Estimation of Forest Biomass Energy Resources Based on Bottom-up Approach in China

Lan Zhang*, Dan Yu, Caihong Zhang and Weidong Zhang

School of Economics & Management, Beijing Forestry University, Beijing, 100083, China

Abstract: Currently, the forest biomass energy development is at an initial stage and the estimation method for the forest biomass energy resource reserve is to be unified and refined although there is a great value and potential in the development and utilization of forest biomass energy in China. Based on the existing studies, the present paper analyzes the origins and types of forest biomass energy resources in the perspective of sustainable forestry management, constructs the estimation model using a bottom-up approach, and estimates the total existing forest biomass energy resource reserve in China based on the data of the 7th Forest Resource Survey. The estimation method and the calculation results provide the important theoretical ground for promoting the rational development of forest biomass energy in China.

Keywords: Bottom-up approach, forest biomass energy, model, resource reserve.

1. INTRODUCTION

The advance of modern biomass energy conversion technology makes the development and harnessing of biomass energy demonstrable and promotable globally. The forest biomass energy, as an important component of modern biomass energy, refers to the energy utilization of partial forest resources and becomes a kind of efficient clean low-carbon energy. Therefore, if we can realize the rational development and harnessing of forest biomass energy, the dependency of human being upon the fossil fuels will be reduced, the energy supply tension can be relieved, the environmental pollution will be decreased by such kind of clean energy, a contribution will be made to the improvement of the climate warming and a harmonious and unified development will be reached between economy and environment.

Many scholars in the world have quantitatively analyzed the potential, development and utilization of forest biomass resources for bio-energy in the different regions globally under multiple scenarios since 90's in last century. The used method and results varied with the deviation in research scope and subjects, for example, the potential and development scale were quantitatively researched for the forest biomass energy resources using Energy-MELA model, biomass energy demand and supply model, bottom-up model (bottom-up model), *etc*. in different regions [1-3]. In recent years, some scholars in China have surveyed and studied the types and quantity of forest biomass energy resources preliminarily [4-9] although disputes remained owing to rougher estimation method without any unity. In the present study, the estimation model for forest biomass energy resources was constructed from the perspective of sustainable production and management in forestry, the bottom-up method proposed by Smeets for estimation of energy resources was referred, and the type and resource reserves of forest biomass energy resources in China were investigated in order to improve the scientific and reasonable development of modern forest biomass energy.

2. TYPES OF FOREST BIOMASS ENERGY RESOURCES

The forest biomass refers to the total biomass of all the resources from the forests. From the functional point of view, on one hand, the forest biomass regulates the climate, purifies the air, conserves the water and soil, shields off the winds and fixes the sand and is an indispensable factor in nature as a balancer of the environment; on the other hand, it is one of the most important raw materials as for the production and living in human beings. The forest biomass energy resources refer to those that can be harnessed as energy, including both the wood waste and residue generated during forest production and processing by human beings and the energy forest is dedicated to provide.

According to its origins, the forest biomass energy resources can be divided into three categories: (1) the forest growth residues refer to the forest residual resources that are growing on the land with lower levels of protection (such as Level IV protect forest in China) or not included in the industrial timber harvesting plan; (2) the forest production residues refer to the wood residue generated during the forest management and production process; (3) the energy forest for harvesting includes the firewood as special energy in the present stage and the future exclusively-managed energy forests. In China, the forest growth residues refer to the residual forest biomass generated during a series of management activities adopted to promote the forest thriving on the woodland in Category 1, such as, forest residues from shrub stumping, economic forest, trees alongside the farm house and roads, rivers and fields, and tending and pruning during urban greening, *etc*. The forest production residues

*Address correspondence to this author at the School of Economics and Management of Beijing Forestry University, Beijing, 100083, China; Tel: 18501252172; E-mail: arlan1017@126.com

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are majorly generated during the three production stages: forest cultivation, soil fertility maintenance and woody forest productions, such as: residues from seedling pruning, stem-fixing and cutting of pseudo-stem, young forest tending (undeveloped forest), thinning, harvesting, commodity forest round cutting, forest products processing and waste wood products.

3. THE BOTTOM-UP ESTIMATION MODEL

According to the origin and type of forest biomass energy resources, the estimation model for forest biomass energy resources was constructed using the bottom-up approach so as to conduct the diversified quantitative estimation of the forest biomass energy resources.

