Amount and availability of forest biomass as an energy resource in a mountainous region in Japan: a GIS-based analysis

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Abstract – Nacrtak

Feasibility of energy utilization of forest biomass in a mountainous region in Japan has been discussed with the aid of a geographic information system (GIS). In this study, logging residues, thinned trees, and broad-leaved forests are defined as forest biomass. First, the distribution map of biomass resources has been completed by use of the GIS, and information on topography of each sub-compartment has been prepared. Second, harvesting and transporting systems have been classified into six types according to the parts of tree used as energy source (two types) and topographical conditions (three types). The equations for calculating the costs whose variables are slope, skidding/yarding distance, and transporting distance have been developed. Finally, the relationship has been analyzed between the mass and procurement cost of forest biomass in the region. As a result, logging residues [*the annual available amount is* 4,035 t/y[1] *(DM*[2]*)*] *proved to be the most cost effective, followed by broad-leaved forests* [20,317 t/y *(DM)*]; *thinned trees* [27,854 t/y *(DM)*] *proved to be the most costly. This analysis could be of help in drawing an operational plan, i.e., in selecting sub-compartments to be felled. For instance, it has been calculated that the amount of biomass resources of 30,106 t/y (DM) was required for the construction of a power-generation plant that covered* 24.8 % *of the power consumed by households in the region. To obtain this amount of forest biomass for energy purposes, forest biomass should be harvested in sub-compartments, whose procurement costs are lower than* 13,037 yen/t *(DM).*

Key words: *forest biomass, case study, mountainous region, GIS, harvesting and transporting cost, Japan*

1. Introduction – *Uvod*

The Japanese forest industries have been in a poor state 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 forest industries as well as to maintaining the relevant ecological, economic, and social functions of man-made forests, which have been largely neglected. With respect to technologies of harvesting and transport of forest biomass on steep terrain in Japan, several basic researches have been carried out by the authors of this paper (Yoshioka et al., 2000, 2002, 2005a, and 2005b). In order to utilize forest biomass as energy in a region where forestry is the major source of

[1] y – unlegal unit of measurement (year); often used in science, economy, statistics and in this paper
y – nezakonita mjerna jedinica (godina); rabi se u znanosti, gospodarstvu, statistici te u ovom radu

[2] Dry matter (DM); refers to biomass that has been dried
Suha tvar (ST); odnosi se na biomasu u suhom stanju

income, however, it is crucial to know the relationship between the annual available amount of forest biomass and its harvesting and transporting cost (procurement cost) in the region. For instance, van Belle et al. (2003) analyzed such a relationship on the basis of a geographic information system (GIS). The GIS has been applied to the studies of forestry operation and forest road planning (Dean 1997, Eriksson and Rönnqvist 2003, Forsberg and Rönnqvist 2003, Kluender et al. 2000, Martin et al. 2001, Pentek et al. 2004 and 2005), and some researchers in the Nordic countries utilized the GIS for estimating the amount of domestic forest biomass resources in detail (Nord-Larsen and Talbot 2004, Ranta 2003 and 2004, Talbot and Nord-Larsen 2003).

In this study, feasibility of energy utilization of forest biomass in a mountainous region in Japan is discussed by analyzing the relationship between the mass and 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 were here defined as forest biomass. It was assumed that forestry mechanization was available for utilization of forest biomass for energy purposes. The objective of this study was to establish the actual situation of the region in terms of energy utilization of forest biomass by investigating the distribution of forest resources, topography, and alignment of forest and public roads as precisely as possible.

2. Materials and methods – *Materijal i metode*

Hikami County in Hyogo Prefecture, the middle part of Japan was here selected as a model region. The gross area of the county is 493.28 km^2, the population is 72,862, and the number of households is 21,769. Its climate is of 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, total forest area is 37,202 ha (the percentage of gross area is 75 %), and man-made forest covers 58 % of the forest area. There are 43 sawmills, and the annual consumption of logs for timber is 78,992 m^3/y. Hikami County is a leading region in forestry and timber business in Hyogo Prefecture. However the annual cut volume of logs has dropped in the region almost by 50 % in the past five years, and the untended forest stands are increasing. Delay in forestry mechanization is one of the major reasons for such a situation.

The forest register, the statistics on forest industries, and the guides to forestry practice were provided by the prefectural office. Using these materials and the GIS, the annual available amount of biomass resources was calculated, and the distribution map was made. With regard to the GIS software, TNTmips® (MicroImages, Inc., the U.S.) was used in this study. The shapes and locations of sub-compartments are vector data, which are managed by the prefecture.

Table 1 Operation patterns of sub-compartments to be felled

Tablica 1. *Opis odsjeka predviđenih za sječu*

Forest *Šuma*	Age (y) *Dob (god.)*	Operation pattern *Operativni uzorak*
Man-made and coniferous[1] *Kulture četinjača[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] *[Izvori biomase: sve drvo iz proreda]* *Prorjeđivanje se provodi u sastojinama s drvnom zalihom većom od 200 m^3/ha uz intenzitet prorede od 20 %. Sve se izrađeno drvo koristi kao izvor energije.[2]*
	Over 61 *Preko 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. *[Izvori biomase: krošnje i grane drveća tijekom pridobivanja drva]* *Provodi se čista sječa. Iz posječenoga se drva izrađuju trupci različitih kakvoćnih razreda, a krošnje i grane se koriste kao izvori energije.*
Naturally regenerated and broad-leaved[1] *Prirodno obnovljive šume listača[1]*	Over 31 *Preko 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. *[Izvori biomase: bjelogorične šume]* *U tridesetogodišnjem se intervalu provode prorede, a sve se drvo koristi kao izvor energije.*

[1]The 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.
*Reprezentativne vrste drveća u regiji su »hinoki« ili čempres (Chamaecyparis obtusa) za četinjače i »keyaki« ili zelkova (*Zelkova serrata*) za bjelogorice.*

[2]It was supposed in this study that all of the cut material in thinnings could be used as an energy source in consideration of the actual Japanese market value.
Za sav je drvni materijal dobiven iz prorede, a iskorišten kao izvor energije, u obzir uzeta njegova sadašnja vrijednost na japanskom tržištu.

