Applied Energy 87 (2010) 2923–2927

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Woody biomass supply potential for thermal power plants in Japan

Tsuguki Kinoshita [a,*], Takashi Ohki [b], Yoshiki Yamagata [a]

[a] National Institute for Environmental Studies, Japan
[b] Mitsubishi Research Institute, Japan

ARTICLE INFO

Article history:
Received 30 April 2009
Received in revised form 20 August 2009
Accepted 20 August 2009
Available online 1 October 2009

Keywords:
Bioenergy
Wood chips
Thermal power plant
Marginal abatement cost

ABSTRACT

Biomass energy is one of mitigation method of CO_2 reduction. In Japan, it aimed to reduce fossil fuels supply 670,000 kL of crude oil equivalent in thermal power plants and 340,000 kL of crude oil equivalent in the utilization of heat by biomass. It was decided to use 25% or more of the forestry products such as logging residues. Japanese government aim to supply 634 PJ of woody biomass for power generation in 2010. This amount of energy accounts for 2.8% of total primary energy. More than 68% of Japan is covered by forests, and more than 40% of these forests are plantations. But the use of woody biomass is limited because it is still not seen as economically viable. In this article, we developed a large scale forestry economic model which can estimate the wood chips supply for coal thermal power plants across all around Japan. By using this model, wood chips supply potential is currently 32,000 m^3/year and supply will increase drastically when wood chips price increase or carbon credit is installed and we found that biomass production of 15 PJ that is the numeric target of Japanese government is possible. Especially, the lengthening of rotation period of forestry and the decrease of wood chips transportation cost is important for wood chips use in coal thermal plant.

1. Introduction

1.1. Renewable energy policy in Japan

In January 2002, the "Law Concerning Special Measures to Promote the Use of New Energy" was amended. One of the amendments was the incorporation of a definition for biomass energy and its use as a source of energy [1]. Specifically, the law considers biomass to be raw materials such as methanol to be used as fuel for the generation of heat and power. In a document titled "Outline for Promotion Effects to Prevent Global Warming" released in March 2002, it proposed using biomass energy to reduce fossil fuel use by thermal power plants by a 670,000 kL crude oil equivalent and by 340,000 kL of crude oil equivalent [2]. The cabinet council published the "Biomass Nippon Strategy" in December 2002, in which it was stated that the government intended to increase biomass utilization [3]. Regarding potential sources of biomass, the council proposed that a target of 80% be set for waste system derived biomass and 25% or more from logging residues. Consequently, the utilization of biomass energy using forestry products, such as logging residues, and construction debris, as well as the technological requirements of these energy sources were considered in the "Basic Plan for Forest and Forestry" in October 2001 [4]. After the "Renewables Portfolio Standard Law" was promulgated in June 2002, electric power companies were obliged to use a minimum amount of renewable energy sources in their operations [5]. The Japanese government aimed to generate 634 PJ, or 2.8% of the total national primary energy needs, using woody biomass for power generation by 2010. However, by 2007, total electric power supply using biomass only accounted for 1% of total primary energy [6]. Further, of the woody biomass used, only 5% was derived from woody chips [7].

1.2. Woody biomass in Japan

Forests occupy 68% of the surface area of Japan, of which 41%, or more than 10.63 million ha consists of cultivated forests. Recently, demand for domestic timber has fallen due to competition with cheaper imports from abroad, and roundwood prices have stagnated. As a result, the felling of timber has decreased, and forest management is not as rigorously managed as it was previously. In addition, due to increases in the price of fossil fuels and calls for limiting carbon dioxide (CO_2) emissions in response to climate change mitigation, the use of woody biomass as an energy source has been increasing globally [8]. This shift means that the profitability of forestry is likely to increase as the value of forestry-based logging residues will increase, and has prompted several economic evaluations of forestry and logging residues for use as energy [9–11]. While the target areas in these studies were limited to the minimum administrative area, Barm et al. [12]

* Corresponding author. Address: 16-2 Onogawa, Tsukuba-shi, Ibaraki-ken 305 0044, Japan. Tel.: +81 29 850 2567; fax: +81 29 850 2670.
E-mail address: kinoshita.tsuguki@nies.go.jp (T. Kinoshita).

0306-2619/$ - see front matter © 2009 Elsevier Ltd. All rights reserved.
doi:10.1016/j.apenergy.2009.08.025

evaluated the use of biomass energy throughout Belgium and concluded that, after bio-ethanol production from sugar beet and wheat, woody biomass is the most efficient within the context of affecting reductions in CO_2 emissions. Similarly, Leduc et al. [13] and Suntana et al. [14] estimated the reductions in CO_2 emissions associated with the use of woody biomass in Sweden and Indonesia, respectively. Although the proportion of land dedicated to forestry is relatively higher than the amount of land dedicated to agriculture, ethanol production using woody biomass is not viable in Japan because the population density and energy consumption in the country are both very high. In this paper we report on the economic evaluation for the whole of Japan in order to contribute to policy planning. To achieve this, we used both forest and access road data for the whole of Japan because the costs associated with transportation are relatively higher than those associated with other processes such as felling, bucking, and because the CO_2 emissions associated with transportation activities are high. However, in the absence of national data of roads and forest compartment it is difficult to estimate woody biomass potential for the whole of Japan as the calculation costs are high. Fortunately, this calculation burden can be reduced by using road density data. Further, although the detailed distribution pattern of cost is less accurate when using road density data, it will suffice to generally evaluate the woody biomass potential for the whole of Japan.

