✦**Title** : CO₂ emissions and economic impacts of using logging residues and mill residues in Maniwa Japan

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❖Abstract:

In the face of increasing demand for woody biomass, mill residues continue being used more frequently than logging residues in Japan because of their relative ease of use. The Japanese government set a target ratio of logging residue use to 30 percent by 2030 compared with less than 1 percent in 2009.

This study examined GHG emissions and the economic effects of logging and mill residues, which are employed as raw materials for various purposes in Maniwa, Japan. In 2012, 23,710 tonnes of woody biomass resources were collected and used in Maniwa, of which roughly 79 percent were logging residues. These resources are manufactured into several types of wood products, such as chips, bark, and chip dust. The manufactured products are then transported and consumed for paper, poultry litter, and fuel. Based on this, three scenarios were organized by changing the type of woody biomass resource use as follows: the business-as-usual (BAU) scenario, the logging-residues-only utilization (LRU) scenario, and the mill-residues-only utilization (MRU) scenario. Under the LRU scenario, the expected regional effect is almost 188 million JPY, whereas the MRU scenario achieves almost 20 times more financial benefits than the LRU scenario with the integrated woody biomass station. However, approximately 13 full-time jobs can be created under the LRU scenario, which is 1.6 times higher than the 6 jobs created under the MRU scenario. In terms of GHG emissions, the LRU scenario can reduce GHG emissions by up to roughly 211t CO₂eq/t compared to the MRU scenario. Overall, the promotion of logging residue use for manufacturing wood products has significant advantages over mill residues in both the reduction of GHG emissions and the growth of regional economies.

❖**Keywords:** Woody biomass use; Logging residues; Mill residues; GHG emissions; Regional economic effect; employment opportunities.

1. Introduction

Although Japan has some of the most valuable forest resources in the world (MAFF, 2012), the recent drop in the price of foreign timber and the shrinking and aging labor force have caused the Japanese forest industry to decline. The Japanese government has been attempting to revive the forest industry mainly by increasing demand for domestic timber, and woody biomass use has been implemented as part of the effort to boost domestic demand.

Woody biomass can be defined as byproducts of trees and woody plants left over from production, harvesting, and processing of forests, woodlands, or wood-using sectors. Woody biomass is generally divided into two main streams in Japan: mill residues and logging residues. Mill residues are produced in sawmills located close to cities, so they can be transported easily. On the other hand, logging residues are the portion of harvested trees that are left in the forest because of high collection and transport costs. Woody biomass can be used as raw materials for paper and pulp, furniture, and value-added products, as well as for bioenergy for generating heat or electricity and bio-based products such as plastics, ethanol, and diesel (USDA, 2007; Kebede et al., 2013; Faaij and Domac, 2006). Because of this practical value, over 300 Japanese rural governments have promoted a variety of new businesses that use woody biomass to revitalize their regions (MAFF, 2013). However, government statistics show that only mill residues are used as raw materials or bioenergy because of their ease of use compared to logging residues (Nikkei Ecology, 2011). In order to increase the use of logging residues, the Japanese government has established the target ratio of logging residue use from less than 1 percent in 2009 to 30 percent by 2030 through the National Basic Plan for the Utilization of Biomass (the Basic Biomass Plan; MAFF, 2010). The Basic Biomass Plan also established a 95 percent target ratio of mill residues used to maintain the 2010 rate by 2030 (MAFF, 2010).

While the general perception is that logging residues are more difficult to use than mill residues are, many studies have been conducted to clarify the economic and environmental effects of the use of logging residues. Bailey et al. (2011), Perez-Verdin et al. (2008), and Moon et al. (2013) reported that the use of logging residues for energy or fuel production can stimulate the development of regional economies and the creation of employment opportunities in a certain region. Moreover, Gan and Smith (2007) and Tabata and Okuda (2012) indicated that additional economic effects are expected through the reduction of CO₂ emissions and the environmental load and savings on site preparation costs.

1 These results suggest a different view of the economic and environmental potential of
2 logging residues, which are rarely used in Japan. However, which effects are expected to
3 improve through the promotion of logging residue utilization over mill residue
4 utilization has not yet been clarified. Although proper harvesting volumes and costs
5 have been calculated to improve the utilization of logging residues (Terada et al., 2010;
6 Yamaguchi et al., 2011), studies assessing the advantages of logging residues compared
7 to mill residues are still limited.

8 This study aims to quantify GHG emissions and economic impacts of the utilization of
9 logging and mill residues as raw materials for various purposes in Maniwa, Japan.
10 Maniwa is a rural region that promotes the use of logging residues collected from its
11 forests and timberlands, and it has produced various types of wood products, mainly
12 using logging residues. The specific objectives of this study are threefold. First, we
13 calculated the amount of GHG emissions, income, and expenditures for implementing
14 the use of logging residues versus mill residues under a life cycle assessment (LCA)
15 perspective. Second, three scenarios were considered to assess the economic and GHG
16 emissions effects of the utilization of logging residues using an optimization analysis.
17 Finally, regional economic effects and employment creation effects of the three scenarios
18 were estimated using an input–output (I/O) analysis.