Table 2 Methods for calculating the amount of biomass resources
Tablica 2. *Metode izračunavanja mogućih količina biomase*

Biomass resources *Izvori biomase*	Equation (s.v.: Stem volume) *Jednadžba (s.v.: obujam debla)*	Note *Bilješka*
Logging residues[1] *Krošnje i grane drveća[1]*	Amount, t (DM) *Količina, t (ST)* = s.v. · 15/92 · 0.40	• 15/92: Ratio of tops and branches' volume to stem volume • 0.40: Density of a coniferous tree • *15/92: Omjer obujma krošnje i grana prema obujmu debla* • *0,40: Gustoća drva četinjača*
Thinned trees *Stabla iz proreda*	Amount, t (DM) *Količina, t (ST)* = 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 • *20/100: Intenzitet prorede* • *100/92: Omjer obujma cijeloga stabla prema obujmu debla* • *0,40: Gustoća drva četinjača*
Broad-leaved forests *Bjelogorične šume*	Amount, t (DM) *Količina, t (ST)* = 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 • *100/80: Omjer obujma cijeloga stabla prema obujmu debla* • *0,56: Gustoća drva bjelogorice*

[1]The method for calculating the cut volume of logs in clearcutting is as follows: Volume of logs (m^3) = s.v. · 85/92 (85/92: Ratio of logs' volume to stem volume)
Metoda izračunavanja očekivanoga obujma trupaca pri čistoj sječi: očekivani obujam trupaca (m^3) = s.v. · 85/92 (85/92: omjer očekivanoga obujma trupaca prema obujmu debla)

The digital elevation model (DEM) was used for calculating the heights above sea level and angles of inclination. Forest and public roads were traced on the digital topographic map of the region and converted to vector data. These data were integrated and processed by the software. Harvesting and transporting systems for forest biomass were classified depending on the parts of tree used for energy purposes and topographical conditions, and the equations were developed for calculating the costs.

2.1. Calculation of annual available amount of forest biomass – *Izračun godišnje moguće količine šumske biomase*

There were 2,168 sub-compartments in the region, and total growing stock was 7,841,851 m^3. In these sub-compartments, there were 1,113 man-made coniferous stands and 398 naturally regenerated broad-leaved stands, and these stands were targeted for harvesting logs and energy sources. The protection forest stands established for the purpose of sediment disaster prevention and water conservation were excluded. This study assumed that thinning and clearcutting were carried out in coniferous forests, and selection felling in broad-leaved forests. Table 1 lists the operation patterns of sub-compartments to be felled. 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 m^3, this value was calculated based on data from the forest register of the region and Table 1) by the annual increment (125,934 m^3/y).

The total stem volume of each sub-compartment is recorded in the forest register. Therefore, if the coefficient that converts the 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 was calculated by using the GIS, and the distribution map of the region was completed.

2.2. Preparation of topographic information – *Priprema topografskih informacija*

First, the vector data on shapes and locations of sub-compartments were input into the GIS software, and the forest register data were laid out at the same time. Second, the digital topographic map of the region (1 : 25,000 scale, the Geographical Survey Institute, Japan) was input into the software, and forest and public roads whose width was greater than 3 m were traced and converted to vector data (Figure 1). Third, the DEM of the region (50 m mesh, the Geographical Survey Institute, Japan) was input into the software to calculate the slope of each sub-compart-