The objective of this study was therefore to estimate the marginal abatement cost function for woody biomass in Japan using geographical data, such as land use data and road density data. In so doing, the potential reduction in CO_2 emissions associated with woody biomass utilization can be estimated.

2. Methods

The economic evaluation model for forestry using in this study was based on Kinoshita et al. [11]. The target area in this study was a town with an administrative area of 234 km^2. Work processes were divided into six stages: felling, bucking, forwarding, transport, chipping and planting. Felling refers to cutting down trees, bucking is delimbing and cross-cutting the trees that have been cut down, forwarding refers to the transportation of the timber from within the forest to a landing point. Transport includes the delivery of the timber from the landing to a factory or an energy plant, and chipping refers to the process of shredding the woody biomass. In this model, the productivities of felling and bucking are proportional to trunk diameter. Similarly, the productivities of forwarding and transportation are calculated as functions of distance. For chipping, the productivity is proportional to the volume being processed. Production costs are estimated by considering the costs associated with machinery, labor, overheads, access road clearing and fixed costs. Annual machinery costs in each stage are calculated as functions of machinery price, machine performance, actual working time and other factors. Overhead costs refer to costs that indirectly increase machinery and labor costs, such as insurance. Fixed costs include the loading and unloading processes required during the forwarding stage. The fixed costs associated with cable forwarding are calculated as a function of logging distance, and the costs associated with vehicle forwarding are estimated using a constant. Road clearing costs consist of the initial cost of constructing an access road, the costs of which are calculated as a function of the gradient of the forest. In the forwarding and transport stages, forest roads distance were obtained using a map (1:50,000) and access road data were obtained by interviews at the forestry cooperative. We used road density data instead of road distance data to calculate a figure representing production costs for the whole of Japan.

The basic model used to perform the economic analysis in this study/in a previous study used forest compartment data, road distance data, and 50 m resolution average slope data. Conversely, we used 1-km resolution data to assess forest area, average slope, and road density in this study/in a previous study [15] to evaluate the costs of forestry in Japan. In the basic model, the distance from forest compartment to the nearest road was calculated by using a function in ArcGIS which employed as follows:

$$df = \frac{2500(1+\eta)}{d} \tag{1}$$

In this equation η is a constant (0.8), df is the distance from the forest component to the nearest road, and d is road density. Road density in each grid cell is estimated only for public and forest roads. In addition, it is not feasible to estimate distance from a forest component to the nearest road because there are many access roads in forests. We therefore used total access road length in each prefecture. Fig. 1 shows a linear relationship between total road length and the length of access roads, public roads and forest roads for 41 cities/towns in Miyazaki prefecture. Eq. (2) is used to estimate road density in each grid cell.

$$d_{i,j} = d'_{i,j}\frac{D_j}{D'_j} \tag{2}$$

In Eq. (2), i refers to the grid cell and j prefecture. d is the total road density and d' is the road density public and forest roads in each grid cell. D is the total road density and D' is public and forest road density in each prefecture.

Transportation costs depend on the destination being considered. Woody biomass currently has two major uses. The first is the supply of households with heat using wood pellets, the second is as fuel in thermal power plants. In the case of household use, the advantage of using woody biomass is the low transportation costs since these systems are primarily used in areas located near forests, while the disadvantage is the high cost associated with making pellets. In 2008, the price of wood pellets (excluding shipping) was 7–13 JPY_{2008}/1000 kcal, which is almost the same as kerosene (in this article, the value of the yen is taken as 2008 levels). In the case of thermal power plants, the transportation distance is 10–200 km, implying that the unit transportation cost is approximately 50 JPY_{2008}/km/ton and transportation cost is 500–10,000 JPY_{2008}/ton. In 2008, the price of wood chips is approximately 2500 JPY_{2008}/ton and it is viable to use wood chips in thermal power plants.

3. Results and discussion

Fig. 2 shows above ground biomass production for one rotation period, which is assumed to be 40 years. The yield table of

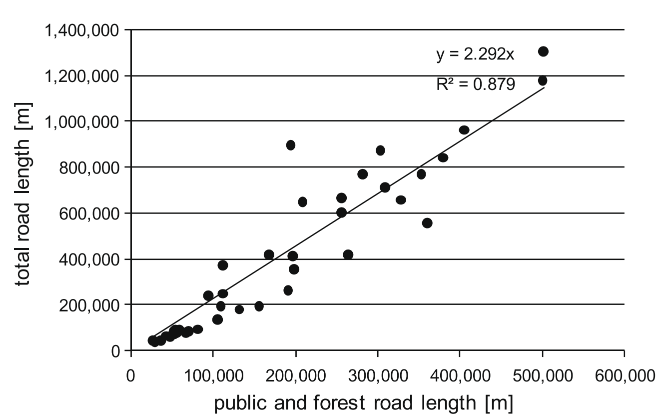

Fig. 1. Relationship of total road length and public and forest road length in cities/towns in Miyazaki prefecture.