19 20 **2. Methodology**

21 22 **2.1. Study area**

23 Maniwa, a city with abundant forest resources in Okayama prefecture, has 82,843
24 hectares of forested area that account for about 80 percent of the total land area (Figure
25 1). An estimated 63,395 m³ of logging residues are produced from the 1,500 hectares of
26 forest area harvested in Maniwa each year.

27 Maniwa has built an integrated woody biomass station (IWBS) as part of its efforts to
28 promote use of wood biomass, especially logging residues. In the IWBS, logging and mill
29 residues are collected and made into four wood products—chips for paper, chips for fuel,
30 bark, and chip dust—and transported to consumers inside and outside the city. Logging
31 residues used in the IWBS can be categorized into two types according to transportation
32 route: logging residues transported directly from the forest in Maniwa (LR_f) and those
33 brought to the IWBS through the timber marketplace (LR_{tm}). Mill residues can also be
34 sorted into two types depending on the specific type used as raw materials in the IWBS:
35 backboard (MR_{bb}) and bark (MR_b).

36 The amount of wood products made using logging and mill residues delivered in the

1 IWBS is shown in Table 1. The information is based on survey results of material flow in
2 the Maniwa forest products industry (Maniwa system exploratory committee, 2009),
3 and an accounting database containing detailed financial reports for woody biomass use
4 was obtained from executives of Maniwa City Hall and the IWBS. In 2012, 23,710
5 tonnes of woody biomass were transported into the IWBS, of which 14,437 tonnes were
6 under LRf and 4,296 tonnes were under LRtm. The total amount of logging residues
7 was 18,733 tonnes, accounting for approximately 79 percent of total woody biomass use.
8 The remaining 4,977 tonnes were mill residues. Of these, 2,579 tonnes of MRbb and
9 2,398 tonnes of MRb were transported to the IWBS. Here, we assumed that the amount
10 of woody biomass transported in 2012 did not change.

11 The amount of each type of wood product (e.g., chips, bark, and chip dust) in the total
12 woody biomass depends on a fixed production ratio obtained from information about
13 production systems for manufacturing wood products from woody biomass provided by
14 executives in the city hall and the IWBS. When logging residues are used to
15 manufacture wood products, all types of wood products can be produced. The fixed
16 production ratio was determined to be 89 percent for chips, 8 percent for bark, and 3
17 percent for chip dust. Chips and chip dust can be manufactured from MRbb, and the
18 fixed production ratios of each were set to 97 percent and 3 percent, respectively. In
19 addition, a certain amount of MRb can be supplied from sawmill regardless of the fixed
20 production ratio. Therefore, the amount of wood products varies depending on the type
21 of woody biomass used because of the fixed production ratios. In addition, the use of the
22 chip can be divided into two varieties: chips for paper and chips for fuel. The fixed
23 production ratios for paper and fuel were set to roughly 99 percent and 1 percent of the
24 total chip production, respectively. As shown in Table 1, in 2012, the total amounts of
25 chips for paper, chips for fuel, bark, and chip dust produced in the IWBS were 18,907
26 tonnes, 267 tonnes, 3,897 tonnes, and 639 tonnes, respectively.

27

28 **2.2. Process flow**

29 The process flow from harvesting logging and mill residues for transport to the
30 consumer was defined as a study boundary, as shown in Figure 2. There are five stages
31 in the process for manufacturing wood products from woody biomass: (1) harvest, (2)
32 transport to the IWBS (TtI), (3) sawmilling, (4) manufacturing, and (5) transport to the
33 consumer (TtC). However, logging and mill residues undergo different stages. Mill
34 residues go through all five stages of wood product manufacturing, while logging
35 residues pass only four stages: harvest, TtI, manufacturing, and TtC. In the harvest
36 stage, logging residues are cut and collected from forests or timber markets only in

1 Maniwa, whereas mill residues are obtained from logs collected from forests not only in
 2 Maniwa but also in many other regions of Japan. In the TtI stage, woody biomass is
 3 transported from forests to the IWBS. Logging residues are transported to the IWBS
 4 directly at this stage, whereas mill residues are collected from logs that have been
 5 transported from many regions to sawmills in Maniwa and then hauled to the IWBS. In
 6 the sawmill stage, mill residues are produced as a byproduct of timber manufacturing in
 7 Maniwa sawmills. In the manufacturing stage, the four types of wood products are
 8 manufactured from logging and mill residues in the IWBS according to the fixed
 9 production ratio. Finally, at the TtC stage, the products are transported to the
 10 consumers in each region. Chips for fuel and bark are consumed as fuel in the city hall
 11 and factories, and chip dust is used as a feedstock in stock farms in Maniwa. Chips for
 12 paper are carried to a paper manufacturing plant located outside the city.