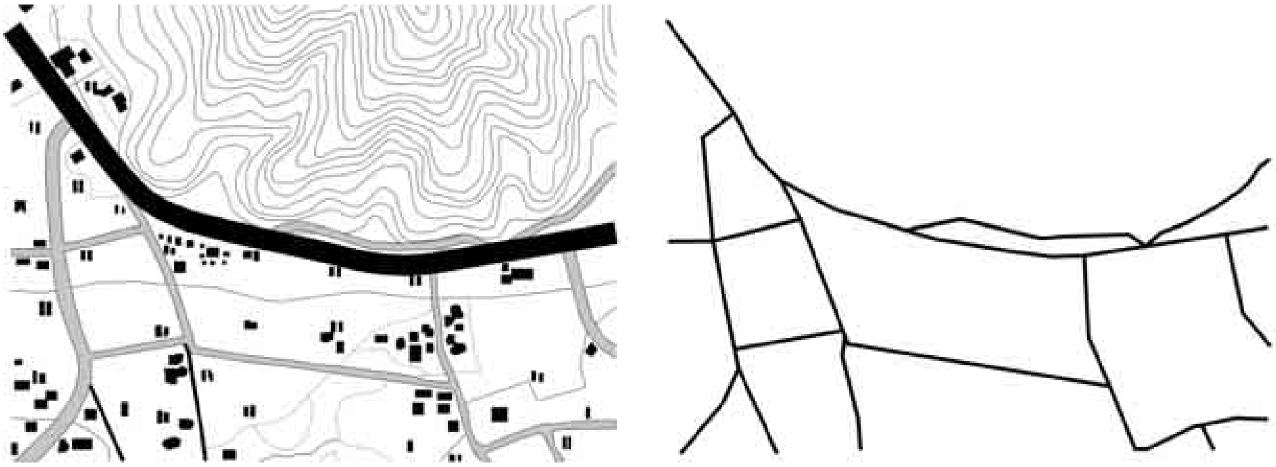
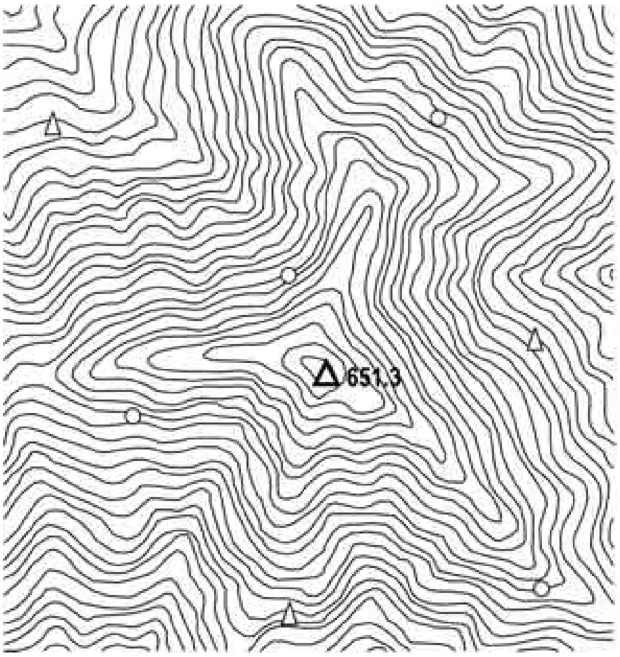


Figure 1 Conversion of forest and public roads into vector data
Slika 1. *Pretvorba šumskih i javnih cesta u vektorske podatke*



364	382	403	430	467	502	503	489	451	452	426	429
389	385	407	433	468	509	538	512	494	476	452	448
406	409	406	435	463	504	549	533	523	504	481	452
422	428	426	436	457	500	544	562	552	529	503	479
440	450	454	455	458	494	537	575	575	551	525	508
450	477	483	498	499	501	538	583	584	542	514	493
475	502	513	524	523	534	553	600	578	529	492	465
510	526	546	559	553	570	591	607	565	522	478	451
541	548	578	593	593	610	625	619	583	539	498	476
566	576	605	620	626	629	645	640	602	562	524	498
565	567	579	590	586	589	620	631	625	581	547	518
541	540	550	551	550	561	599	599	597	601	566	526
517	510	522	516	515	546	582	565	560	585	576	542
496	478	498	488	488	530	559	530	528	555	579	556
475	451	477	463	468	512	529	505	497	526	551	555
448	431	445	438	451	488	499	482	464	499	509	530
421	400	409	403	443	473	460	447	442	458	484	494

Figure 2 DEM (right) corresponding to a contour map (left)
Slika 2. *DMV (desno) koji odgovara karti sa slojnicama (lijevo)*

ment and to judge the skidding/yarding direction (uphill or downhill) (Figure 2). Fourth, all vector data were converted to raster data. Vector data are projected on a digital topographic map. The converted raster data on shapes and locations of sub-compartments are shown in Figure 3, and the converted raster data on forest and public roads in Figure 4.

Finally, the following items on topography were processed by GIS software packages. First, the skidding/yarding distance of each sub-compartment was determined. The distance between the »center of gravity« mesh of a sub-compartment and the nearest road mesh from the sub-compartment was calculated here, and a landing was to be arranged in the road mesh. Second, transporting distance was 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 was calculated, and skidding/yarding direction (uphill or downhill) was judged by comparing the altitudes of the »center of gravity« mesh with the »landing« road mesh. Thus, all topography data of the sub-compartments were prepared.

608302	608302	608302	608302	608302	608302	608302	608403	608403	608403	608403	608403	608403	608403	608403	608403	608403	608403	608403	608502	608502	608702	608702	608702	608702
608302	608302	608302	608302	608302	608302	608302	608403	608403	608403	608403	608403	608403	608403	608403	608403	608403	608501	608501	608502	608502	608502	608502	608702	608702
608302	608302	608302	608302	608302	608302	608302	608403	608403	608403	608403	608403	608403	608403	608403	608403	608403	608501	608501	608502	608502	608502	608502	608502	608502
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608301	608301	608403	608403	608403	608403	608403	608403	608403	608402	608402	608402	608402	608402	608501	608501	608501	608501	608501	608502	608502	608502	608502	608502	608503
608301	608301	608403	608403	608403	608403	608403	608403	608402	608402	608402	608402	608402	0	608501	608501	608501	608501	608501	608502	608502	608502	608502	608503	608503
608301	608301	608403	608403	608403	608403	608401	608402	608402	608402	608402	608402	608402	0	608402	0	608501	608501	608501	608502	608502	608502	608503	608503	608503
608301	608403	608401	608403	608401	608401	608401	608401	608402	608402	608402	608402	608402	0	0	0	0	0	0	0	608503	608503	608503	608503	608503
608403	608403	608401	608401	608401	608401	608401	608401	608402	608402	0	0	608402	0	0	0	0	0	0	0	0	608503	608503	608503	608503
608403	608403	608401	608401	608401	608401	608401	608401	608401	608401	0	0	0	0	0	0	0	0	0	0	0	0	0	608503	608503
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602001	602001	601902	601902	601902	601902	601902	601902	601902	601902	601902	601902	601902	601902	601902	601901	601901	601901	601901	601901	601901	601901	0	0	0

