Consideration and Application of Evaluation Indicators of Regional Circular and Ecological Sphere (CES) for the Utilization of Woody Biomass

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ABSTRACT

The "Regional Circular and Ecological Sphere" takes advantage of the SDGs' concept of integrated solutions to numerous concerns, complementing and supporting resources based on the region's features while maximizing the utilization of local resources. This research makes a comprehensive evaluation of the three aspects of the environment, economy, and society. First, formulate the evaluation indicators of the regional circulation symbiosis zone. Then, choose the cutting conditions of trees according to geographical factors, use the thinning forecasting system and forest GIS data to evaluate the supply potential of thinned wood in the area, and calculate the heat and power generation of wood biomass. According to the above analysis and calculation, 12,000 tons of unused wood chips can be supplied per year for 36 years from 2016 to 2051. From the economic point of view, the purchase of wood chips of 146 million yen due to the local circulation of wood fuel is expected to save about 50 million yen in intermediate input. And it is estimated that if 12,000 tons of unused wood chips can be supplied in the city per year, and about 98.4 million yen can be saved annually. Finally, from a social perspective point of view, biomass power generation of unused thinned timber using materials worth about 146 million yen is expected to create about 20 jobs.

INTRODUCTION

The "Regional CES" is one of the main initiatives of Japan's "Fifth Environmental Basic Plan," which was approved by the Cabinet in 2018, and each area uses its unique qualities to leverage its strengths. It entails establishing a larger network by establishing a self-sustaining and decentralized community in which resources circulate while coexisting and communicating with neighboring areas.

Since 2013, Kitakyushu City has been promoting a "regional energy base promotion project," and biomass utilization plays a vital role as a renewable energy source, but it also has a strong affinity with regional symbiotic sphere measures. Furthermore, attempts to accomplish the United Nations Sustainable Development Goals (SDGs) are widely recognized as significant, but biomass consumption has the potential to affect not only the environment but also many other fields. It needs to be considered as a goal to be considered. The purpose of this study is to estimate the availability of woody biomass in Kitakyushu City and to make a comprehensive evaluation from the three aspects of environment, economy, and society. First, we will evaluate the regional circulation symbiosis area's evaluation index. The amount of thinned timber supply potential in the region is assessed using the thinning harvest prediction system and forest GIS data, followed by power generation and heat consumption using woody biomass. Evaluate low carbon and resource-saving effects by substituting fossil resources and reducing long-distance transportation. Third, estimate the amount of direct job creation.

MATERIALS AND METHODS

Examination of Evaluation Index

Environment: In this study, evaluation indexes were examined from the three aspects of environment, economy, and society. In addition to the concept of the regional circulation symbiotic area, the evaluation index was set based on the evaluation index of SDGs. Although forests cover 38% of the Kitakyushu metropolitan area (approximately 18,598 ha), the forestry sector is dormant, and the trees

are still being cut down even after thinning, and the forests are not being used properly. From an environmental point of view, the planned use of unused thinned wood not only leads to the maintenance and management of healthy forests but also contributes to the maintenance and improvement of ecosystem services. Utilizing the woody biomass resources in the region can be regarded as a sustainable and ideal regional resource.

Economy: From the perspective of supporting the region such as city life and industrial activities, the purchase of fossil fuels has been reduced by shifting to a low carbon / decarbonized society, creating a sustainable economic society that embodies the SDGs and introducing renewable energy. It can also be expected to have the effect of reducing the amount of money that flows out of the region.

Society: By incorporating the perspective of a low-carbon society and a recycling-oriented society, the degree of contribution to a sustainable society will increase, so local companies and individuals will participate to build a regional economy and create new employment. Indexes are selected and evaluated in consideration of regional characteristics. The indicators set in Table 1 below are shown, and the indicators evaluated in this study were marked those indicators in blue.