13

14 **2.3. Quantifying GHG emissions**

15 Estimation of GHG emissions using logging and mill residues was based on the LCA
 16 methodology. LCA is a tool for estimating and assessing the inputs and outputs of
 17 materials and energy and the associated environmental impacts of a product or service
 18 throughout its life cycle (CSIRO, 2009). The LCA method is a useful tool for determining
 19 the environmental impacts of a specific product by analyzing each stage of the process
 20 for product manufacture. LCA is also widely used to evaluate GHG emissions or the
 21 environmental load in the process of woody biomass use (Hitoe and Hattori, 2011;
 22 Tabata et al., 2012). In order to calculate GHG emissions by LCA, a certain range of
 23 process boundaries must be used to apply the same conditions to every study target,
 24 such as logging and mill residues. As previously mentioned, on the basis of the process
 25 flow, Equation [1] shows that the total amount of GHG emissions in all stages was
 26 assessed by summing the amount of GHG emissions of each stage.

27

$$28 \quad \mathbf{GHG}_t = \sum_{s=1}^n \mathbf{GHG}_s \quad [1]$$

29 Here, $\mathbf{GHG}$ is the amount of GHG emissions (t CO₂ eq); t means total amount in all
 30 stages; and s indicates the stage of the process ($n = 1-5$), where 1 is harvest, 2 is TtI, 3 is
 31 sawmilling, 4 is manufacturing, and 5 is TtC.

32

33 The amount of GHG emissions of each stage can be obtained by multiplying the
 34 amount of each type of logging and mill residue delivered to the IWBS ($\mathbf{P}$, Table 1) by
 35 energy consumption per unit tonne ($\mathbf{ec}$) and GHG emissions coefficients ($\mathbf{gue}$), as shown
 36 in Equation [2]. Here, detailed data on the three types of energy consumption per unit

tonne and GHG emissions coefficients adapted to each process were determined, as shown in Table 2. Of these, GHG emissions are calculated as the sum of CO₂, CH₄, and N₂O emissions directly measured from the consumption of fossil fuels such as light diesel oil, kerosene, and electricity and converted to metric tonnes of CO₂ equivalent based on the global warming potentials for a given time horizon of 100 years (IPCC, 2007). GHG emissions coefficients of each energy type were obtained from JEMAI-LCA Pro, which is a system for supporting LCA by providing the basic calculation features required for LCA, including inventory analysis and impact assessment (JEMAI, 2010).

$$GHG_s = P \times ec \times gue \quad (S = 1, 2, 4) \quad [2]$$

Here, P is the amount of each type of logging and mill residue delivered to the IWBS (t); ec is energy consumption per unit tonne (L, Kwh/t); and gue is the GHG emissions coefficients (kg CO₂eq/Kwh, L). The GHG emissions coefficients we used are based on JEMAI (2010).

In particular, in the Ttl and TtC stages (which are related to transport), we calculated the amount of GHG emissions using the “TON-KM method” suggested by the government (METI and MLIT, 2006). The TON-KM method is a useful method for calculating truck GHG emissions when information on the amount of fuel consumption and fuel efficiency are unclear (METI and MLIT, 2006). To estimate the amount of GHG emissions in these stages using the “TON-KM method,” additional data for transportation distance are necessary, as shown in Equation [3]. Information about transportation distance (due) was obtained from a research report (NEDO, 2010) and with the help of the city hall executives (Table 3). All processes were assumed to use 4-tonne dump trucks with a 62% loading ratio.

$$GHG_s = P \times ec \times due \times gue \quad (S = 3, 5) \quad [3]$$

Here, P is the amount of each type of logging and mill residue delivered to the IWBS (t); ec is energy consumption per unit tonne (L, Kwh/t); due is the transportation distance (km); and gue is the GHG emissions coefficient (kg CO₂ eq/Kwh, L). The GHG emissions coefficients that we use are based on JEMAI (2010).

2.4. Quantifying income and expenditure

In order to quantify the economic effects of logging and mill residue utilization, data related to income and expenditure of the IWBS were obtained via internal financial records of the IWBS released by executives of the city hall and the IWBS.

1 Total expenditure was estimated using the total cost of raw materials, light diesel oil
2 and electricity, depreciation, maintenance, personnel, and general management. Table 4
3 presents the unit production cost categorized by logging and mill residues. For the cost
4 of diesel and electricity, we set annual average prices to 114.72 JPY/L and 28 JPY/Kwh,
5 respectively, as measured by the IWBS. The total amount of fixed costs, such as
6 depreciation, maintenance, personnel, and general management, accounted for
7 approximately 28% of total expenditure.

8 Total income was defined as the total sales of wood products plus the total rural
9 authority subsidy. Table 5 shows the unit sale price for each wood product. Rural
10 authority subsidies, which are used for machine installation and plant construction,
11 accounted for roughly 14% of total income.

12 Lastly, the benefit of making wood products in the IWBS using logging and mill
13 residue utilization was obtained by subtracting total expenditure from total income.
14

15 **2.5. Scenario setting and optimization analysis**

16 In order to examine the GHG emissions and economic effects by increasing logging
17 residues utilization, we created different situations according to the use of logging and
18 mill residues. Three scenarios were proposed as follows.