Figure 3 Converted raster data on shapes and locations of sub-compartments
Slika 3. *Pretvoreni rasterski podaci po odsjecima*

0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
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0	0	0	0	0	0	0	0	0	0	0	3984	0	0	0	0	0	4027	4027	4027	4027	0	0	0	0
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0	0	0	0	613	613	613	0	0	0	0	0	0	0	0	0	0	0	0	602	0	0	0	0	0
613	613	613	613	613	0	0	0	0	0	0	0	0	0	0	0	1367	1367	1367	5234	5234	0	0	0	0
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0	0	0	0	0	0	0	0	0	0	0	0	1367	1367	0	0	0	0	0	0	0	2392	2392	1365	0
7026	7026	7026	7026	7026	7026	1367	1367	1367	1367	1367	1367	1367	0	0	0	0	0	0	0	0	2392	0	1365	1365
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0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2392	2392	0	0

Figure 4 Converted raster data on forest and public roads
Slika 4. *Pretvoreni rasterski podaci za šumske i javne ceste*

2.3. Classification of forest biomass harvesting and transporting systems – *Razredba sustava pridobivanja i transporta šumske biomase*

In this study the whole trees are used as energy sources (Table 1), and a larger chipper is required for their comminutation than the chipper for comminuting logging residues. For the chipping process, the use of a small-sized chipper (the engine power output of 23 PS /17.2 kW/) was assumed for comminuting logging residues, and a middle-sized chipper (200 PS /149 kW/) for comminuting thinn-

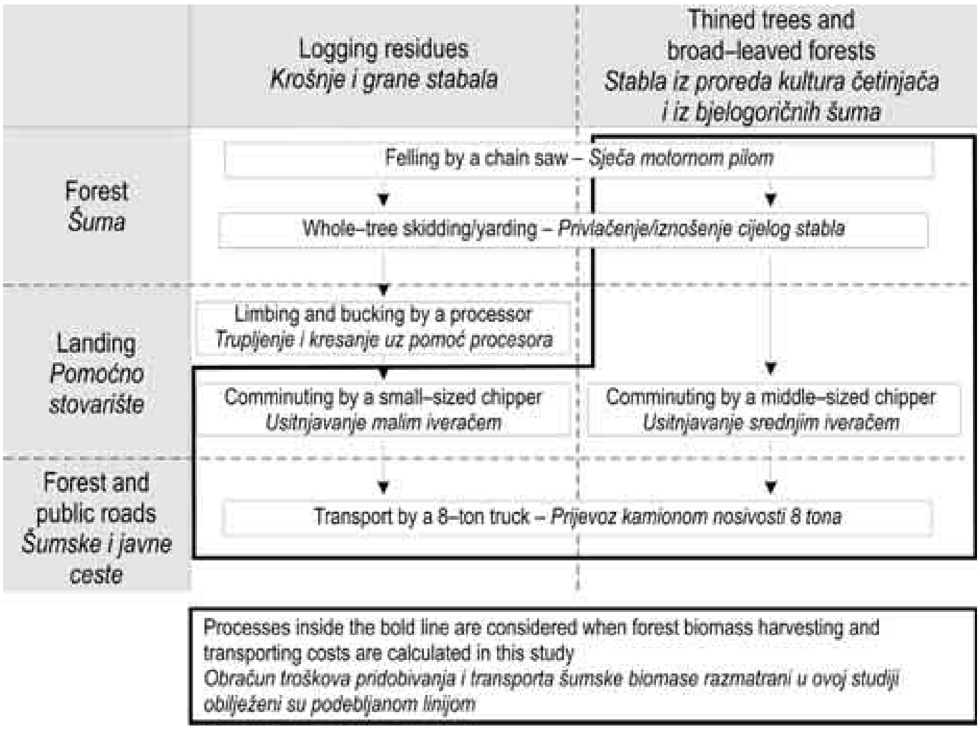

Figure 5 Classification of systems according to the parts of a tree for energy purposes
Slika 5. *Prikaz modela prema dijelovima stabala korištenih kao izvor energije*

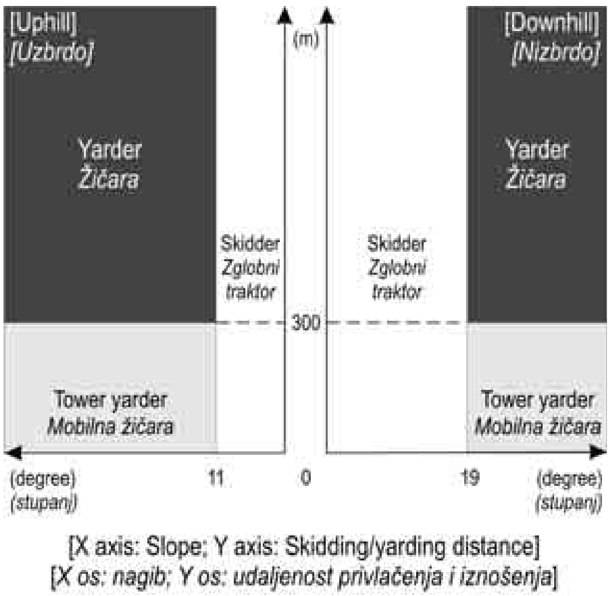

Figure 6 Classification of machines according to topographical conditions
Slika 6. *Razredba strojeva za pridobivanje drva prema topografskim uvjetima*

ed trees and broad-leaved trees. According to the parts of tree for energy purposes (logging residues or the whole tree), forest biomass harvesting and transporting systems were classified into two types (Figure 5). The machine for skidding/yarding is usually selected according to topographical conditions, i.e., slope, skidding/yarding distance, and skidding/yarding direction (uphill or downhill). In this study, the use of tractors (skidders), tower yarders (mobile yarders), and yarders is assumed for skidding/yarding process, and Figure 6 shows the classification of skidding/yarding machines according to topographical conditions of sub-compartments.