Forest Resources and CO_2 Absorption

Estimating forest resources: In the forest resource survey, the number of forest resources was estimated using the Kitakyushu City Forest Book (Kitakyushu City Forest Book 2016) and the GIS-based forest interpretation data. The area estimation results for each tree species are shown in Table 2.

The forest area of Kitakyushu City is 18,598 ha, of which the area covered by the regional forest plan (private forest area) is 15,727 ha and the forest ratio is about 38%. Of the privately owned forests, the planted forest is about 4,622 ha, and the area of Japanese cedar and Cypress occupies about 90.8%. The distribution ratio of each tree species is shown in Fig. 1.

It was also taken into consideration that about 70.5% of the total are 10 years old (Fukuoka Area Forest Plan 2016) or older and that the planted forest resources are mature and need to promote forest circulation when they reach the utilization period. The age distribution map of Japanese cedar and cypress is shown in Fig. 2.

Setting thinning conditions: For deforestation (including main deforestation, thinning, and deforestation), the presence or absence of forest roads, steep slopes and the situation of the surface, and the possibility of carrying out should be taken into consideration.

Table 1: Discussion on evaluation index.

|	Index	Building a Regional CES area	SDGs goal
Environment	Forest resources Land use change Carbon stock CO2 absorption Fossil fuel consumption by use	Contributing to the maintenance and improvement of ecosystem services by contributing to the maintenance and management of healthy forests. The transition to a low-carbon/decarbonized society and the creation of a sustainable economic society that embodies the SDGs.	15.2 By 2020, promote the implementation of sustainable management of all types of forests and so on 7.2 By 2030, increase substantially the share of renewable energy in the global energy mix
Economy	Volume of thinned timber and amount that can be used as woody biomass	Proper thinning will produce high-quality timber while maintaining the biodiversity of the forests, while aiming to reduce CO2 by using thinned wood as heat energy.	7.a enhance international cooperation to facilitate access to clean energy research and technology, including renewable energy, energy efficiency and advanced and cleaner fossil-fuel technology, and promote investment in energy infrastructure and clean energy technology
	Electricity/thermal efficiency of woody biomass and creation of economic value	Local resources are circulated by utilizing the woody biomass resources of the area.x	
	Collection and transportation costs for carrying out thinned wood, etc.	-	-
Society	Amount of food supply (such as bamboo shoots)	Including delicious food and materials, disaster prevention and mitigation functions, life culture and recreation, etc.	2. End hunger, achieve food security and improved nutrition and promote
	Number of jobs created by forestry employees	local companies and individuals will participate to build a regional economy and create new jobs.	8.9 By 2030, devise and implement policies to promote sustainable tourism that creates jobs and promotes local culture and products
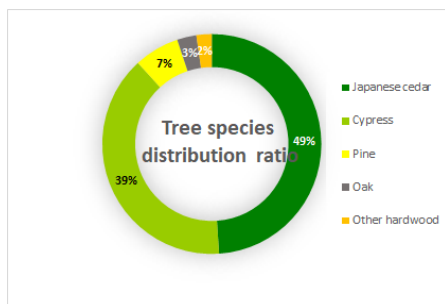
Fig. 1: Tree species distribution ratio.
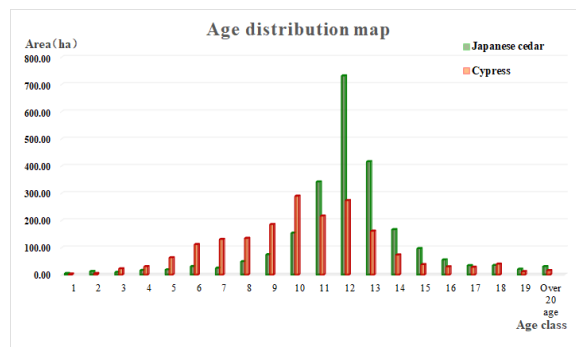
Fig. 2: Japanese cedar and cypress age distribution map.