3.1. For Wood Growth Residues

This part of wood residues refer to various forest residues generated from seedling fixing, thinning, tending, *etc*. in order to promote the healthy growth of forests during the growth process. The following formula (1) is applied to estimate both the Category 1 woodland growth residues and Category 2 forest residues from the seedling cultivation, forest tending and thinning, bamboo harvesting, *etc*.

$$L_1 = \sum_{i=1}^{n} FR_i \cdot U_i \cdot V_i \quad (1)$$

L_1 - the forest biomass energy resource reserve from the forest growth residues;

FR_i -- the i^{th} kind of forest resource reserve;

U_i - the residue output coefficient from Category i forest;

V_i - Energy utilization coefficient of Category i forest residues.

The residues from the forest harvesting and log bucking.

Some forests are harvested and log-bucked up to the harvesting standard for the forest product manufacture yearly in order to meet the needs of market economic development. The residues generated are known as harvesting and log-bucking residues, which are not totally discarded, but utilized forward as per the sizes, merely a few of them were discarded and can be recycled for the production of biomass energy.

$$L_2 = TC \times P_2 \cdot C_2 \quad (2)$$

where: L_2 - the forest biomass energy resource reserve from the forest harvesting and log-bucking residues;

TC - the total forest cutting volume;

P_2 - the output ratio of forest harvesting residues;

C_2 - the recycling ratio of forest harvesting residues.

3.2. Wood Processing Residues

The biomass energy resource potential from wood processing residues can be calculated with the industrial raw material production multiplied by the output ratio and recycling ratio of wood processing residues.

The specific formula is as follows:

$$L_3 = IC \times P_3 \times C_3 \quad (3)$$

where: L_3-the forest biomass energy resource reserve from the wood processing residues;

IC- the industrial and construction wood consumption;

P_3 - the output ratio of forest processing residues;

C_3 - the recycling ratio of forest processing residues

3.3. Waste Wood Products

There are many sources of waste wood products, including waste wood furniture or its parts; wooden decoration waste; wooden construction and demolition waste, *etc*. The biomass energy of wooden product waste is calculated as per following formula:

$$L_4 = IB \times P_4 \times C_4 \quad (4)$$

where: L_4-the forest biomass energy resource reserve from wooden product waste;

IB -the industrial and building timber consumption;

P_4 - the output ratio of wooden product residue;

C_4- the recyclable ratio of wood product waste

3.4. Energy Forest

The estimation model for estimating the energy forest resource reserve is as below:

$$L_5 = EF \times P_5 \times C_5 \quad (5)$$

where: L_5- the energy forest resource reserve;

EF- the planting area of energy forest;

P_5-the growth amount of energy forest in unit area;

C_5 - the harvesting ratio of energy forest

4. ESTIMATION OF FOREST BIOMASS ENERGY RESOURCES OF CHINA

4.1. The Forest Growth Residues

The forest growth residues, in China, are mainly from the production activities, such as shrub stumping, economic forest tending & management, tending and pruning of trees alongside the villa, house, road and water, tending and pruning in urban greening. The forest biomass energy resource is estimated as per the estimation model of forest growth residues and basic data published in "The Eighth Forest Inventory Report" and the "2013 Statistical Yearbook in Forestry of China". The conversion coefficient U_i and usability coefficient V_i in the formula are derived based on the experimental data obtained from the test plots and the related literatures [5, 7, 10, 11]. For the residues from the urban greening update and pruning, China's average annual residues from the forest pruning and tree update reach 40 million tons, about 50% of which can be used as an energy resource according to the urban greening data published by the National Afforestation Committee as shown in Table **1**.

4.2. The Forest Production Residues

4.2.1. The Residues of Seedling Cultivation, Forest Tending and Thinning

The residues from the forest thinning include not only the residues from the young forest tending and thinning, but also the residues from the under-growing shrub pruning, cleaning, forest pruning for firebreaks, burnt tree cleaning, trees died of diseases and pests, *etc*. The area of middle-young forest tending and thinning was 7.85 million hm^2 in China in 2013 and the forest residues generated reach about 5.65 million tons with the above parameter calculation. During the process of seedling cultivation, the forest residues from the seedling pruning, stem-fixing and cutting of pseudo-stem reach about 2.2 million tons. And the residues from the under-growing shrub pruning and cleaning, forest pruning for firebreaks, burnt tree cleaning, tree died of disease and pests, *etc*. reach about 200 million tons [11].

4.2.2. The Residues from the Forest Harvesting and Log-Bucking

The forest biomass energy resources of the residues from the forest harvesting and log-bucking are estimated based on the total harvesting volume in China. As per the national forest cutting quota approved by the State Council in "The 12^{th} Five-year Plan", China's annual cutting quota is about 275 million cubic meter, as the total capacity (TC), the timber production was about 115 million cubic meter and the output ratio of harvesting and log-bucking residues was 58%.