19 (1) The business-as-usual (BAU) scenario: The BAU scenario describes the current
20 woody biomass utilization in the IWBS, in which 79% of logging residues are used as
21 raw materials.

22 (2) Logging residue utilization (LRU) scenario: The LRU scenario describes the
23 situation where logging residues are utilized only as a raw material in the IWBS.

24 (3) Mill residue utilization (MRU) scenario: The MRU scenario describes the situation
25 where only mill residues are utilized in the IWBS.

26 Here, the program Numerical Optimizer (NUOPT) was applied to organize the
27 optimum conditions for maximizing the use of logging or mill residues as raw materials
28 in the IWBS. NUOPT, which was developed by NTT DATA Mathematical Systems Inc.,
29 is a mathematical programming program to determine the most suitable value for a
30 particular purpose under certain conditions (NTT DATA, 2009b). That is, it is a useful
31 tool for producing the best possible solution to meet the current needs of users. NUOPT
32 is widely used in many universities and research institutes in Japan (NTT DATA, 2006).
33 To use NUOPT, a new formula must be established where objective, variable, and
34 constraint components must be described using SIMPLE, a programming language
35 (NTT DATA, 2009a). In this research, the fixed production ratio used to determine the
36 amount of wood products from raw logging and mill residue materials were used as

model constraints. Furthermore, the production and demand amounts of wood products in the current situation were also used as constraints to determine the optimization criteria. The amount of logging residues and mill residues used as each wood product to meet the condition specified in each scenario were set as a model variable.

2.6. Estimating regional economic effects and employment opportunities

I/O modeling allows the quantification of direct and indirect effects that result from inter-industrial exchanges and additional industrial activities in a specific economic area such as city, prefecture, or country (Miller et al., 2009), and it is widely used as a tool for regional economic analysis. Gan and Smith (2007), Perez-Verdin et al. (2008), and Moon et al. (2013) adopted I/O models to identify the effects of economic outputs and employment of woody biomass utilization in a specified region.

The changes of total output throughout the regional economy (X) can be assumed by multiplying the changes of final demand (f) by the Leontief inverse using I/O models as shown in Equation [4-1] (Yasuda, 2008). The I/O models introduced in Equation [4-1] generally treat imports as exogenous, whereas imports are considered part of final demand. However, total output is affected by not only final demand but also by imports. If a regional economic analysis is applied to regions or nations that are heavily dependent on imports (e.g., Japan), other types of I/O models in which total output is calculated using imports and final demand should be used (Fujikawa, 2008). Here, an I/O model where imports are treated as endogenous can be proposed, as shown in Equation [4-2] (Yasuda, 2008; Fujikawa, 2008). In this model, changes in imports can be taken into consideration in the total output, so the technical coefficient becomes smaller. Therefore, the effects on total output using the I/O model in Equation [4-1] are likely larger than those using the I/O model in Equation [4-2] (Fujikawa, 2008).

$$X = (I - A)^{-1}f \quad [4-1]$$

Here, X is the vector of total output (throughout the economy); $(I - A)^{-1}$ is a Leontief inverse matrix; I is the identity matrix; A is a technical coefficient matrix; and f is the final demand vector.

$$X = [I - (I - M)A]^{-1}[(I - M)f^d + E] \quad [4-2]$$

Here, $[I - (I - M)A]^{-1}$ is a Leontief inverse matrix different from that used in Equation [4-1]; M is a diagonal matrix; f^d is the vector of district final demand; and E is the export vector.

In this research, the 2008 I/O table for Maniwa was used as a database to estimate the regional economic effects of using logging and mill residues. The table, which is categorized into 64 industrial sectors at the municipal level, is based on the 2004 I/O table for Okayama prefecture and was developed using intra-industry and inter-industry trade data for Maniwa industries obtained from questionnaire and telephone surveys in Maniwa by Chugoku Regional Research Center (SME, 2008).

There are three types of regional economic effects found using I/O modeling: direct, indirect, and induced effects. The direct effect is the gross regional output that occurs as a direct result of logging and mill residue utilization. The indirect effect, which is caused by inter-industrial activities resulting from the promotion of logging and mill residue utilization, can be evaluated by multiplying the increased output of raw material by the Leontief inverse matrix. The induced effect, which results from additional industrial activities resulting from the direct and indirect effects of woody biomass utilization, can be determined by multiplying the vector of regional private consumption expenditure by the Leontief inverse matrix.

Using these results, the number of jobs created can be estimated as shown in Equation [5].

$$iE = cE \times RI \quad [5]$$

Here, iE is the increased number of jobs; cE is the employment coefficient given as $cE = nE/GRP$; nE is the number of employed (MIC, 2009); GRP is the gross regional product in mil. JPY (SME, 2008); and RI is the regional economic effects.

