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AMOUNT AND AVAILABILITY OF FOREST BIOMASS AS AN ENERGY RESOURCE IN A MOUNTAINOUS REGION IN JAPAN: A GIS-BASED ANALYSIS

Feasibility of the energy utilization of forest biomass in a mountainous region in Japan was discussed with the aid of a geographic information system (GIS). In this study, logging residues, thinned trees, and broad-leaved forests were defined as the forest biomass. First, using the GIS, the distribution map of biomass resources was completed, and the information on the topography of each sub-compartment was prepared. Second, harvesting and transporting systems were classified into six types according to the parts of a tree for energy (two types) and the topographical conditions (three types), and the equations for calculating the costs whose variables were slope, skidding/yarding distance, and transporting distance were formed. Finally, the relationship between the mass and the procurement cost of forest biomass in the region was analyzed. As a result, logging residues (the annual available amount was 4,035 tDM/y) were the cheapest, followed by broad-leaved forests (20,317 tDM/y); thinned trees (27,854 tDM/y) were the most costly. This analysis was considered to help draw an operational planning, *i.e.*, selecting sub-compartments to be felled. For instance, the amount of biomass resources for the construction of a power-generation plant that covered 24.8 % of the power consumed by households in the region was calculated as 30,106 tDM/y. To obtain this amount of forest biomass for energy should be harvested from the sub-compartments whose procurement costs were cheaper than 13,037 yen/tDM.

Keywords: annual available amount, case study in a Japanese mountainous region, forest biomass, GIS, harvesting and transporting cost

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Енергетичні запаси деревної біомаси в гірських регіонах Японії: ГІС-аналіз

Можливості використання енергії деревної біомаси у гірських регіонах Японії були проаналізовані за допомогою геоінформаційної системи (GIS). У цьому дослідженні відходи лісозаготівлі, деревина, заготовлена рубаннями догляду, та широколистяні ліси визначені як біомаса. Найперше, використовуючи GIS, була складена карта запасів біомаси та описані топографічні особливості кожного лісового кварталу. Потім виконана класифікація за шістьма типами: за частинами дерева (два типи), за топографічними умовами (три типи) і за рівняннями для розрахунку вартості біомаси, що залежать від ухилу місцевості та довжини транспортування (один тип). На кінцевому етапі були проаналізовані залежності між запасами і вартістю деревної біомаси. Як результат: залишки лісозаготівлі (щорічний запас – 4,035 тон сухого матеріалу/рік) виявилися найдешевші, наступні за питомою вартістю – широколистяні ліси (20,317 тон сухого матеріалу/рік) і найдорожча деревина, заготовлена рубаннями догляду (20,854 тон сухого матеріалу/рік). Мета цього аналізу – здійснити оперативне планування. Наприклад, запас деревної біомаси для теплової електростанції, яка покриває 24,8 % енергетичних потреб регіону, визначений в 30,106 тон сухого матеріалу/рік. Для отримання цієї кількості деревної біомаси потрібно витратити на одну тону сухого матеріалу на 13,037 єни менше.

Ключові слова: річний доступний запас, дослідження в Японському гірському регіоні, деревна біомаса, GIS, вартість заготівлі і транспортування деревини.

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1. Introduction

The Japanese forest industries have been depressed for a long time. There are so many regions where forestry is not mechanized and the logging cost cannot be reduced. On the other hand, forest biomass attracts a great deal of attention in such regions. This is because the energy utilization of forest biomass is expected to contribute to revitalizing the forest industries as well as to maintaining the relevant ecological, economic, and social functions of man-made forests, but many of which are behind in tending. In order to utilize forest biomass as energy in a region where forestry is the major source of income, it is crucial to know the relationship between the annual available amount and the harvesting and transporting cost (procurement cost) of forest biomass in the region. However, such a relationship has never been examined in Japan. Some detailed analyses based on a geographic information system (GIS) have already been carried out in the Nordic countries, *e.g.*, Denmark [1] and Finland [2].