In this study, set the thinning conditions for the maintenance of the planted forests:

- Inclination angle of planted forest (35 degrees or less)
- Distance from planted forest to a forest road (within 500m)
- Distance from plantation to the sawmill (within 30km)

The reason is that working in areas with an inclination angle of 35 degrees or more is dangerous and cutting a lot of trees affects the natural stability of the terrain. As a past record, the distance from the forest road is often within about 500 meters. Therefore, the priority of timber cutting is decided based on the above three geographical factors.

In the analysis of ArcGIS, the DEM data for the entire Kitakyushu city was downloaded from the official website of the Geographical Survey Institute of the Ministry of Land, Infrastructure, Transport, and Tourism. hen, using the downloaded data, take out the administrative divisions of Kitakyushu City. Because the raster data transformed by ArcGIS includes data from areas that aren't relevant to our study, the parts other than Kitakyushu City will be cut out using the ArcGIS clip tool.

Fig. 3 shows the use management tool in ArcGIS's Arc toolbox. Using ArcGIS, the raster data of the entire administrative area of Kitakyushu is completely extracted from the map of Fukuoka Prefecture

Fig. 4 shows all slope and shadow calculations are performed using the map algebra operation of the Arc toolbox

special analyst tool. Once the calculation is completed, the map algebra operation of the special analyst tool can be used to extract the terrain data of the slope above or below the specified value.

Fig. 5 shows the polyline data of the forest road is targeted, and the buffer map of the forest road is created by using the buffer analysis of ArcGIS to create the area around the forest road and the surrounding area of 500 me-
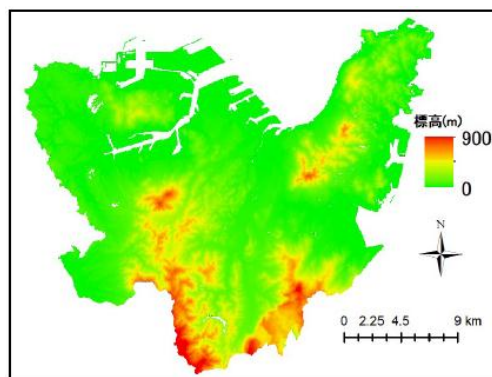

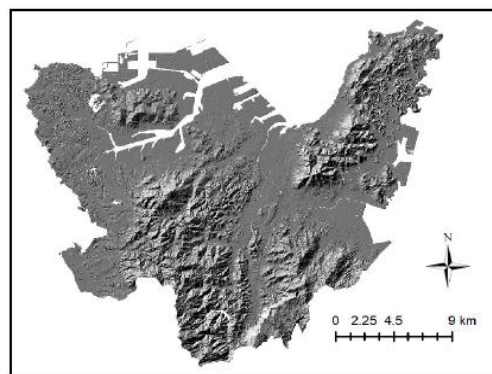Fig. 3: Topographic raster data of Kitakyushu area.

Fig. 4: Topographic shadow map of Kitakyushu area.

Table 2: Area of each tree species.

Tree species	Area [ha]
Japanese cedar	2,328.8
Cypress	1,868
Pine	318.2
Oak	135.72
Other hardwood	107.42

ters. Then combine the distribution map of the forest with a buffer map.

The forest composition of both Japanese cedar forest and cypress forest peaked at 51-60 years old, and 46-60 years old dominated when the forest area by tree type and age was validated from the forest book.

Estimating thinned wood that can be harvested from plantations: To estimate the available thinned wood, first, use the Kitakyushu City Forest Book Data (2016) and the Fukuoka Prefecture Japanese cedar/cypress Plantation Harvest Prediction System (Narasaki et al. 2015)

To determine the annual amount of thinned woodcut among unused wood, the author made a trial calculation.

In addition, to examine the study's long-term sustainability, the degree of growth was calculated using the artificial forest in Fukuoka Prefecture's stand density control chart (Narasaki et al. 2015) and the Fukuoka Prefecture's volume table (Forestry Agency 2018).

