Forest biomass energy evaluation for sustainable utilization in Numazu City, Shizuoka Prefecture

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Abstract: We estimated the sustainable use of forest biomass energy in Numazu City by using a software geographical information system (GIS). We used two criteria: one was the position of the road, and the other was the methods of logging. The two criteria also had five (0–100, 0–200, 0–300, 0–400 m, all) and three (maximum growth age, a standard felling age, usage of harvest residues) cases, respectively. We assess 15 cases framed by these criteria. As a result, the forest in the city would generate 2.65% of the city's power consumption.

Key Words: Biomass energy, Distributed generation, Geographical Information System

1 Introduction

Since the 1960s, Japan's power supply has heavily relied on oil. However, following the oil shocks, the country has promoted the use of coal, natural gas, nuclear power, and other energy sources, increasing its share. By the fiscal year 2013, the energy mix was composed of oil (42.7%), coal (25.1%), natural gas (24.2%), and nuclear power (0.4%) [1]. Japan's power supply is primarily dominated by centralized large-scale power generation. However, the adoption of decentralized power sources has been progressing due to the need for a stable regional power supply [2].

Among these decentralized power sources, biomass energy has gained attention, particularly given that forests cover 68.5% of Japan's land area and social issues such as the decline of the forestry industry, the degradation of woodlands around urban areas, and other related challenges[3]. However, the collection and management of biomass involve significant costs. Biomass is widely dispersed, and harvesting trees far from forest roads is not economically feasible. Therefore, to realistically consider the utilization of forest biomass energy in each region, it is necessary to assess the potential of forest biomass energy quantitatively, considering geographical conditions such as the distance from forest roads [4]. This study applies the method by Tanaka et al. (2003) to Numazu City and uses geographic information systems (GIS) to quantitatively evaluate the potential of biomass energy in the city's forests.

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2 Methods

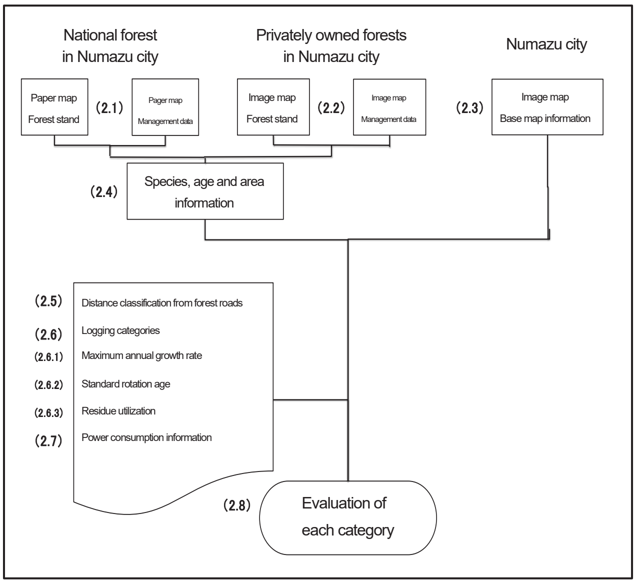


Fig. 1 Flow of the present research

2.1 National forest data in Numazu City

The forest management implementation plan map for national forests [5] was obtained and converted into image data. Forest stand shapefiles were manually created with this data in a GIS software (hereafter called QGIS). Subsequently, the tree species and forest age from the management above plan map were read, and the attribute data was manually input.

2.2 Data on privately owned forests in Numazu City

Forest planning maps and forest registers [6] were obtained in QGIS data format.

2.3 Base map information of Numazu City

The base map information of Numazu City [7] was obtained and displaied it in QGIS.

2.4 Information on tree species, forest age, and area

Using the analysis functions in QGIS, the area for each forest stand was calculated and linked with the corresponding tree species and forest age.

2.5 Distance classification from forest roads

The distance from forest roads to each forest compartment was measured using the analysis functions in QGIS. This study established five classifications based on the distance from forest roads, as shown in Table 1 [4]. To illustrate how each of these segments was distributed on the map, each segment was color-coded.

Table 1 Distance classification from forest road

Classification	Distance from forest roads to each forest stand (m)
1	0–100
2	0–200
3	0–300
4	0–400
5	All forest stands are used.