In this study, feasibility of the energy utilization of forest biomass in a mountainous region in Japan is discussed by analyzing the relationship between the mass and the procurement cost of biomass in the region with the aid of the GIS. A model region was selected, and logging residues, thinned trees, and broad-leaved forests are defined as forest biomass here. Mechanization in forestry for the energy utilization of forest biomass was supposed to be available. The objective of this study is to find out the actual situation of the region for the energy utilization of forest biomass by investigating the distribution of forest resources, the topography, and the alignment of forest and public roads as exactly as possible.

2. Materials and methods

Hikami County in Hyogo Prefecture, the middle part of Japan was selected as a model region here. The gross area of the county is 493.28 km², the population is 72,862, and the number of households is 21,769. Its climate belongs to the inland and basin type, the annual average temperature is 13-14 degrees Celsius, and the annual precipitation is 1,500-1,600 mm/y. Its forest belongs to the lucidphyllous forest zone, the forest area is 37,202 ha (the percentage to the gross area is 75 %), and man-made forest covers 58 % of the forest area. The number of sawmills is 43, and the annual consumption of logs for timber is 78,992 m³/y. Hikami County is a leading region in forestry and timber business in Hyogo Prefecture. However, in the region, the annual cut volume of logs has dropped almost by 50 % in the past five years, and the forest stands behind in tending are increasing. Delay in mechanization in forestry is one of the major reasons for such a situation.

The forest register, the statistics on the forest industries, and the guides to forestry practice were offered from the prefectural office. Using these materials and the GIS, the annual available amount of biomass resources was calculated, and the distribution map made. With regard to the GIS software, TNTmips[®] (Micro-Images, Inc., the U.S.) is used in this study. The shapes and the locations of sub-compartments are vector data, which are managed by the prefecture. In order to calculate the heights above sea level and the angles of inclination, the digital elevation model (DEM) is utilized. Forest and public roads are traced on the digital to-

pographic map of the region and converted to vector data. These data are integrated on the software and processed. Harvesting and transporting systems for forest biomass were classified depending on the parts of a tree for energy and the topographical conditions, and the equations for calculating costs are made.

2.1. Calculation of annual available amount of forest biomass

The number of sub-compartments in the region was 2,168, and the total growing stock was 7,841,851 m³. Among these sub-compartments, there were 1,113 man-made coniferous stands and 398 naturally regenerated broad-leaved stands, so these stands are targeted for harvesting logs and energy sources. But the protection forest stands for the purpose of sediment disaster prevention and water conservation were excluded. In this study, thinning and clearcutting are supposed to be carried out in the coniferous forests, and selection felling in the broad-leaved forests. Table 1 lists the operation patterns of sub-compartments to be felled.

Table 1. Operation patterns of sub-compartments to be felled

Forest	Age (y)	Operation pattern
Man-made and coniferous ¹	31-60	[Biomass resources: Thinned trees] Thinning is carried out in the stands with more than 200 m ³ /ha growing stocks per hectare with a 20 % of thinning rate, and the whole trees are used as energy sources. ²
	Over 61	[Biomass resources: Logging residues] Clearcutting is carried out to all the stands. Trees are limbed and bucked, logs are harvested, and tops and branches are used as energy sources.
Naturally regenerated and broad-leaved ¹	Over 31	[Biomass resources: Broad-leaved forests] Selection felling is carried out at 30-year interval cycle, and the whole trees are used as energy sources.

¹The representative tree species in the region are "hinoki" or a cypress (*Chamaecyparis obtusa*) for coniferous and "keyaki" or a zelkova (*Zelkova serrata*) for broad-leaved.

²It is supposed in this study that all of the cut material at thinnings can be used as an energy source in consideration of the actual Japanese market value.

In the man-made coniferous forest, the annual cut volume of the forest was supposed to be the same as the annual increment, so the cutting cycle was calculated as 9.2016 years by dividing the total cut volume (1,158,796 m³, this value was calculated from the forest register of the region and Table 1) by the annual increment (125,934 m³/y).

The total stem volume of each sub-compartment is recorded in the forest register. Therefore, if the coefficient that converts stem volume to dry mass is known, the amount of biomass resources can be calculated from the stem volume and the coefficient. The coefficients to calculate the amount of biomass resources are listed in Table 2.

