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# Supply potential and annual availability of timber and forest biomass resources for energy in Japan †

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**Abstract:** This study calculated incomes and expenditures such as silvicultural and harvesting as well as stumpage prices on the Japanese cedar, cypress, pine, and larch forests using the silvicultural prescriptions set based on the regional forest plans and operation systems set based on topographic conditions such as slope angles and height differences with GIS. Then, this study estimated the availability of unused materials for woody biomass power generation plants under operation with FIT at the end of June 2020 as the supply potential from the profitable subcompartments. Considering the subsidy rate of 100% to secure the reforestations, the availabilities met the demands in Japan as a whole.

**Keywords:** Forest GIS; woody biomass power generation; unused material; supply potential; availability

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## 1. Introduction

Japan's forests account for two-thirds of national land area and cover approximately 25 million hectares. Total growing stock has reached approximately 4.9 billion m$^3$ [1]. Extraordinary efforts have been made to recover forests devastated during World War II and the subsequent restoration age. Approximately 10 million hectares have planted forests, and more than half of these planted forests are over 46 years old, fully ready for harvest. To promote sustainable timber and forest biomass utilization, technically feasible and economically viable availability should be estimated considering forest regeneration. Therefore, this study calculated incomes and expenditures such as silvicultural and harvesting as well as stumpage prices on the Japanese cedar, cypress, pine, and larch forests using the silvicultural prescriptions set based on the regional forest plans and operation systems set based on topographic conditions such as slope angles and height differences with GIS.

## 2. Materials and Methods

This study used forest registration data (tree species and site index) and GIS data (information on roads and subcompartment layers) from the prefecture for private and communal forests, GIS data (subcompartment layers, including tree species), from the Forestry Agency of Japan for national forests, as well as 10 m grid digital elevation models (DEMs) from the Geographical Survey Institute. Then, this study estimated the availability of unused materials for woody biomass power generation plants under operation with FIT at the end of June 2020 as the supply potential from the profitable subcompartments. Most of existing studies estimated them as a unit of municipality or a 1 km mesh [2-4] whereas the present study estimated them as a subcompartment, which was an actual forest management unit. The method we developed with MATLAB could be used to make estimations for the whole of Japan, within a reasonable timeframe, defining units as subcompartments. Full technical details on the data analysis methods can be found in earlier papers [5,6].

Forest resources in each stand were predicted using the system yield table, Local Yield Table Construction System (LYCS3.3) [7]. The supply potential of timber and forest biomass resources was estimated using the cutting ages and rates based on the forest management plans obtained from the prefectures, as well as the rates of timber (75%) and forest biomass (15%), according to stem volumes over barks without branches. The remaining 10% included stems left in the forests and barks removed in the sawmills and factories. Then, revenues were estimated using log prices and rates, which were set based on the Forestry Agency of Japan [8]. Log prices of forest biomass resources were set to the same price as chip logs, because there were no statistical data, and forest biomass resources are currently similar to chip logs, such as small-diameter or defect stem logs, rather than logging residues in Japan.

Costs of commercial thinning and final harvesting were estimated after setting the forest operation systems and machine sizes according to the topographical conditions, such as slope angles and height differences within 500 m [9]. The forest operation systems included CTL (cut-to-length), G9-13t, W9-13t, S9-13t, W6-8t, S6-8t, W3-4t, tower yarder, and yarder. The harvesting costs in the stands (Figures 1 and 2) were the sums of the operation costs, such as felling, bunching/winching/yarding, processing, and forwarding, as well as construction of the strip-road network [10,11]. In addition, transportation costs [12] from forests to log markets for timber and woody biomass power generation plants under operation with Feed-In-Tariff (FIT) at the end of June 2020 for forest biomass resources were estimated. Furthermore, woody biomass power generation plants approved by FIT were included in the additional analyses to estimate future demand.

Regeneration costs, including site preparation, planting, weeding, pruning, and precommercial thinning were estimated according to the forest management plans obtained from the prefectures. For regeneration operations, subsidies were received from the government of Japan [13]. Furthermore, some prefectures allocated additional subsidies to secure regeneration operations through new taxation schemes [14]. Therefore, subsidies covering 100% of the regeneration costs were examined in this study. In this study, subsidies for commercial thinning operations and strip-road construction were also examined [15]. Those subsidies were provided for operational site areas larger than 5 ha. Standard unit costs for thinning operations were estimated according to thinning rate, processing methods such as chain saw or mechanized, extraction methods such as ground-based or yarder, and extracted volumes per hectare. Standard unit costs for strip-road construction were estimated using road width and slope angles. The road width for G9-13t, W9-13t, and S9-13t was 3.5 m, whereas that for W6-8t, S6-8t, and W3-4t was 2.5 m. Finally, profitable forests were identified as those with profits more than stumpage prices, and annual availability was estimated as the supply potential from profitable forests divided by rotation ages.

## 3. Results and Discussions

Supply potentials of timber and forest biomass were estimated at 65,490,336 $m^3$/year and 13,098,067 $m^3$/year, respectively whereas those availabilities from subcompartments, which were typical operation units in Japan, were estimated at 31,080,672 $m^3$/year and 6,216,134 $m^3$/year, respectively. Therefore, the rate of the availabilities to the supply potentials was 47.5%. Furthermore, the rate of the availabilities to the current demands was 71.6%. Considering the subsidy rate of 100% to secure the reforestations, the rate of the availabilities to the current demands increased to 106.2%. Thus, the availabilities met the demands in Japan as a whole.