Table 3 shows the equations for calculating forest biomass harvesting and transporting costs whose variables are slope, skidding/yarding distance, and transporting distance. The costs of labor, machine, and fuel are considered here. By applying topographical data of each sub-compartment to the equations listed above, the procurement costs of forest biomass of all sub-compartments in the region can be calculated.

3. Results and discussions – *Rezultati i rasprava*

3.1. Annual available amount of forest biomass – *Godišnja moguća količina šumske biomase*

The annual available amount of biomass resources in the region was calculated by the method described in Section 2.1. and Table 4. About half of the

Table 3 Equations for calculating forest biomass harvesting and transporting costs

Tablica 3. *Jednadžbe za izračunavanje troškova pridobivanja i prijevoza šumske biomase*

Machine – *Stroj*	Equation, yen/t (DM)[1,2] – *Jednadžba*, jen/t (ST)[1,2]
Skidder – *Zglobni traktor*	[Logging residues] $0.068 \cdot L_T + 4{,}888$ *[Krošnje i grane]* [Thinned trees] $2.11 \cdot L_{SY} + 0.068 \cdot L_T + 229 \cdot e^{0.117 \cdot d} + 11{,}408$ *[Stabla iz proreda]* [Broad-leaved forests] $1.51 \cdot L_{SY} + 0.048 \cdot L_T + 164 \cdot e^{0.117 \cdot d} + 8{,}371$ *[Bjelogorične šume]*
Tower yarder – *Mobilna žičara*	[Logging residues] $0.068 \cdot L_T + 4{,}888$ *[Krošnje i grane]* [Thinned trees] $13.85 \cdot L_{SY} + 35{,}908 / L_{SY} + 0.068 \cdot L_T + 8{,}650$ *[Stabla iz proreda]* [Broad-leaved forests] $9.893 \cdot L_{SY} + 25{,}648 / L_{SY} + 0.048 \cdot L_T + 6{,}402$ *[Bjelogorične šume]*
Yarder – *Žičara*	[Logging residues] $0.068 \cdot L_T + 4{,}888$ *[Krošnje i grane]* [Thinned trees] $1{,}904 / L_{SY}\text{-}0.2142 + 31{,}023 / L_{SY} + 0.068 \cdot L_T + 8{,}518$ *[Stabla iz proreda]* [Broad-leaved forests] $1{,}360 / L_{SY}\text{-}0.2142 + 22{,}159 / L_{SY} + 0.048 \cdot L_T + 6{,}307$ *[Bjelogorične šume]*

[1]Yen to Euro exchange rate was about 135 at the beginning of September 2005. – *Početkom rujna 2005. godine devizni je tečaj bio 135 jena za 1 euro*

[2]L_{SY}: Skidding/yarding distance (m), L_T: Transporting distance (m), d: Slope (degree) – L_{SY}: *udaljenost privlačenja (m)*, L_T: *udaljenost prijevoza (m), d: nagib (stupanj)*

sub-compartments in the region were targeted for harvesting logs and energy sources, and the annual available amount was calculated as a total 52,206 t/y (DM). Both man-made coniferous forests and naturally regenerated broad-leaved forests will be felled in a sustainable way, i.e., by considering the forests cutting cycles. Therefore, the forests' health is expected to be improved by energy utilization of biomass resources. At least 143 t (DM) [52,206 t/y (DM) / 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 m^3/y of the cut volume of logs corresponds to 72 % of the annual consumption of logs for timber in the region, and the total amount of logs and energy sources to be harvested are enough to introduce large efficient forestry machines.

3.2. Relationship between the mass and procurement cost of forest biomass – *Ovisnost troškova pridobivanja šumske biomase o njezinoj masi*

Topography data presented in Section 2.2 and equations for calculating the costs classified in Section 2.3 were used here. First, the skidding/yarding machine to be used in each sub-compartment was selected according to the sub-compartment topographical conditions (Figure 6). Second, the harvesting and transporting systems for forest biomass were selected according to the parts of tree for energy purposes (logging residues or the whole tree, Figure 5). Third, the topographical conditions of all sub-compartments were applied to the equations for calculating the harvesting and transporting costs

Table 4 Annual available amount of forest biomass in the region

Tablica 4. *Godišnja moguća količina šumske biomase u istraživanom području*

Biomass resources *Izvori biomase*	Number of sub-compartments *Broj odsjeka*	Amount t/y (DM) *Količina* t/god. (ST)	Cut volume of logs (m^3/y) *Obujam izrađenih trupaca* (m^3/god.)
Logging residues – *Krošnje i grane*	120	4,035	57,162
Thinned trees – *Stabla iz proreda*	637	27,854	-
Broad-leaved forests – *Bjelogorične šume*	266	20,317	-
Total – *Ukupno*	1,023	52,206	57,162