A majority of the forest harvesting residues was used for continuous production, and a small number of abandoned harvesting residues could be used for the forest biomass energy. Based on the above data, the usable volume for the forest biomass energy from forest harvesting, log-bucking and processing totaled about 49 million tons, as per the recycling ratio 26.14% [7].

4.2.3. The Residues from the Forest Product Manufacture

In China, the total capacity of the present timber products in forest is 84 million cubic meter, the residues from the forest product manufacture is about 15%~34.4% of logs [10] as per the "2013 Forestry Development Report". In the present paper, with 20% of output ratio of residues from manufacturer, the recycling ratio is about 26.14% as the recycling ratio of harvesting and log-bucking residues. The total resources of residues from the forest product manufacture utilizable for energy is about 4.4 million m^3 converted to about 5.1 million tons.

4.2.4. Wood Product Wastes

The wood product wastes include the abandoned wooden furniture, doors and windows, sleepers, building timber *etc*. According to incomplete statistics, the wood product wastes consisting mainly of abandoned furniture reach about 60 million tons in China [12]. The recyclable amount reaches about 30 million tons if the utilization ratio of forest biomass energy is 50%.

4.3. Energy Forest Harvesting

The energy forest refers to the forest that is managed and planted for the main purpose of energy. In China, the energy forest used to develop the forest biomass energy includes firewood forest at the present stage and energy forest that is planted for biomass energy in future specially. As the firewood forest has begun to take shape, the annual firewood forest area reaches about 2.49 million ha in 2013, and the annual firewood forest output reaches 9.96 million tons of wood resources as per stumping once every 4 years and unit annual output 16 tons/ha, see the Table **2**.

CONCLUSION

The forest growth residues, forest production residues and biomass energy resource reserves of energy forest were preliminarily estimated using the bottom-up estimation model respectively. Resultantly, the estimated forest residue resource is about 700 million tons, adding the residues from the under-growing shrub pruning and cleaning, forest pruning for firebreaks, burnt tree cleaning, trees died of disease and pests, nearly 200 million tons, and the total forest residue resource is 900 million tons. The residue utilizable to biomass energy resource is 265.3 million tons. The abundant raw material resource is a premise of development and utilization of forest biomass energy in China [13, 14].

Table 1. Estimation coefficient and results of partial forest growth residue.

Origin and Type of Forest Residues	Forest Area ($10^3 hm^2$)	Output Coefficient for Residue (Ui)	Weight Converted	Derivable Forest Biomass Resource ($10^6 t$)	Energy Utilization Coefficient (Vi)	Forest Biomass Energy Resource Reserve ($10^6 t$)
Shrub stumping	55900	33%	10t/hm²	184.5	56%	103.3
Tending and pruning of economic forest	20570	100%	7.2t/hm²	148.1	20%	29.6
Tending and pruning of trees alongside villa, house, road and water	23.6 (10^9 tree)	100%	2kg/tree	47.2	33%	15.6
Update and pruning in urban greening				40.0	50%	20.0
Tending and thinning of middle-young forest	7874.2	10%	7.2t/hm²	5.65	22%	1.24
Seedling pruning, stem-fixing and cutting of pseudo-stem	17.6 (10^9tree)	100%	0.125kg/tree	2.2	67%	1.47

Table 2. Forest biomass energy resource reserves of China.

Resource Type	Type	Derivable Residue Capacity (Unit: 10^6t)	Utilization Amount of Forest Biomass Energy (Unit: 10^6t)
Forest Growth Residue	Residue from shrub stumping	184.5	103.3
	Residue from economic forest tending and pruning	148.1	29.6
	Residue from tending and pruning of trees alongside villa, house, road and water	47.2	15.6
	Residue from tending and pruning in urban greening	40.0	20.0
	Total	419.8	168.5
Forest Production Residue	Residue from seedling pruning, stem-fixing and cutting of pseudo-stem	2.2	1.5
	Reside from forest tending and thinning	5.65	1.24
	Residue from forest harvesting and log-bucking	187.5	49
	Residue from forest product manufacture	14.9	5.1
	Wood product waste	60	30
	Total	270.3	86.84
Energy Forest	Firewood forest	9.96	9.96
Total		**700**	**265.3**

Among all above kinds of forest biomass resource types, the forest growth residues and forest production residues make up a relatively large proportion and are the raw material resources that are relatively economic and easy to gain at the present stage.

To get the forest residue resources listed in the present paper does not have any influence on the original ecological and economic benefits of the forests, but transform the forest litters and forest production residues into the modern energy efficiently. The energy forest planting based on the short-term rotation will arise with the development of forest biomass energy industry. The energy forest is characterized by forestation once, cutting multiply and usage for many years. It is easy to intensively manage an important source of forest biomass energy in the future.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

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