Looking at the results of the annual thinning possible amount estimation of Japanese cedar/cypress as shown in Fig. 6, we can see the trend of yearly decrease. According to the 2016 version of the forest book data, medium-aged Japanese cedar/cypress trees in the planted forest will be cut down in order from the 20th grade (older trees) to the 4th grade (young trees). Therefore, if thinning is done without proper forest management, the number of trees that can be collected will decrease steadily.

Estimated CO$_2$ Absorption: The carbon accumulation amount (C) is the bulk density (V) of the thinned wood by tree type obtained by 3-3, the volume density (D), the biomass expansion coefficient (BEF), and the ratio of the underground part to the above-ground part (R), Estimated

by multiplying the carbon content (CF) per dry matter weight. The calculation formula is as shown in the following formula (1).

$$C = \sum_j \quad \{[V_j \times D_j \times BEF_j] \times (1 + R_j) \times CF\}$$
$$\dots(1)$$

C: Carbon stock amount

V: Volume

D: Bulk density

BEF: Biomass Expansion Factor

R: Ratio of the underground to above ground

CF: Carbon content per dry matter weight

j: Tree species

The amount of CO2 absorbed was calculated by considering its molecular composition (44/12) based on the amount of carbon accumulated.

Each parameter is quoted from the Japan Greenhouse Gas Inventory Report (National Institute for Environmental Studies) (Table 3).

The calculation results are shown in Table 4.

The total amount of carbon dioxide emissions in 2016 was 17,531 thousand tons, and the amount absorbed only for the thinned wood to be harvested was about 0.061%.

RESULTS AND DISCUSSION

The Economic Value of Woody Biomass Energy

The economic value that wood fuel replaces fossil fuel: Logs harvested from forests cannot be used directly as raw materials for power generation and are processed into wood chips as a type of fuel for woody biomass. Based on the
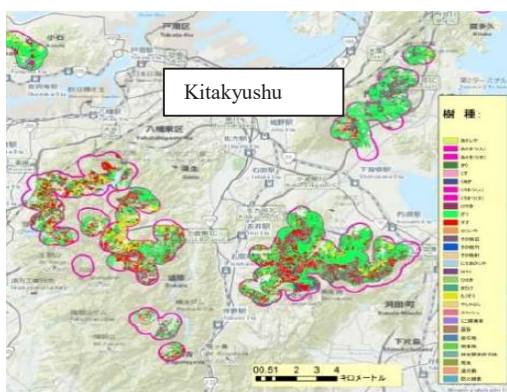

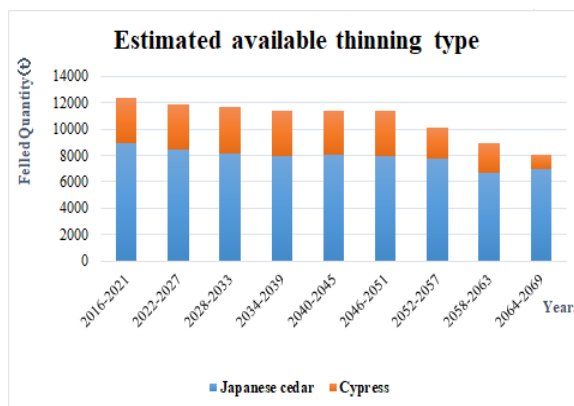Fig.5: Distribution map of forests that can be felled.

Fig. 6: Estimated available thinning type.

estimation results of the annual logging amount of 3-3, it was judged that about 123,000 tons of wood chips (Nakamura & Shibata 2013, Wood Chip Conversion Factor 2020) can be stably supplied every year in the five years from 2016 to 2021 as an example.