2.6 Logging categories

2.6.1 Logging category 1: maximum annual growth rate

Keeping the annual logging volume within the range of the forest's annual growth is necessary to sustainably utilize forests. In this study, the average annual growth rate per unit area of the forest was defined as follows [4], and this value was used to calculate the annual biomass availability of the forest every five years.

$$G = \frac{(B_t - B_{t-5})}{(A_t - A_{t-5})}$$

G：Average annual growth rate per unit area (m^3 ha^{-1} y^{-1})

A_{t-5}：Age of the forest five years ago (y)

A_t：Current age of the forest (y)

B_{t-5}：Timber volume per hectare five years ago (m^3 ha^{-1})

B_{t-5}：Current timber volume per hectare (m^3 ha^{-1})

Table 2 Average annual growth per unit area by species and age

Age (y)	Unit: m^3 ha^{-1} y^{-1}				
	National Forest			Privately owned forest	
	PF		NF	PF	NF
	CJ	CO	BT	CT	BT
0–4	0.3	0.2	0.6	ND	ND
5–9	1.2	1.2	1.9	0.2	0.0
10–14	12.2	9.0	5.8	5.5	0.0
15–19	10.1	7.7	5.8	1.8	9.4
20–24	10.5	8.1	7.9	5.0	5.9
25–29	11.0	8.5	11.6	5.1	1.7
30–34	10.8	9.2	17.8	5.4	–5.2
35–39	10.0	7.5	10.0	4.8	–11.8
40–44	8.8	6.0	–0.1	6.6	0.0
45–49	8.2	3.8	–3.9	5.9	19.7
50–54	7.9	2.6	–4.9	6.3	0.5
55–59	5.3	2.1	–2.8	4.8	2.9
60–64	3.3	2.2	–4.2	5.6	–0.3
65–69	4.9	3.0	–4.1	5.1	–4.7
70–74	2.2	0.4	2.3	4.8	20.3
75–79	1.1	0.0	6.8	4.5	–38.4
80–84	1.8	–0.4	4.1	4.7	ND
85–89	0.6	1.1	–3.9	6.2	ND
90–94	–0.4	–1.3	4.2	3.6	ND
95–99	0.0	0.0	0.0	–3.0	ND
100–	0.0	0.0	0.0	–11.5	ND

PF: Planted forest, NF: Natural forest

CJ: *Cryptomeria japonica*, CO: *Chamaecyparis obtusa*

BT: Broadleaf tree, CT: Coniferous tree

ND: No data

The annual growth rate per unit area, detailed by tree species and forest age, is presented in Table 2. This calculation was based on the forest area and timber volume by species and age. Data for national forests were obtained from the Forestry Agency's statistical information [8], and data for private forests were obtained from the Fuji Regional Forest Plan [9]. Table 2 identified the optimal rotation age, where the average annual growth rate was maximized, and all the wood harvested at this stage was utilized for power generation.

2.6.2 Logging category 2: standard rotation age

The forest was harvested to utilize the central timber for construction materials and other purposes, at the standard rotation age shown in Table 3, and all the harvested wood was used for power generation. This category presumes that the central timber was initially used for construction materials, expecting all such timber to be fully recovered and repurposed for power generation. Additionally, it considered an ideal scenario in which the annual amount of timber used for construction and the amount recovered for energy purposes were equivalent.

Table 3 Standard logging age of forests in shizuoka Prefecture

Unit: year

CJ	CO	OCT	BT	CT	BT
40	45	50	25	50	25

OCT: Other coniferous tree
Other abbreviations are the same as in Table 2.

2.6.3 Logging category 3: residue utilization

In this category, the forest was harvested at the standard rotation age, but only the residues from timber used for construction materials were utilized for power generation. The residue generation rate (residue generation volume/logging volume) was assumed to be 31% [10].

2.7 Power consumption information

The annual residential electricity consumption in the eastern part of Shizuoka Prefecture was calculated based on the number of households in Numazu City and other municipalities in eastern Shizuoka Prefecture. The annual residential electricity consumption data for the eastern part of Shizuoka Prefecture and the number of households were obtained from the 2014 Edition of the Numazu City Statistical Yearbook [11].