3. Results

3.1. GHG emissions

GHG emissions per tonne of woody biomass in each stage are shown in Table 6. In the process of wood products production using logging residues, GHG was emitted from each process stage as follows: the harvest stage, TtI stage, manufacturing stage, and TtC stage emitted 7.9kg CO₂eq/t, 8.0kg CO₂eq/t, 12.2kg CO₂eq/t, and 8.2kg CO₂eq/t, respectively. Total unit GHG emissions were 36.3kg CO₂eq/t. In contrast, total unit GHG emissions using mill residues were 40.3kg CO₂eq/t. Looking into each stage of production using mill residues, GHG emissions in the harvest stage, Ttl stage, sawmilling stage, manufacturing stage, and TtC stage were 7.9kg CO₂eq/t, 16.2kg CO₂eq/t, 2.5kg CO₂eq/t, 8.4kg CO₂eq/t, and 5.2kg CO₂eq/t, respectively. Thus, logging residues resulted in a 3kg CO₂eq/t reduction of GHG emissions compared to mill

residues. This is because logging residues can reduce the amount of GHG emissions by skipping the sawmilling stage and by shortening the distance between the forest harvest regions and the IWBS.

3.2. Financial benefit

Manufacturing wood products using logging and mill residues in the IWBS generated approximately 204 million JPY as total income. Total expenditures were about 186.3 million JPY, accounting for around 91% of total income, resulting in a financial benefit of 17.7 million JPY in the IWBS. Based on this result, unit income, expenditure, and benefits of logging and mill residues used for wood products are summarized in Table 7. Overall, unit expenditure, income, and benefit of all woody biomass was 7,859JPY/t, 8,603JPY/t, and 745JPY/t, respectively, and these values vary depending on the type of woody biomass. When logging residues are used as raw materials for wood products, unit expenditure was 8,573JPY/t for a unit benefit of 426 JPY/t. Meanwhile, using mill residues can generate a unit benefit of 1,942 JPY/t, which is 1,516 JPY/t greater than that from logging residues. Therefore, manufacturing wood products using mill residues has higher potential to generate financial benefit for the IWBS than logging residues do.

3.3. Amount of GHG emissions and economic benefit

The optimal proportion of logging residue utilization in the BAU scenario, the LRU scenario, and the MRU scenario was 79%, 0%, and 100%, respectively. Using the results for GHG emissions (Table 6) and unit benefit (Table 7) of logging and mill residues, GHG emissions, and the economic benefits for each scenario were analyzed, as shown in Figure 3. GHG emissions in the LRU scenario were roughly 36.0kg CO₂eq/t, which is the lowest among the three scenarios. In contrast, the MRU scenario emitted around 44.9kg CO₂eq/t of GHG emissions, which was the highest among the three scenarios. The MRU scenario also produced the highest benefit of 2,077JPY/t, which was three times larger than the BAU scenario benefit of 745JPY/t and almost twentyfold larger than the LRU scenario benefit of 100JPY/t. Thus, raising the utilization rate of logging residues to 100% in the implementation of woody biomass utilization in Maniwa can contribute to the reduction of GHG emissions but cannot generate the highest benefit.

3.4. Regional economic effects

In order to analyze the regional economic effects, we categorized the detailed expenditure, income, and benefit results of the three scenarios into industry sectors, as shown in Table 8. Among these, we used data values for six endogenous industry sectors

1 that are directly related to woody biomass utilization to estimate the regional economic
2 effects from promoting woody biomass utilization. The endogenous sectors were 1)
3 forestry, 2) manufacture of lumber and wood products, 3) manufacture of petroleum and
4 coal products, 4) electricity, gas, heat, and water supply, 5) services incidental to
5 transport, and 6) automobile and machine repair.

6 The regional economic effect results in each scenario are presented in Table 9. In the
7 LRU scenario, 134.4 million JPY of direct gross output was obtained using logging
8 residues in the IWBS, and 51.4 million JPY of indirect gross output and 18.1 million
9 JPY of induced gross output were also generated. The MRU scenario, in which only mill
10 residues are used as raw materials for manufacturing wood products, generated 75.8
11 million JPY of direct gross output in the IWBS, 33.8 million JPY of indirect gross output,
12 and 14.4 million JPY of induced gross output. Therefore, total gross output of the MRU
13 scenario was roughly 123.9 million JPY, which was 55–80 million JPY less than that in
14 the other two scenarios. The proportion of indirect and induced effects in the MRU
15 scenario was approximately 39%, which was larger than that in the other two scenarios:
16 This proportion in both the BAU and LRU scenarios was 34.4%.

17 The utilization of logging residues in the IWBS can contribute to the regional
18 economy by creating full-time job opportunities. In the LRU scenario, 12.5 jobs were
19 produced, of which 7.7 jobs were created through direct effects and 4.8 jobs were
20 through indirect and induced effects. In comparison, only 5.9 job opportunities were
21 generated in the MRU scenario, of which 2.6 jobs were created by direct effect and 3.3
22 jobs were produced by induced effect.