Consequently, by applying Tables 1 and 2 to the forest register and considering the cutting cycles of coniferous and broad-leaved forests, the annual available amount of forest biomass in the region can be calculated.

On the other hand, the amount of biomass in each sub-compartment is calculated by using the GIS, and the distribution map of the region is completed.

Table 2. Methods for calculating the amount of biomass resources

Biomass resources	Equation (s.v.: Stem volume)	Note
Logging residues ¹	Amount (tDM) = s.v. · 15/92 · 0.40	· 15/92: Ratio of tops and branches' volume to stem volume · 0.40: Density of a coniferous tree
Thinned trees	Amount (tDM) = s.v. · 20/100 · 100/92 · 0.40	· 20/100: Thinning rate · 100/92: Ratio of the whole tree's volume to stem volume · 0.40: Density of a coniferous tree
Broad-leaved forests	Amount (tDM) = s.v. · 100/80 · 0.56	· 100/80: Ratio of the whole tree's volume to stem volume · 0.56: Density of a broad-leaved tree

¹The method for calculating the cut volume of logs in clearcutting is as follows:
Volume of logs (m³) = s.v. · 85/92 (85/92: Ratio of logs' volume to stem volume)

2.2. Preparation for topographic information

First, the vector data on the shapes and the locations of sub-compartments are input into the GIS software, and the data on the forest register are laid out at the same time. Second, the digital topographic map of the region (1:25,000 scale, the Geographical Survey Institute, Japan) is input into the software, and forest and public roads whose width is greater than 3 m are traced and converted to vector data (Figure 1). Third, the DEM of the region (50 m mesh, the Geographical Survey Institute, Japan) is input into the software to calculate the slope of each sub-compartment and to judge the skidding/yarding direction (uphill or downhill) (Figure 2). Fourth, all the vector data are converted to raster data. In Figure 3, vector data are projected on a digital topographic map. The converted raster data on the shapes and the locations of sub-compartments are shown in Figure 4, and the converted raster data on forest and public roads in Figure 5.



Figure 1. Conversion of forest and public roads into vector data

Finally, the following items on topography are processed on the GIS software. First, skidding/yarding distance of each sub-compartment is determined. The distance between the "center of gravity" mesh of a sub-compartment and the nearest road mesh from the sub-compartment is calculated here, and a landing is to be arranged in the road mesh. Second, transporting distance is determined by calculating the distance between the "landing" road mesh and an energy-conversion plant, which is to be in the center of the region. Third, the average angle of inclination of each sub-compartment is calculated, and skidding/yarding direction (uphill

or downhill) is judged by comparing the altitudes of the "center of gravity" mesh with the "landing" road mesh. Thus, all the data on the topography of the sub-compartments are prepared.