2.8 Evaluation of each category

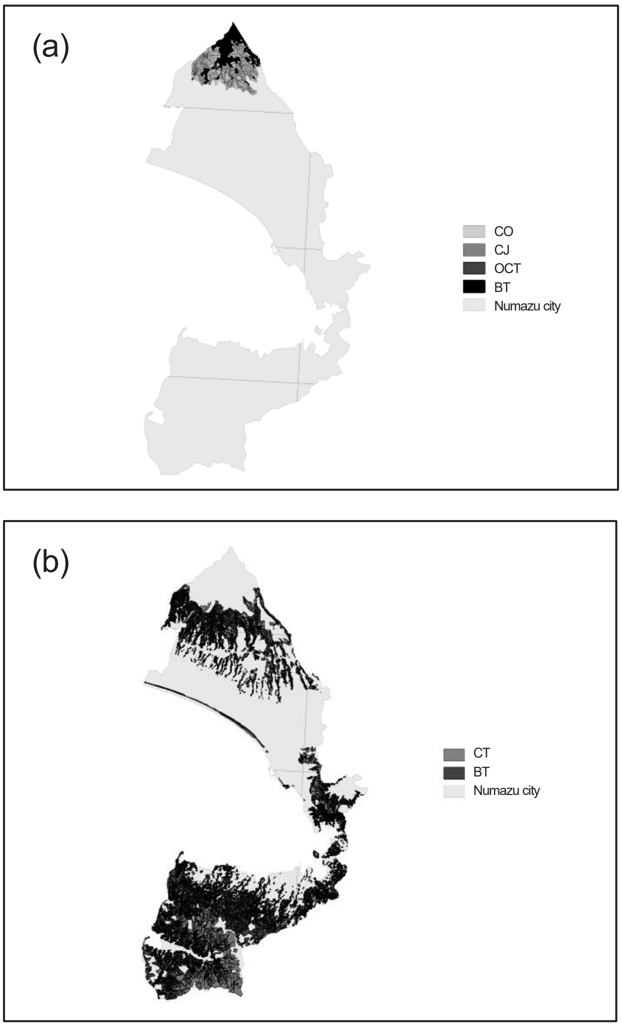
The power generation potential was calculated from the annual forest biomass availability for the 15 combinations of categories set in Sections 2.5 and 2.6 (3×5). These results were compared with the annual residential electricity consumption in Numazu City to evaluate each category. The power generation potential from forest biomass was calculated using the following equation:

$$P = U \times S \times C \times E$$

P : Power generation potential (kWh)
U : Available biomass (m^3)
S : Specific gravity (kg m^{-3})
C : Calorific value (kJ kg^{-1})
E : Power generation efficiency (=25%)

The specific gravity and calorific value of the tree species, necessary for calculating the power generation potential, were based on the values referenced from Tanaka et al. (2003) [4].

3 Results and Discussion



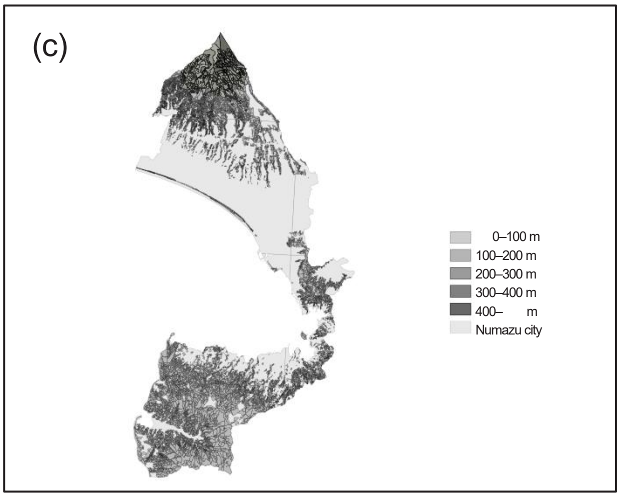


Fig. 2 GIS data
(a) national forests, (b) private forests, and (c) distance floor classification maps are shown.

The GIS data, a significant component of this study, was visually represented in Figure 2, providing a comprehensive overview of the research. The annual biomass power generation for each category was calculated, and the ratio of this value to the annual residential electricity consumption was determined. The results were presented in Figure 3. The relationship between the ratio of annual biomass power generation to annual electricity consumption for each category and the corresponding area was presented in Figure 4.