23 The numbers of full-time jobs created in each industry sector are shown in Figure 4.
24 In the LRU scenario, 7.7 jobs were generated in forestry, which was the sector most
25 affected, followed by 2.1 jobs created in other tertiary industries. The tendency of job
26 creation in the BAU scenario was similar to that in the LRU scenario because the
27 utilization ratios of logging residues between the two scenarios are similar. In contrast,
28 in the MRU scenario where only mill residues are used as raw materials in the IWBS,
29 the lumber and wood product manufacturing sector (which is strongly related to the
30 utilization of logging residues) was the most affected with 1.6 jobs created, followed by
31 1.3 jobs in other tertiary industries and 1.1 jobs in commerce and service incidental to
32 transport.

34 **4. Discussion and conclusions**

35 This study examined the GHG emissions and economic effects of the utilization of
36 logging and mill residues in Maniwa, a typical rural area in Japan. In the LRU scenario,

1 a substantial benefit cannot be expected because of the burden of expenditure in the
2 collecting stage compared to the MRU scenario. Although the results indicate that the
3 utilization of logging residues is financially unfavorable, the results of the regional
4 economic effects estimated using an I/O analysis shows different effects. The regional
5 economic effect in the LRU scenario was 188 million JPY, which is roughly 77 million
6 JPY more than that in the MRU scenario. Similarly, in the regional economic effect
7 results, the LRU scenario produced roughly 13 full-time jobs, 1.6 times higher than the
8 approximately 6 full-time job opportunities under the MRU scenario. In particular,
9 approximately 8 job opportunities could be created in the forestry sector under the LRU
10 scenario, whereas only 0.5 jobs were created in this sector in the MRU scenario. Thus, it
11 can be expected that the expansion of logging residue utilization increases employment
12 in the forestry sector. Overall, the economic effects indicate that utilization of logging
13 residues contribute to an increase in employment opportunities (particularly in the
14 forestry sector) and help promote regional economies. However, the utilization of mill
15 residues provides the greatest financial benefits in the IWBS.

16 In terms of GHG emissions, the LRU scenario can reduce GHG emissions by up to
17 roughly 211t CO₂eq/t compared to the MRU scenario. The reason why mill residues emit
18 19% more GHG than logging in the process flow is that mill residues are created by
19 collecting logs transported from many other regions and from Maniwa at the harvest
20 stage and because an additional stage for producing mill residues in the sawmill is
21 required. In this study, the range of process flows for GHG reduction analysis was
22 limited from the harvest stage to the TtC stage. Furthermore, considering that the
23 process is extended to consumer consumption, a certain quantity of GHG reductions
24 generated by replacing fossil fuels with woody biomass can also be estimated, as shown
25 in Table 10. Using 267t of chips and 3,897t of bark for fuel in Maniwa, 1,260t CO₂eq of
26 GHG reductions can eventually be expected regardless of the type of woody biomass.

27 The empirical study results indicate that even though logging residues are more
28 advantageous to reducing GHG emissions and to promoting regional economies and the
29 creation of full-time jobs, the financial burden of expenditure in the stage of logging
30 residue collection remains a problem. In contrast, mill residues could be a better
31 resource for creating benefits from the promotion of woody biomass utilization. Figure 5
32 also clearly shows that increasing the proportion of mill residue utilization can help
33 decrease expenditure, whereas increasing the logging residue utilization can contribute
34 to the reduction of GHG emissions. The problem also acts as an obstacle to greater
35 utilization of logging residues. Likewise, to improve the price competitiveness of logging
36 residues to the level of mill residues, financial incentives or subsidies provided by the

1 government and prefecture should be supported. In response to renewable energy
2 obligation schemes such as feed-in tariffs (FIT) implemented in Japan in July 2012, the
3 government set the value of logging residues as raw materials for producing electricity
4 roughly 10 JPY/Kwh higher than mill residues in consideration of the current problems
5 of logging residues. More research is needed to consider a more effective method of
6 woody biomass utilization that can adequately reflect the characteristics of logging and
7 mill residue use. Further research on effective cyclical use of woody biomass in local
8 areas will be assessed in terms of economic and environmental value. Another future
9 task that could be valuable for promoting the utilization of woody biomass is to study
10 how to ensure a constant supply of logging residues to keep up with demand.

11 **Acknowledgements**

12 This work was funded by Japan Science and Technology Agency (JST) and The
13 Environment Research and Technology Development Fund (K2364). We are grateful to
14 Maniwa city and Maniwa Biomass Lab officials for providing valuable data for our
15 research.
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Table 1 Amount of wood products made using logging and mill residues delivered in IWBS (2012)

Table 2 Energy consumption per unit tonne and GHG emissions coefficients in each stage of the process

Table 3 Transportation distance in the Ttl and TtC stages

Table 4 Unit production costs of logging and mill residues

Table 5 Unit price for wood products

Table 6 GHG emissions per unit tonne of logging and mill residues for wood product production in each stage of the process

Table 7 Unit expenditure, income, and benefit of logging residues and mill residues for wood product production