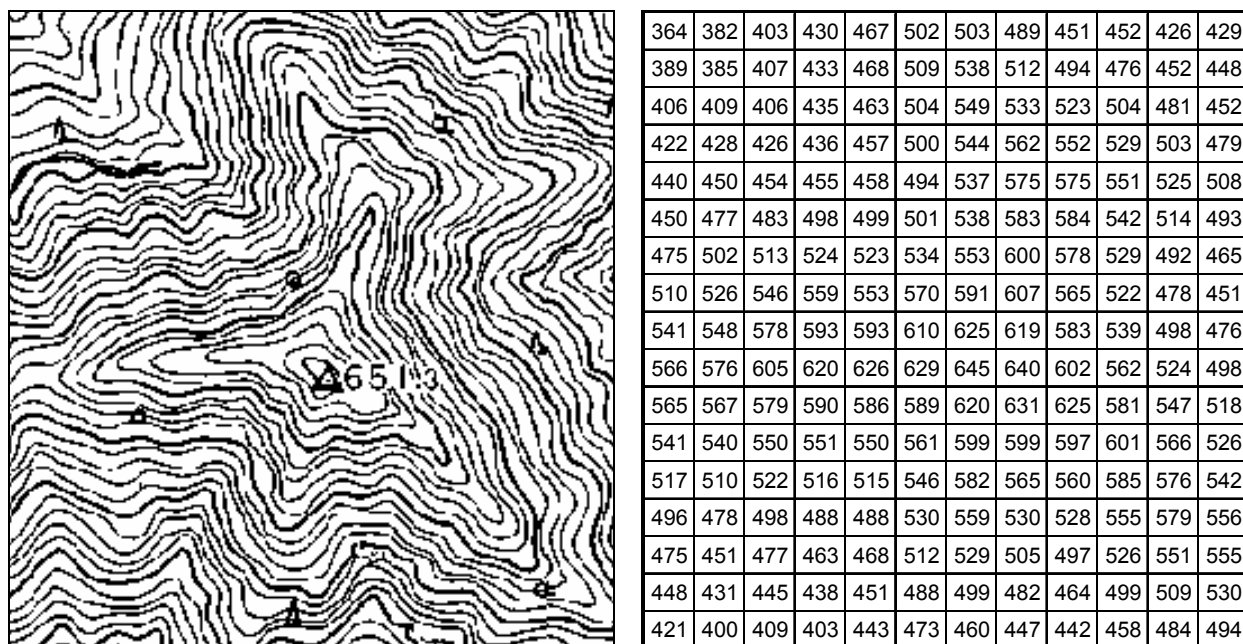
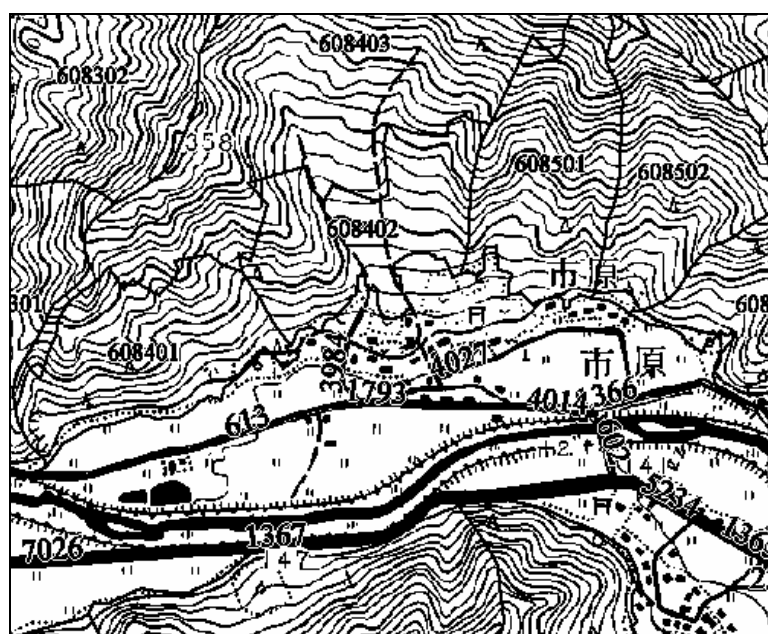


Figure 2. DEM (right) corresponding to a contour map (left)



[illegible]

The flowchart illustrates the processes for harvesting and transporting logging residues and thinned trees/broad-leaved forests. The processes are categorized into three horizontal zones: Forest, Landing, and Forest and public roads. A bold line encloses the processes from 'Felling by a chain saw' down to 'Transporting by a 8-ton truck'.

	Logging residues	Thinned trees and broad-leaved forests
Forest	Felling by a chain saw	Felling by a chain saw
Landing	Whole-tree skidding/yarding	Whole-tree skidding/yarding
	Limbing and bucking by a processor	
Forest and public roads	Comminuting by a small-sized chipper	Comminuting by a middle-sized chipper
	Transporting by a 8-ton truck	Transporting by a 8-ton truck

Processes inside the bold line are considered when harvesting and transporting costs are calculated in this study.

classified into two types (Figure 6). The machine for skidding/yarding is usually decided according to the topographical conditions, *i.e.*, slope, skidding/yarding distance, and skidding/yarding direction (uphill or downhill). In this study, tractors (skidders), tower yarders (mobile yarders), and yarders are to be used for the skid-

ding/yarding process, and Figure 7 shows the classification of skidding/yarding machines according to the topographical conditions of sub-compartments.