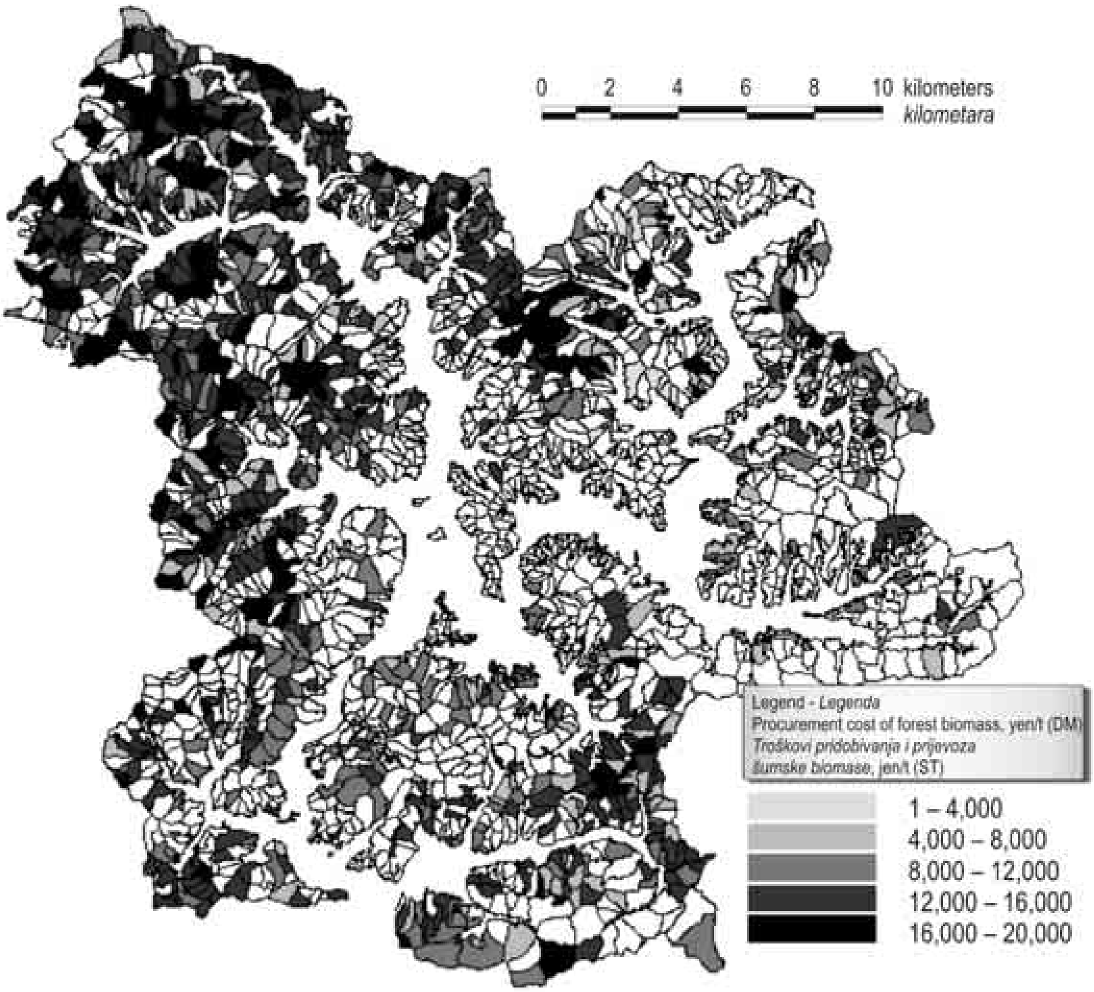

Figure 7 Distribution map of the procurement cost of forest biomass, yen/t (DM)
Slika 7. *Prikaz raspodjele troškova pridobivanja i prijevoza šumske biomase, jen/t (ST)*

(Table 3). As a result, the masses and procurement costs of all sub-compartments were prepared. Figure 7 shows the distribution map of the procurement cost of forest biomass from each sub-compartment, and Figure 8 shows the relationship between the annual available amount and cost for harvesting and transporting forest biomass in the region.

Logging residues were the most cost effective, followed by broad-leaved forests; thinned trees were the most costly. In this study, logging residues, i.e., tree tops and branches which are generated during limbing and bucking, are regarded as by-products in logging operations (Figure 5). Therefore, the procurement costs of residues were calculated by considering only the chipping and transporting processes, and these costs proved to be the lowest. Although the procurement cost of thinned trees was roughly the same as that of broad-leaved forests per cubic meter, the cost of broad-leaved forests was lower than the cost of thinned trees in Figure 8 because of higher bulk density of a broad-leaved tree than that of a coniferous tree.

For achieving the energy utilization of forest biomass in the region, the following three advantages, already mentioned above, should be taken into consideration:

1) 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/t (DM) or less will be accepted,« the annual available amount of the plant biomass can be determined.
2) On the other hand, when the annual amount of the required forest biomass is set up, e.g., »20,000 t/y (DM) of biomass will be necessary for the operation of an energy-conversion plant,« the plant can determine the ceiling purchase price.