Table 8 Classification of the detailed results on expenditure, income, and benefits for the three scenarios for the regional economic effect analysis inputs

Table 9 Regional economic effects in each scenario

Table 10 Substitution effects of woody biomass combustion with kerosene fuel

Table 1 Amount of wood products made using logging and mill residues delivered in IWBS (2012)

Type	Unit	Total amount	Type			
			Logging Residues		Mill Residues	
			LRf ^{a)}	LRtm ^{b)}	MRbb ^{c)}	MRb ^{d)}
Total	t/year, (52% wet)	23,710	14,437	4,296	2,579	2,398
Chips for paper		18,907	12,670	3770	2,467	-
Chips for fuel		267	179	53	35	-
Bark		3,897	1,155	344	-	2,398
Chip dust		639	433	129	77	-

* Moisture content of woody biomass resources in Maniwa is set to approximately 52%.

^{a)} LRf is short for logging residues carried from the forest in Maniwa.

^{b)} LRtm is short for logging residues transported via the timber marketplace.

^{c)} MRbb stands for backboard, a type of mill residue.

^{d)} MRb stands for bark, a type of mill residue.

Table 2 Energy consumption per unit tonne and GHG emissions coefficients in each stage of the process

Categories & Process		Light diesel oil	Kerosene	Electricity	Sources
		L/t, L/t·km	L/t	Kwh/t	
Energy consumption per unit tonne	Harvest	2.5	-	-	NEDO (2010)
	Ttl	0.0844	-	-	METI and MLTI (2006)
	Sawmilling ^{a)}	0.037 (0.034)	0.461 (0.428)	1.749 (1.626)	Fuchigami et al. (2012), Internal data (2012–2013)
	Manufacturing	1.49	-	11.097 (17.601)	Internal data (2012–2013)
	TtC	0.0844	-	-	METI and MLTI (2006)
GHG emissions coefficients		kg CO ₂ /L	kg CO ₂ /L	kg CO ₂ /Kwh	
		3.170	3.001	0.64	JEMAI (2010)

^{a)} Each type of energy consumed per unit tonne in the sawmilling stage is referred to in Fuchigami, Y. et al. (2012), in which the amount of light diesel oil, kerosene, and electricity consumption per cubic meter of total timber are measured as $3.4L/m^3$, $41.8L/m^3$, and $158.8kwh/m^3$, respectively. Using this data, energy consumption per unit tonne of logging residues in the sawmilling stage could be obtained by multiplying the amount of light diesel oil, kerosene, and electricity consumption per cubic meter of total timber by the ratio of MRb and MRbb in the total amount of timber. The ratio of MRbb and MRb are set as 0.011 and 0.0102, respectively, based on internal information (2012–2013).

* Data in brackets are used to calculate the energy consumption of MRb production.

Table 3 Transportation distance in the Ttl, and TtC stages

Process	Departure		Arrival	Distance	Sources
				km	
Ttl	Forests in Maniwa		IWBS	30	NEDO (2010)
	Forests outside Maniwa			45.9	
	Forests outside the prefecture			226.3	
TtC	Chip collection facility	Chips for paper	Paper manufacturing plant	69.3	NEDO (2010), Internal data (2012-2013)
		Chips for fuel	City Hall	5.0	
		Bark	Bark consumers	5.4	
		Chip dust	Stock farm consumers	24.5	

Table 4 Unit production costs of logging and mill residues

Type		Collecting	Manufacturing	Transport			
				Inside the city	Outside the city		
Unit		JPY/t (52% wet)					
Logging Residues	LRf ^{a)}	4,000	2,735	920	1,447		
	LRtm ^{b)}	5,800	2,735				
Mill	MRbb ^{c)}	3,000	2,720				
Residues	MRb ^{d)}	50	2,410				

* Moisture content is set to approximately 52%.

^{a)} LRf is short for logging residues carried from the forest in Maniwa.

^{b)} LRtm is short for logging residues transported via the timber marketplace.

^{c)} MRbb stands for backboard, a type of mill residue.

^{d)} MRb stands for bark, a type of mill residue.

Table 5 Unit price for wood products

Type	Chips for fuel	Chips for paper	Bark	Chip dust
Unit	JPY/t (30% wet)	JPY/dry-t	JPY/t (52% wet)	JPY/t (52% wet)
Unit price	12,500	17,000	3,500	8,000

Table 6 GHG emissions per unit tonne of logging and mill residues for wood product production in each stage of the process