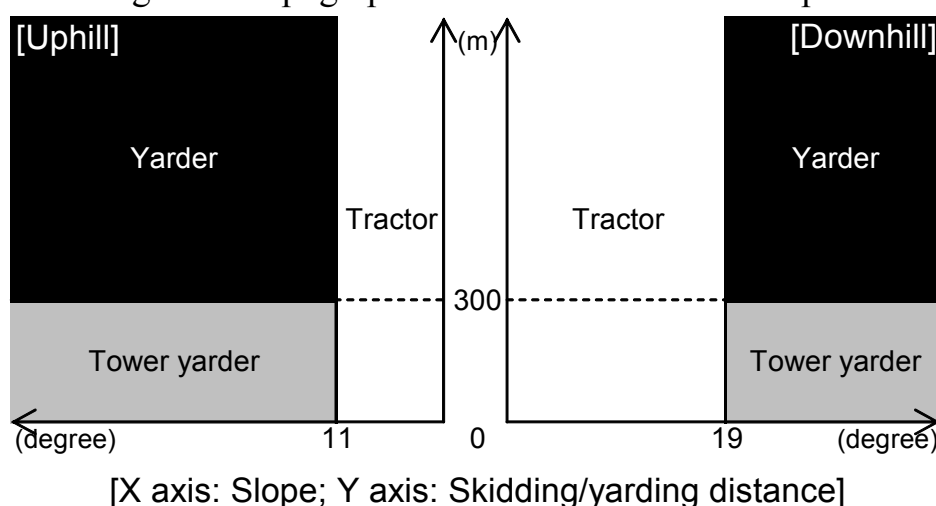


Figure 7. Classification of machines according to the topographical conditions

Table 3 shows the equations for calculating the harvesting and transporting costs of forest biomass whose variables are slope, skidding/yarding distance, and transporting distance. The costs of labor, machine, and fuel are considered here.

Table 3. Equations for calculating the harvesting and transporting costs of forest biomass

Machine	Equation (yen/tDM) ^{1,2}
Tractor	[Logging residues] $0.068 \cdot L_T + 4888$
	[Thinned trees] $2.11 \cdot L_{SY} + 0.068 \cdot L_T + 229 \cdot e^{0.117 \cdot d} + 11408$
	[Broad-leaved forests] $1.51 \cdot L_{SY} + 0.048 \cdot L_T + 164 \cdot e^{0.117 \cdot d} + 8371$
Tower yarder	[Logging residues] $0.068 \cdot L_T + 4888$
	[Thinned trees] $13.85 \cdot L_{SY} + 35908 / L_{SY} + 0.068 \cdot L_T + 8650$
	[Broad-leaved forests] $9.893 \cdot L_{SY} + 25648 / L_{SY} + 0.048 \cdot L_T + 6402$
Yarder	[Logging residues] $0.068 \cdot L_T + 4888$
	[Thinned trees] $1904 / L_{SY}^{-0.2142} + 31023 / L_{SY} + 0.068 \cdot L_T + 8518$
	[Broad-leaved forests] $1360 / L_{SY}^{-0.2142} + 22159 / L_{SY} + 0.048 \cdot L_T + 6307$

¹The exchange rate was about 110 yen to the U.S. dollar at the end of May 2004.

² L_{SY} : Skidding/yarding distance (m), L_T : Transporting distance (m), d : Slope (degree)

By applying the topographical data on each sub-compartment to the equations listed above, the procurement costs of forest biomass from all sub-compartments in the region can be calculated.

3. Results and discussions

3.1. Annual available amount of forest biomass

The annual available amount of biomass resources in the region is calculated by the method discussed in Section 2.1 (Table 4). About half of the sub-compartments in the region are targeted for harvesting logs and energy sources, and the annual available amount in total is calculated as 52,206 tDM/y. Both man-made coniferous forests and naturally regenerated broad-leaved forests are felled in a sustainable way, *i.e.*, by considering the cutting cycles of the forests. Therefore, the forests' health is expected to be improved by the energy utilization of biomass resources. At least 143 tDM (52,206 [tDM/y]/ 365 [d/y]) of biomass can be supplied

to an energy-conversion plant every day (the mass varies with the days of operation). On the other hand, 57,162 m³/y of the cut volume of logs corresponds to 72 % of the annual consumption of logs for timber in the region, and the total amounts of logs and energy sources to be harvested are enough to introduce large efficient forestry machines.