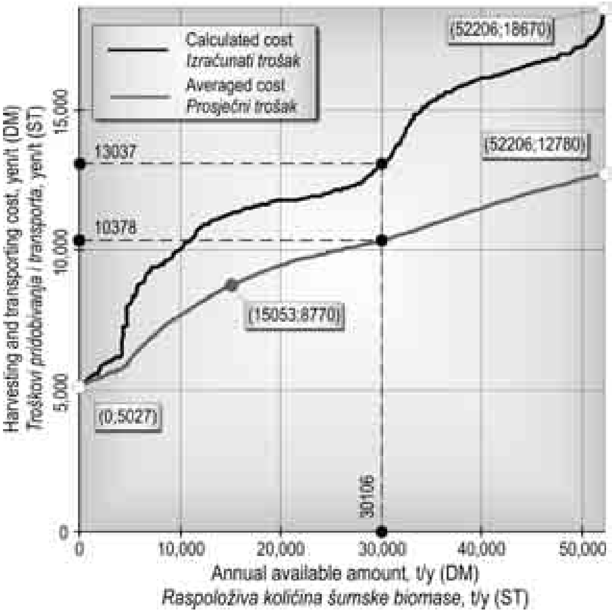

Figure 8 Relatioship between the mass and procurement cost of forest biomass

Slika 8. *Ovisnost troškova pridobivanja šumske biomase o njezinoj godišnjoj proizvodnji*

3) The procurement costs from all sub-compartments in the region are calculated. Therefore, the terms referred to in both 1) and 2) above, can contribute to drawing up an operational plan, i.e., »From which sub-compartment forest biomass should be harvested and transported?«

Here are some considerations about the construction of a power-generation plant that uses forest biomass as fuel and supplies electricity to the region. Concerning the scale of the plant, the net power output is assumed to be 3 MW, the thermal efficiency 12 %, and the operating rate 70 %. This scale of the plant would cover 5,400 households, i.e., 24.8 % of households in the region, and consume 30,106 t/y (DM) of forest biomass. Therefore, the ceiling purchase price of biomass can be read as 13,037 yen/t (DM) in Figure 8, and the plan to harvest and transport biomass from sub-compartments whose costs are lower than 13,037 yen/t (DM) 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 total sum of forest biomass purchase price by the amount of biomass to be purchased. The averaged cost for the supposed plant can be read as 10,378 yen/t (DM) in the above figure, and this value is equivalent to 16.95 yen/kWh. From the cost point of view, 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 energy utilization of forest biomass should not be only discussed in terms of cost. A comprehensive assessment of utilization of forest biomass should be made taking into consideration the effects of reduction of carbon dioxide (CO_2) emission and increase of job opportunities in the region.

4. Conclusions – *Zaključci*

Feasibility of forest biomass energy utilization 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 forest biomass. First, the distribution map of biomass resources was completed by use of the GIS, and information on topography of each sub-compartment was prepared. Second, harvesting and transporting systems were classified into six types according to the parts of tree used as energy source (two types) and topographical conditions (three types), and the equations for calculating the costs whose variables are slope, skidding/yarding distance, and transporting distance were developed. Finally, the relationship between the mass and procurement cost of forest biomass in the region was analyzed. As a result, logging residues [the annual available amount was 4,035 t/y (DM)] proved to be the most cost effective, followed by broad-leaved forests [20,317 t/y (DM)]; thinned trees [27,854 t/y (DM)] proved to be the most costly. This analysis could be of help in drawing an operational plan, i.e., in selecting sub-compartments to be felled. For instance, it was calculated that the amount of biomass resources of 30,106 t/y (DM) was required for the construction of a power-generation plant that covered 24.8 % of the power consumed by households in the region. To obtain this amount of forest biomass for energy purposes, forest biomass should be harvested in sub-compartments, whose procurement costs are lower than 13,037 yen/t (DM).

In addition to forest biomass discussed in this study, it would be convenient and cost effective to utilize mill residues (wood shavings and barks generated in sawmills and plywood industries), wood-based waste material, and trimmings of park trees, roadside trees, and garden trees. For instance, if half the amount of biomass necessary for the supposed plant [15,053 t/y (DM)] were covered by mill residues, wood-based waste material and trimmings generated in the region, the averaged cost of forest biomass would be reduced to 8,770 yen/t (DM) (Figure 7). Moreover, many of the mill residues, wood-based waste material and the trimmings can be obtained free of charge, so that the effectiveness of the reduction in biomass procurement cost would be even greater on the whole, e.g., {15,053 [t/y (DM)] · 8,770 [yen/t (DM)] + 15,053 [t/y (DM)] · 0 [yen/t (DM)]} / 30,106 [t/y (DM)] = 4,385 [yen/t (DM)]. On the other hand, the relationship between the mass and procurement cost of forest biomass analyzed in this study was only focused on the present moment. Considering a long-term feasibility of a sustainable utilization of forest biomass, further studies and discussions should be carried out.

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Sažetak

Šumska biomasa kao izvor energije u planinskom području Japana: GIS studija

Japansko je šumarstvo dugo vremena bilo nerazvijeno. I danas ima puno regija u kojima šumarstvo i šumski radovi nisu mehanizirani te su troškovi sječe izuzetno visoki. S druge je strane šumska biomasa u tim regijama izuzetno zanimljiva za cjelokupno japansko gospodarstvo. Očekuje se, naime, kako će uporaba šumske biomase za energiju pridonijeti razvitku šumarstva uz istodobno unapređenje ekoloških, ekonomskih i socijalnih funkcija šumskih kultura kojima dosad nije gospodareno na zadovoljavajući način. Pri tome je nužno izraditi studije kojima će se prikazati mogućnosti proizvodnje šumske biomase te troškovi njezina pridobivanja i transporta.