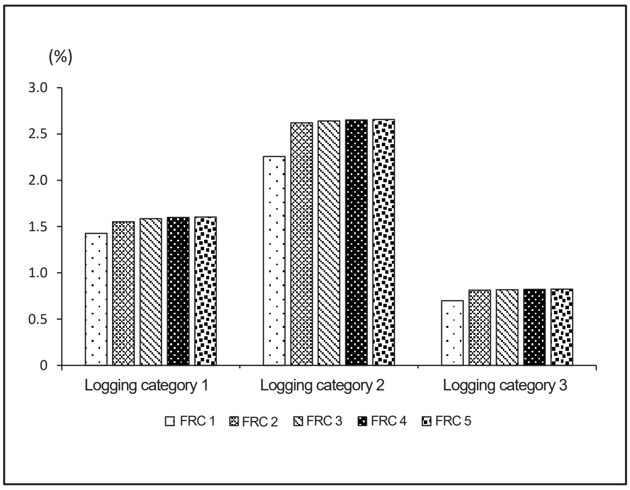


Fig. 3 Annual biomass power generation as a percentage of annual consumer electricity consumption on each forest road classification (FRC) for three logging categories

This study meticulously converted species, age, and area information for national and private forests in Numazu City into QGIS data. By overlaying distance categories from forest roads and logging categories, we calculated the potential forest utilization amount for sustainable use across various categories. These results underscore the promising potential of forest biomass energy utilization in Numazu City, as depicted in Figure 3.

It was found that the maximum annual power generation potential using the maximum sustainable forest utilization in Numazu City corresponds to approximately 2.65% of the annual residential electricity consumption in the city. The increase in the utilization from distance category 1 to distance category 2 from forest roads was significant, with the subsequent increases diminishing, indicating that utilizing forests within 200 meters of forest roads was most efficient in Numazu City.

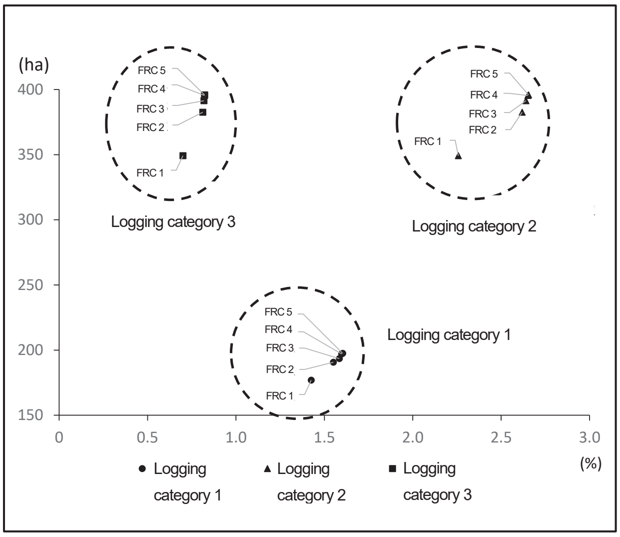


Fig. 4 Percentage of each category (annual biomass power generation/annual electricity consumption) vs. area

It was found that the maximum annual power generation potential using the maximum sustainable forest utilization in Numazu City corresponds to approximately 2.65% of the annual residential electricity consumption in the city. The increase in the utilization from distance category 1 to distance category 2 from forest roads was significant, with the subsequent increases diminishing, indicating that utilizing forests within 200 meters of forest roads was most efficient in Numazu City.

The relationship between the ratio of annual biomass power generation to annual electricity consumption for each category and the corresponding area showed that the categories were grouped according to logging categories, and the impact of the distance from forest roads was minimal.

Finally, we delved into the future challenges that require further exploration. This study, while comprehensive, did not consider the impact of terrain slope on operations. The inclusion of this factor could lead to a more realistic utilization of forest biomass energy. Additionally, the standard rotation age adopted in this study aggregates several tree species, such as other conifers. Subdividing these categories could yield more accurate data, necessitating the use of higher-quality data. These are areas that future research should focus on to enhance our understanding of forest biomass energy potential.

It was assumed that logging category 1, which involved logging at the age of maximum growth, would yield the highest annual power generation potential. However, logging category 2, which involves logging at the standard rotation age, produced more. This is because private forests predominantly contain 50-year-old trees. Compared to forests around 40 years old, where growth was at its maximum, the area of forests around 50 years old was nearly 1.88 times larger [13], influencing the results. To produce sustainable and stable forest biomass, it is preferable to log at the age of maximum growth and reforest to ensure the same amount of timber is produced annually. Future work will involve quantitatively evaluating the potential of forest biomass energy in regions beyond Numazu City.