Table 4. Annual available amount of forest biomass in the region

Biomass resources	Number of sub-compartments	Amount (tDM/y)	Cut volume of logs (m ³ /y)
Logging residues	120	4035	57162
Thinned trees	637	27854	-
Broad-leaved forests	266	20317	-
Total	1023	52206	57162

3.2. Relationship between the mass and the procurement cost of forest biomass

The data on the topography prepared in Section 2.2 and the equations for calculating the costs classified in Section 2.3 are used here. First, the skidding/yarding machine to be used in each sub-compartment is decided according to the topographical conditions of the sub-compartment (see Figure 7). Second, the harvesting and transporting systems for forest biomass are decided according to the parts of the tree for energy (logging residues or the whole tree, see Figure 6). Third, the topographical conditions of all the sub-compartment are applied to the equations for calculating the harvesting and transporting costs (see Table 3). As a result, the masses and the procurement costs of all sub-compartment are prepared. Figure 8 shows the relationship between the annual available amount and cost for harvesting and transporting forest biomass in the region.

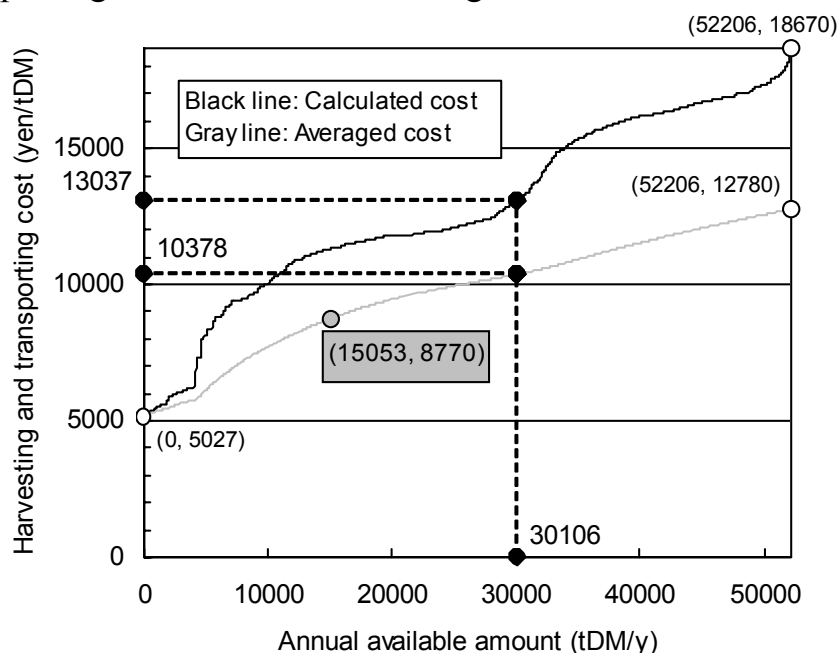


Figure 8. Relationship between the mass and the procurement cost of forest biomass

Logging residues are the cheapest, followed by broad-leaved forests; thinned trees are the most costly. In this study, logging residues, *i.e.*, tree tops and branches which are generated during lambing and bucking, are regarded as by-pro-

ducts in logging operations (see Figure 6). Therefore, the procurement costs of the residues are calculated by considering only the chipping and transporting processes, and are the cheapest. Although the procurement cost of thinned trees is roughly the same as that of broad-leaved forests per cubic meter, broad-leaved forests are cheaper than thinned trees in Figure 8 because of the higher bulk density of a broad-leaved tree than that of a coniferous tree.

For realizing the energy utilization of forest biomass in the region, there are the following three advantages in the relationship mentioned above:

- When an energy-conversion plant puts the upper limit of a purchase price of forest biomass, *e.g.*, "Biomass resources whose prices are 10,000 yen/tDM or less will be accepted," the annual available amount of biomass at the plant can be determined.
- On the other hand, when the annual amount of forest biomass necessary is set up, *e.g.*, "20,000 tDM/y of biomass will be necessary for the operation of an energy-conversion plant," the plant can determine the ceiling on a purchase price.
- The procurement costs from all sub-compartments in the region are calculated. Therefore, in both 1) and 2) above, the relationship can contribute to drawing up an operational planning, *i.e.*, "From which sub-compartment forest biomass should be harvested and transported?"