U ovom se radu raspravlja o mogućnosti uporabe šumske biomase u jednoj od planinskih regija u Japanu uz primjenu geografskoga informacijskoga sustava (GIS). Kao model za provedbu istraživanja odabrano je područje Hitami (u pokrajini Hyogo) površine 493,82 km^2, od čega na šume i šumsko zemljište otpada oko 75 % (58 % je šumskih kultura četinjača, dok prirodnih šuma listača ima 42 %). Izdvojeno je 2168 odsjeka s ukupnom drvnom zalihom od 7 841 851 m^3.

Cilj je rada utvrditi postojeću situaciju na istraživanom području glede mogućnosti uporabe šumske biomase za energiju uz definiranje detaljnoga rasporeda šumske biomase po odsjecima, odabir tehničkoga sredstva za njezino privlačenje (iznošenje) i iveranje te analizu postojeće mreže šumskih i javnih cesta, kao i konfiguracije terena.

Definirane su tri inačice uporabe šumske biomase s obzirom na tip i dob šume. U kulturama se četinjača u dobi od 31 do 60 godina sva drvna masa iz prorednih sječa koristi kao izvor energije. U istim se kulturama četinjača u dobi preko 61 godine provode čiste sječe, od debala se posječenih stabala izrađuje tehnička oblovina, dok se kao izvor energije koriste samo krošnje i grane posječenih stabala. U trećem se slučaju šumska biomasa pridobiva iz prirodnih šuma listača; sječe se provode svakih 30 godina i sva se drvna masa rabi za energiju.

Primjenom je GIS-a izrađen tematski zemljovid distribucije šumske biomase istraživanoga područja. Za svaki su odsjek definirani i parametri konfiguracije terena (nagiba) kako bi se odredio smjer privlačenja/iznošenja drvne biomase. Određene su i prosječne srednje udaljenosti privlačenja/iznošenja drvne biomase (primjenom težišne metode) te srednje udaljenosti kamionskoga transporta drvne biomase do krajnjega korisnika.

Pri sječi je stabala upotrebljavana motorna pila, čitava su stabla privlačena (iznošena) do pomoćnoga stovarišta na kojem su samo iz stabala četinjača starijih od 61 godine izrađivani trupci (izradba je drvnih sortimenata obavljena procesorom). Odabir je tehničkoga sredstva za privlačenje (iznošenje) drva obavljen temeljem topografske raščlambe svakoga odsjeka, a moglo se odabrati između zglobnoga traktora, mobilne žičare i žičare. Iveranje se obavljalo na pomoćnom stovarištu šumske ceste. Transport je do krajnjega korisnika izveden kamionom nosivosti 8 t.

Dizajnirani su matematički modeli izračuna troškova pridobivanja i transporta šumske biomase (od šume do krajnjega korisnika) u ovisnosti o objašnjenim utjecajnim čimbenicima.

Rezultati analiza pokazuju kako je na istraživanom području moguće proizvesti ukupno 52 206 t/god. šumske drvne biomase, što iznosi oko 143 t dnevno. Od toga je 27 854 t/god. iz kultura četinjača u dobi od 31 do 60 godina (637 odsjeka), 4 035 t/god. iz kultura četinjača u dobi preko 61 godine (120 odsjeka) i 20 317 t/god. iz prirodnih šuma listača (266 odsjeka). Također je, uz navedenu količinu šumske biomase, moguće izraditi i 57 162 m^3/god. trupaca različite kakvoće (što je 72 % godišnje potrebe 43 pilane u regiji). Rezultati će ove analize pomoći pri izradbi operativnoga plana pridobivanja šumske biomase, a u kombinaciji s troškovnom komponentom odabiru odsjeka iz kojih se postupak pridobivanja može provesti najjeftinije.

Prosječna srednja udaljenost privlačenja/iznošenja šumske biomase iznosi 262 m, a prosječna udaljenost kamionskoga prijevoza šumske biomase 14,5 km.

Ukupna količina moguće šumske biomase istraživanoga područja s ukupnom cijenom pridobivanja i transporta nižom od 13 037 yen/t (što je uzeto kao gornja cjenovna granica) iznosi 30 106 t/god. i pokriva 24,8 % godišnjih potreba za energijom kućanstava u regiji Hitami.

Prosječna cijena pridobivanja i transporta šumske biomase iznosi 10 378 yen/t, što odgovara cijeni od 16,95 yen/kWh električne energije. Cijena električne energije u Japanu danas iznosi 18,17 kWh, pa kada se cijeni pridobivanja i transporta šumske biomase pribroje i ostali troškovi potrebni za proizvodnju električne energije iz šumske biomase, tada samo s troškovnoga stajališta donošenja odluke ideja se ne bi mogla podržati. Međutim, troškove je moguće dodatno smanjiti uporabom biomase iz drugih izvora (npr. ostaci nastali orezivanjem parkovnoga drveća, drveća uz rubove cesta, ostaci iz pilana itd.) te svesti ukupnu cijenu pridobivanja biomase na 8 770 yen/t. Nije opravdano raspravljati o mogućnosti i potrebi uporabe šumske biomase za energiju samo s gledišta troškovne isplativosti. Treba uzeti u obzir i mogućnost otvaranja novih radnih mjesta, smanjenje emisije ugljičnoga dioksida (CO_2) itd. Prikazani je model nužno sagledati u širem okruženju te će daljnje studije i rasprave ići u tom smjeru.

Ključne riječi: *šumska biomasa, studija isplativosti, planinsko područje, GIS, troškovi pridobivanja i prijevoza, Japan*

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