Compared with the conventional boiler using fuel oil A as fuel for heat utilization, when switching from fuel oil A to the use of wood chips, if the economic effect is better than fuel oil purchased from outside the city, it will reduce the cost of biomass users. By replacing fossil fuels with wood fuel, which has excellent thermal efficiency, industries that purchase wood fuels can save intermediate inputs. The estimation was based on the following formula.

Reduction in fossil fuel interim input due to purchase of wood fuel-fuel purchase amount

= (Available amount of wood chips in the city ×0.17× Unit price of fuel oil A) - Purchase amount of wood chips

= 38.5 million yen

Calculation of CO_2 reduction when used as an alternative fuel:

Fuel consumption x calorific value per unit calorific value x carbon emissions per unit calorific value x 44/12

= 2,040 t x 48.875 GJ / t x 0.0189 t C / GJ x 44/12

= 99,705 GJ x 0.0189 t C / GJ x 44/12

= 6,909.56 t-CO2

In this case, if wood chips were used as an alternative fuel to the boiler instead of fuel oil A, the annual CO_2 reduction was calculated to be 6,909.56 t-CO_2.

Power generation of wood chips for fuel: From the calculation results (Table 6), in this case, the annual power generation is equal to a small-scale (100-500 kW class) wood biomass power plant with an output of 400 kW.

On the other hand, according to the business plan of the woody biomass burning power plant in Kitakyushu City, there is a plan to import fuel chips from overseas, which requires about 100 thousand tons to 320 thousand tons per year.

According to the Ministry of Finance's "Trade Statistics" data and the Japan Woody Biomass Energy Association's statistical data (Statistical data of Japan Woody Biomass Energy Association 2019) (Fig.7), the average purchase price of imported wood chips is 20,000 yen.ton[-1], or 2 to 6.4 billion yen per year if all imported chips are used overseas. It is estimated that supplying the city with 12,000 tonnes of unused wood chips per year will save the city approximately 98.4 billion yen annually.

Creating Jobs for Forestry Workers

In addition to direct job creation such as logging and transportation associated with the processing of wood into fuel, indirect and multifaceted job creation effects are expected as a ripple effect. The Input-output analysis was used for the estimation, and the calculation was made quantitatively. In this study, the employment coefficient was calculated in EXCEL with reference to the input-output table of Kitakyushu (Kitakyushu City Input-Output Table 2011).

The sum of the employment induction factors for the forestry industry in Kitakyushu is 0.0472, and if demand for combustion chips of 147.6 million yen is generated for power plants, the employment of 6 people will be indirect and rippled.

Furthermore, if a job is created in the processing of fuel chips and a new woody biomass power plant is constructed, an operator will be required. In the chip processing industry, it is estimated to be about 12 people when calculated from the employment coefficient (0.0831) in the input-output table.

In addition, about 1 to 2 people are required for the output of 400 kW. Summing up the above results, it is expected that the biomass power generation of unused thinned wood, which

Table 3: Biomass expansion coefficient by tree type, the ratio of aboveground to belowground, volume density, etc.

		BEF		R	D	CF
		≤20	>20	[-]	[t-d.m./m3]	[t-C./t-d.m]
	Japanese cedar	1.57	1.23	0.25	0.314	
	Cypress	1.55	1.24	0.26	0.407	
	Red pine	1.63	1.23	0.26	0.451	
	Black pine	1.39	1.36	0.34	0.464	
softwood	Other	2.55	1.32	0.34	0.352	0.51
hardwood	Oak	1.36	1.32	0.26	0.668	
	Other	1.37	1.37	0.26	0.469	0.48

Table 4: Estimates of carbon accumulation and CO_2 absorption.