The construction of a power-generation plant that uses forest biomass as fuel and supplies electricity to the region is discussed here. Concerning the scale of the plant, the net power output, the thermal efficiency, and the operating rate are supposed to be 3 MW, 12 %, and 70 %, respectively. This scale of the plant will cover 5,400 households, *i.e.*, 24.8 % of the households in the region, and consume 30,106 tDM/y of forest biomass. Therefore, the ceiling on a purchase price of biomass can be read as 13,037 yen/tDM from Figure 8, and the plan to harvest and transport biomass from the sub-compartments whose costs are cheaper than 13,037 yen/tDM can be laid out. In this case, the average skidding/yarding and transporting distances are 262 m and 14.5 km, respectively (362 m and 13.2 km for logging residues, 146 m and 13.1 km for thinned trees, 275 m and 15.1 km for broad-leaved forests).

Figure 8 also shows the averaged cost, which is calculated by dividing the sum total of the purchase price of forest biomass by the amount of biomass to be purchased. The averaged cost for the supposed plant can be read as 10,378 yen/tDM from the figure, and this value is equivalent to 16.95 yen/kWh. From the viewpoint of cost, it seems to be difficult to utilize forest biomass as an energy resource in the region because the unit price of electricity per kWh in Japan is 18.17 yen/kWh. However, the feasibility of the energy utilization of forest biomass should not be discussed only from the viewpoint of cost. Including the effects on the reduction in the amount of carbon dioxide (CO₂) emission and the job creation in the region, the energy utilization of forest biomass should be evaluated comprehensively.

4. Conclusion

In addition to the forest biomass discussed in this study, it would be realistic and valuable to utilize mill residues (wood shavings and barks generated in the saw-mill and plywood industries), wood-based waste material, and trimmings of park trees, roadside trees, and garden trees together. For instance, if half the amount of

biomass necessary for the supposed plant (15,053 tDM/y) is covered by mill residues, wood-based waste material, trimmings generated in the region, the averaged cost of forest biomass will be reduced to 8,770 yen/tDM (Figure 8). Moreover, many of the mill residues, the wood-based waste material, and the trimmings can be obtained free of charge, so the effectiveness of the reduction in the procurement cost of biomass will be greater on the whole, *e.g.*, $(15,053 \text{ [tDM/y]} \cdot 8,770 \text{ [yen/tDM]} + 15,053 \text{ [tDM/y]} \cdot 0 \text{ [yen/tDM]}) / 30,106 \text{ [tDM/y]} = 4,385 \text{ [yen/tDM]}$.

5. Acknowledgement

This study was supported in part by a Grant-in-Aid for Scientific Research from the Ministry of Education, Culture, Sports, Science and Technology, Japan (No. 16-10303).

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ПАРАМЕТРИ І ТЕХНІЧНИЙ СТАН ДОРОЖНЬОЇ МЕРЕЖІ В ЛІСФОНДІ ВЕЛИКОБИЧКІВСЬКОГО ДЛМП

Представлено результати інвентаризації лісових автомобільних доріг. Подано інформацію про наявність і технічний стан лісових автодоріг та параметри дорожньої мережі в лісовому фонді Великобичківського ДЛМП.

Ключові слова: гірські ліси, дорожня мережа, характеристика, технічний стан.

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Parameters and technical condition of roads net in the forest area of Velykobychkivsky DLMP

The result about forest automobile roads inventory are given. The information about forest automobile roads quantity and roads net technical condition and parameters in the forest area of Velykobychkivsky DLMP are made.

Keywords: mountain forest, roads net, characterization, technical condition

Вступ. Прийнятим в 2000 році Законом України "Про мораторій на проведення суцільних рубок на гірських схилах в ялицево-букових лісах Карпатського регіону" [1] поставлені завдання із забезпечення економічно збалансованого лісокористування, запобігання проявам згубних наслідків сти-

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