass is distributed over extensive areas. Thus the transportation cost becomes a critical factor in planning new biomass power plants [1–4]. Transportation costs can be reduced by optimizing the locations of power plants. Spatial information technologies, particularly remote sensing and geographical information systems (GIS), can be highly helpful in evaluating the feasibility of setting up new biomass power plants in a given region and optimizing their locations.

Remote sensing can be used to efficiently locate biomass over vast areas. For example, Baath et al. [5] used Landsat 5 TM and SPOT 2 images, with reference to the national forest inventory, to estimate the current and future forest fuels in two areas in Sweden. As a matter of fact, within the field of remote sensing a vast literature exists for land-use/land-cover classification and net primary production (NPP) estimation, which can be integrated to estimate biomass energy

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doi:10.1016/j.biombioe.2007.06.008

potential for different land-cover classes. This can be done in two ways: (1) by applying pre-determined "available biomass" values to each land-cover unit [5] and/or (2) by applying standard NPP-to-available biomass ratios to each land-cover unit [6]. In the first case, the assumption is made that variability in available biomass occurs spatially but not temporally (i.e., is determined by the land cover and is not influenced temporally by climate). The second method incorporates temporal variability (such as that due to drought or shifts in the success of agricultural management) in addition to spatial variability. Note that for agricultural land supporting annual crops, annual NPP is equivalent to the standing biomass at the time of harvest.

GIS, on the other hand, is a powerful tool to integrate data of various factors and to perform spatial analyses for feasibility evaluation and location optimization. Noon and Daly's BRAVO (The Biomass Resource Assessment Version One) might be the first GIS-based decision support system in the biomass energy sector [1]. The authors of BRAVO found that transportation accounted for a major part of the overall cost, and thus power plant location is crucial to the feasibility of converting coal-fired power plants into co-firing plants (plants using both coal and biomass as the fuel source). Since then, quite a few studies have been done on site selection for biomass power plants [e.g., 2–4,7]. Generally, site selection in this field has taken two approaches: suitability analysis and optimality analysis. Suitability analysis mainly uses geoprocessing procedures (e.g., buffer and overlay) to locate *suitable* sites based on a number of constraining and favoring factors (e.g., land use, distance to roads, distance to transmission line, etc.). Ma and Scott [7] used this analysis to locate the best sites for new power plants that utilize manure resources in New York State. The highlight of their work is the use of analytic hierarchy process for weighting different factors. Optimality analysis, on the other hand, considers the relationship between biomass and power plants similar to that between supply and demand in business and aims at finding the optimal power plant locations that minimize the transportation cost. In practice, the final decision should be based on both *suitability* and *optimality*. The work of Voivontas et al [2] for utilizing agricultural residues on the island of Crete attempted to achieve that combination.

The potential of spatial information technologies in the biomass energy sector has received considerable attention, but there is a general deficit of exemplar case studies illustrating the comprehensive process beginning from a biomass survey using remote sensing and ending at a site selection using GIS. This paper presents such a case study in Guangdong Province, China. The case study started with mapping the biologically available biomass in Guangdong using the widely available MODIS/Terra and TM remote sensing data. It ended with identifying, using GIS, a few most optimal locations for setting up new biomass power plants in the province. In between the biomass estimation using remote sensing data and the site selection using GIS, a generic model was employed to estimate the amount of biomass that is eventually *usable* for energy production at a specific location. The construction of this model was inspired by the work of Voivontas et al [2] that classifies biomass into four sequential potential levels—theoretical, available, technological, and economical. The model used in this study adjusts the *biologically available* biomass by ecologic, economic, and other factors to obtain an estimate of the *usable* biomass. Site selection performed by GIS was then based on the spatial distribution of the *usable* biomass.

2. Study area

Adjacent to Hong Kong, the study area of this research, Guangdong Province, lies in the southernmost part of China. In the past 20 years, it has grown from a traditionally agricultural province into one of the most developed regions in the country. Its gross domestic production and export trade output have been significantly higher than those of other provinces in China since 1997. The province attracted over half of the nation's foreign investment on processing industries and joint ventures. Not surprisingly, Guangdong is currently facing serious energy and environmental problems. On the other hand, the province has a subtropical or tropical monsoon climate, experiencing abundant sunshine, warmth, and rainfall. Its mean annual sunshine duration is 1745 h, mean annual temperature 22.3 °C, and mean annual precipitation 1777 mm. Its total area of land that is suitable for agriculture is 43,400 km^2 and for forestry 110,000 km^2 [8]. Therefore, its physical condition sets a solid basis for the development of the bioenergy industry. It is expected that the energy problem of Guangdong can be partly resolved by utilizing local biomass resources.

3. Estimation of usable biomass

3.1. *A generic model for estimating usable biomass*

Not all biologically available biomass can be used for energy production because of a series of restrictions. These restrictions can be in ecological (e.g., soil carbon maintenance), economical (e.g., higher value uses), and other aspects. Here we propose a generic model for estimating the amount of biomass that is eventually usable for energy production at a specific location:

$$P = B \times r \times m \times (1 - c - e - l), \quad (1)$$

where all parameter values are specific to the vegetation type at the test location.

B is the *biologically available* biomass, derived from the annual NPP. For crops, this means the above-ground biomass when the crops are ready for harvest. For forest, this refers to the net annual change of the above-ground biomass. It is the ultimate source of the biomass for energy production and thereby is the most basic variable in the model. Remote sensing can be used to estimate this value.

The ratio r is in the fraction of B that is not primary yield. For crops, usually only the residues (e.g., straws and stems) are used for energy production, resulting in a relatively low value of r. For fast-growing grass/trees that are dedicated to energy production, r can be equal or close to 1 [9,10].