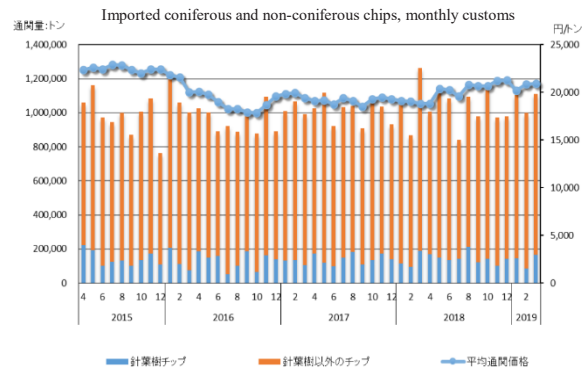| Year	Volume growth (m^3)	Carbon stock (t-C)	CO_2 absorption (t-CO_2)
2016-2021	57,990	13,427.63	49,234.63
2022-2027	34,065	7,898.20	28,960.08
2028-2033	29,785	7,762.98	28,464.27
2034-2039	28,815	7,081.18	25,964.34
2040-2045	24,245	6,130.59	22,478.83
2046-2051	22,640	5,873.48	21,536.08
2052-2057	34,465	8,363.74	30,667.04
2058-2063	24,475	5,583.05	20,471.17
2064-2069	25,635	5,643.88	20,694.21

Fig. 7: Imported coniferous and non-coniferous chips, monthly customs.

Table 5: Alternative ratio of wood chip fuel and fossil fuel.

classification	Generated heat		A heavy fuel oil→1 ton of wood fuel	Price of fuel oil A this year	Wood fuel price	Amount of wood fuel equivalent to the purchase price of fuel oil A
	Wood fuel	fuel oil A				
	L	L				
	①	②	③ = ① / ②	④	⑤	⑥ = ③ × ④
chips→fuel oil A	8,380MJ/t	48,875MJ/t	0.171	74.8Yen/L	1,2000 Yen/t	15,507.3 t
Interim input reduction:38.5million Yen						

uses about 147.6 million yen of material, will have the effect of creating employment for about 20 people.

CONCLUSION

In this study, we estimated the availability of unused woody biomass in Kitakyushu City.

According to the calculation results, it was found that 12,000 tons of unused wood chips can be supplied annually for 36 years from 2016 to 2051. During this period, the total amount of new carbon accumulated due to tree growth was estimated to be about 68,000 tons, and the amount of CO_2 absorbed was estimated to be about 249,000 t-CO_2. To evaluate the utilization of woody biomass, it is necessary to compare the amount of carbon accumulated and the amount of CO_2 absorbed depending on whether or not it is utilized, which is a future issue. On the other hand, to provide a constant supply, a road network that can enter the forest and transport timber, the selection of an effective harvesting method, staffing, and forest management planning for continuous harvesting, among other things, are required. There are additional challenges.

From the economic point of view, the purchase of wood chips of 147 million yen due to the local circulation of wood fuel is expected to save about 38.5 million yen in intermediate input. It was also estimated that there would be a CO_2 reduction effect of approximately 7,000 t-CO_2 by replacing heavy oil A with woody biomass fuel. The average purchase price of imported wood chips is 20,000 yen.ton^{-1}, and it is estimated that if 12,000 tons of unused wood chips can be supplied in the city per year, about 98.4 million yen can be saved annually.

Table 6: Annual power generation (Japanese cedar & Cypress)

W.B.(%)	LHV(kcal/kg)	Thermal efficiency (%)	Ideal calorific value(kcal/kg)	Power generation efficiency(%)	Ideal annual power generation(kWh)
0	4,562	20	$1.13×10^{19}$	34	$4.44×10^6$
10	4,020	20	$9.92×10^9$	34	$3.91×10^6$
20	3,476	20	$8.58×10^9$	34	$3.38×10^6$
30	2,937	20	$7.25×10^9$	34	$2.86×10^6$
40	2,395	20	$5.91×10^9$	34	$2.33×10^6$
50	1,853	20	$4.57×10^9$	34	$1.80×10^6$

Finally, from the social point of view, it was revealed that the employment creation effect related to the power generation of unused wood biomass in the region will revitalize the local economy by increasing the number of employees, although there is a difference in the calculation.

ACKNOWLEDGEMENT

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