4 Acknowledgments

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References

[1] Agency for Natural Resources and Energy: Part 2 Energy Trends, Chapter 1 Domestic Energy Trends, In: Agency for Natural Resources and Energy (ed), Annual Report on Energy for FY2014, Ministry of Economy, Trade and Industry, (2015), pp. 105-157. (資源エネルギー庁: 第2部 エネルギー動向, 第1章 国内エネルギー動向, In: 資源エネルギー庁 (ed), 平成26年度エネルギーに関する年次報告, 経済産業省, (2015), pp. 105-157.)

[2] Yamazaki, K.: Science of Energy and Environment, viii, 211p, Kyoritsu Shuppan, (2011). (山崎耕造: エネルギーと環境の科学, 211p, 共立出版, (2011).)

[3] Forestry Agency: Part 1 Trends in Forests and Forestry, Chapter I Multiple Functions of Forests and Forest Management in Japan, 1. Multiple Functions of Forests and Forest Management, In: Forestry Agency (ed), Annual Report on Forest and Forestry in Japan Fiscal Year 2013, Ministry of Agriculture, Forestry and Fisheries, (2014), pp. 8-23. (林野庁: 第1部　森林及び林業の動向, 第Ⅰ章　森林の多面的機能と我が国の森林整備, １.森林の多面的機能と森林整備, In: 林野庁 (ed), 平成25年度 森林・林業白書, 農林水産省, (2014), pp. 8-23.)

[4] Tanaka T, Kuki Y, Tanaka Y, Yoshida S, Sadohara S: The Application of GIS for Evaluating the Sustainable Use of Forest Biomass Energy, Theory and Applications of GIS, 11, (2003), 45-52.

[5] Shizuoka Forest Management Office: The 4th National Forest Operation Implementation Plan Map for Fuji Forest Planning Area, Shizuoka Forest Management Office, (2010). (静岡森林管理署: 富士森林計画区 第4次国有林野施業実施計画図, 静岡森林管理署, (2010))

[6] Shizuoka Prefecture Forest Planning Division: Forest Registry and Forest Planning Map, Shizuoka Prefecture Forest Planning Division. (静岡県森林計画課: 森林簿・森林計画図, 静岡県森林計画課.)

[7] Geospatial Information Authority of Japan: Fundamental Geospatial Data Download Service, http://fgd.gsi.go.jp/download/, (accessed: 2015-10-28). (国土地理院: 基盤地図情報ダウンロードサービス, <http://fgd.gsi.go.jp/download/>, (アクセス日: 2015-10-28).)

[8] Forestry Agency: Statistical Handbook of Forest and Forestry 2015, Ministry of Agriculture, Forestry and Fisheries, (2015). (林野庁: 森林・林業統計要覧 2015, 農林水産省, (2015).)

[9] Shizuoka Prefecture Department of Transportation Infrastructure, Forest Bureau, Forest Planning Division: Revised Forest Plan for Fuji Region, Shizuoka Prefecture Department of Transportation Infrastructure, Forest Bureau, Forest Planning Division, (2014). (静岡県交通基盤部森林局森林計画課: 富士地域森林計画変更計画

書，静岡県交通基盤部森林局森林計画課, (2014).）

[10] Yamaji, K., Yamamoto, H., and Fujino, J.: Bioenergy, 237p, Mihosin Publishing, (2000).（山地憲治，山本博巳，藤野純一：バイオエネルギー，237p，ミオシン出版，(2000).）

[11] Numazu City: Statistical Yearbook of Numazu City 2014 Edition, Numazu City, (2014).（沼津市：沼津市統計書 平成 26 年版，沼津市, (2014).）

[12] Abe F: The thermochemical study of forest biomass, Bulletin of the Forestry and Forest Products Research Institute, 352, (1988), 1-95.

[13] Shizuoka Prefecture: Shizuoka Prefecture Forestry and Forest Industry Statistical Handbook I Overview of Forestry and Forest Industry, Shizuoka Prefecture, (2015).（静岡県：静岡県森林・林業統計要覧　I　森林・林業の概要，静岡県, (2015).）