The government of Japan investigated a number of forestry households only having more than 1 ha of forests, and 74% of forestry households had less than 5 ha [1]. There are numerous other forestry households having less than 1 ha of forests that have not been investigated. The government of Japan implemented the "Experimental Projects of Forest and Forestry Revitalization Plan", which includes aggregating small forests, establishing forest road networks, and promoting mechanization in order to conduct forestry operations efficiently on a large scale and reduce costs [16]. Therefore, the present study made aggregated forests while merging subcompartments in the same watersheds [17], and availability from aggregated forests was also estimated.

Considering aggregation in the same watershed with access road costs of JPY25,000/m, availabilities of timber and forest biomass were estimated at 53,694,872 $m^3$/year and 10,738,974 $m^3$/year, respectively. Therefore, the rate of the availabilities to the supply potentials increased to 82.1%. Furthermore, the rate of the availabilities to the current demands also increased to 123.6%. However, since future demands including woody biomass power generation plants approved by FIT in addition to plants under operation with FIT increased from 8,685,784 $m^3$/year to 11,018,104 $m^3$/year, the rate of the availability to the future demands was decreased to 97.5% although the availability slightly increased to 10,744,158 $m^3$/year.

Considering the subsidy rate of 100% to secure the reforestations again, the rate of the availabilities to the future demands increased to 114.6%. Therefore, aggregation and subsidies would play an important role in increasing the annual availability of timber and forest biomass resources in Japan. The results obtained in the present study can contribute to the effective utilization of forest resources under sustainable forest management.

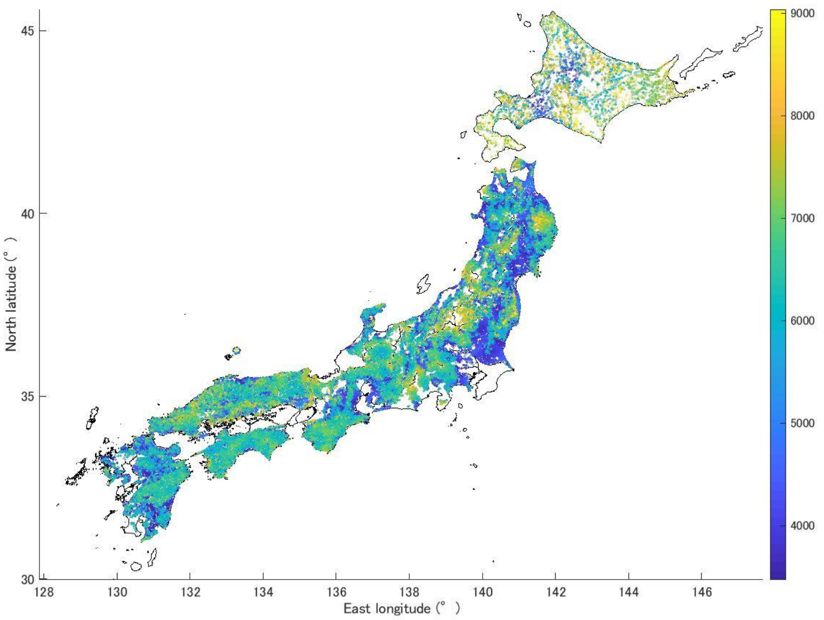


**Figure 1.** Harvesting costs (JPY/$m^3$, EUR 1 = JPY 132.40 as of June 24, 2021).

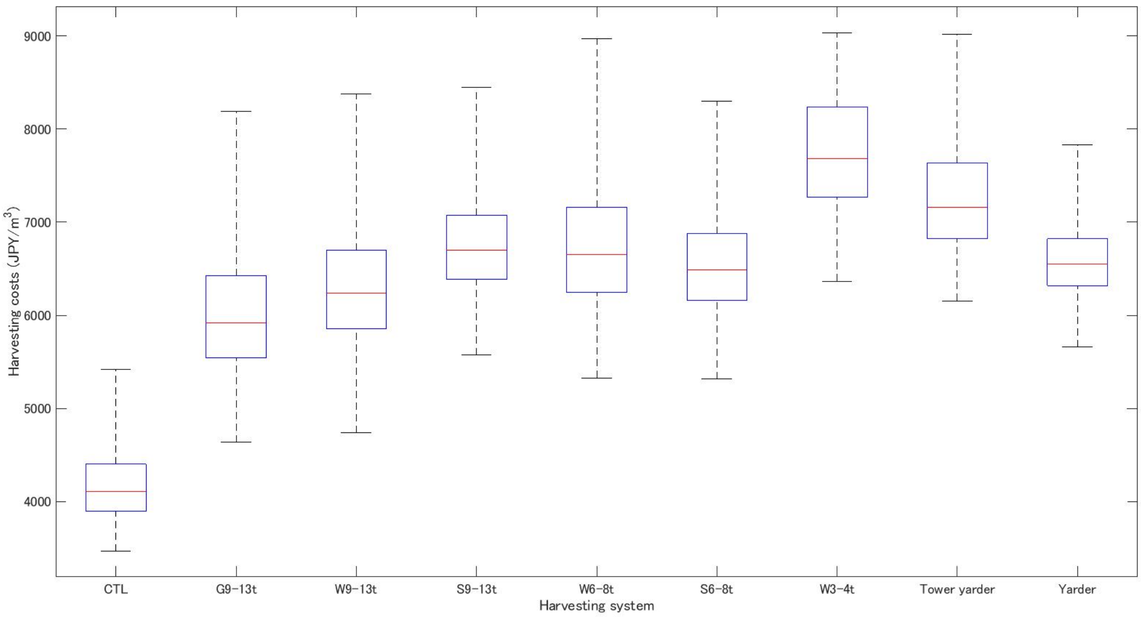


**Figure 2.** Harvesting costs according to harvesting systems.

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**Conflicts of Interest:** The authors declare no conflicts of interest.

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