Stage			Total	Harvest	TtI	Sawmil ling	Manufact uring	TtC
Unit			kg-CO ₂ eq/t (52% wet)					
Total			37.1	7.9	9.7	0.5	11.4	7.6
Logging Residues			36.3	7.9	8.0	0.0	12.2	8.2
Mill Residues			40.3	7.9	16.2	2.5	8.4	5.2
Logging Residues	LRf	Chips for paper	36.7	7.9	8.0	0.0	11.8	8.9
		Chips for fuel	28.7	7.9	8.0	0.0	11.8	0.9
		Bark	33.4	7.9	8.0	0.0	16.0	1.4
		Chip dust	34.3	7.9	8.0	0.0	11.8	6.6
	LRtm	Chips for paper	36.7	7.9	8.0	0.0	11.8	8.9
		Chips for fuel	28.7	7.9	8.0	0.0	11.8	0.9
		Bark	33.4	7.9	8.0	0.0	16.0	1.4
		Chip dust	34.3	7.9	8.0	0.0	11.8	6.6
Mill Residues	MRbb	Chips for paper	47.5	7.9	16.2	2.6	11.8	8.9
		Chips for fuel	39.4	7.9	16.1	2.6	11.8	0.9
		Chip dust	45.2	7.9	16.3	2.6	11.8	6.6
	MRb		32.7	7.9	16.2	2.4	4.7	1.4

* Moisture content is set to approximately 52%.

Table 7 Unit expenditure, income, and benefit of logging and mill residues for wood product production

			Total amount	Unit expenditure	Unit income ^{a)}	Unit benefit ^{b)}
Unit			t (52% wet)	JPY/t (52% wet)		
Total			23,710	7,859	8,603	745
Logging Residues			18,733	8,573	9,000	426
Mill Residues			4,977	5,168	7,111	1,942
Logging Residues	LRf	Chips for paper	12,670	8,168	9,376	1,209
		Chips for fuel	179	8,788	9,765	977
		Bark	1,155	7,402	4,676	-2,727
		Chip dust	433	9,720	9,176	-545
	LRtm	Chips for paper	3,770	9,968	9,378	-589
		Chips for fuel	53	10,588	9,902	-686
		Bark	344	9,202	4,676	-4,527
		Chip dust	129	11,520	9,176	-2,345
Mill Residues	MRbb	Chips for paper	2,467	7,168	9,376	2,208
		Chips for fuel	35	7,788	9,747	1,959
		Chip dust	77	8,720	9,176	455
	MRb		2,398	2,960	4,676	1,716

* Moisture content is set to approximately 52%.

* Figures are rounded to the nearest whole number.

^{a)} Total income can be calculated by summing the total sales of wood products and the rural authority subsidy as mentioned in Chapter 2.4. When we estimate unit income, we need to ensure two things: moisture content and method for estimating the unit rural authority subsidy of each wood product or woody biomass of the total subsidy. First, the moisture content for the unit sales price differs from the type of wood product, as shown in Table 5. When the unit price was calculated, moisture content was unified to roughly 52%. Second, the unit rural authority subsidy of each wood product or woody biomass can be obtained by multiplying the ratio of each wood product or woody biomass in the total amount by the total rural authority subsidy.

^{b)} The total benefit can be obtained by subtracting expenditures from income, as indicated in Chapter 2.4.

Table 8 Classification of the detailed results on expenditure, income, and benefits for the three scenarios for the regional economic effect analysis input [unit:Mil. JPY]

Industry sectors	Scenarios			Items
	BAU	LRU	MRU	
Forestry	82.7	104.6	0.0	Purchase cost for logging residues
Manufacture of wood products	7.9	0.0	59.6	Purchase cost for mill residues
Manufacture of petroleum and coal products	4.1	4.1	4.1	Diesel
Electricity, gas, heat, and water supply	6.9	8.1	6.2	Electricity
Services incidental to transport	31.8	31.8	31.8	Cost of transport
Automobile and machine repair	5.6	5.7	5.7	Maintenance
Total endogenous sector	138.8	154.2	107.3	
Consumption expenditures outside households	2.8	2.8	2.8	General management
Compensation of employees	18.8	18.8	18.8	Personnel expenses
Operating surplus	17.7	2.4	49.3	Benefit
Capital consumption allowance	25.8	25.8	25.8	Depreciation
Indirect taxes	0.0	0.0	0.0	Taxes
Current subsidy	−27.9	−27.9	−27.9	Subsidy
Gross value added	37.2	21.9	68.8	
Total amount	176.0	176.1	176.1	

Table 9 Regional economic effects in each scenario

	Variable	Unit	Direct effect	Indirect effect	Induced effect	Total effect	Multiplier
BAU	Total output	Mil.JPY	117.6	45.3	16.5	179.5	1.5
	Value-added	Mil.JPY	69.0	21.1	12.0	102.1	1.5
	Employment	No. of Jobs	6.5	3.1	1.2	10.8	1.7
LRU	Total output	Mil.JPY	134.4	51.4	18.1	203.9	1.5
	Value-added	Mil.JPY	80.2	23.9	13.2	117.3	1.5
	Employment	No. of Jobs	7.7	3.5	1.3	12.5	1.6
MRU	Total output	Mil.JPY	75.8	33.8	14.4	123.9	1.6
	Value-added	Mil.JPY	34.1	15.7	10.5	60.3	1.8
	Employment	No. of Jobs	2.6	2.3	1.1	5.9	2.3

Table 10 Substitution effects of woody biomass combustion with kerosene fuel

	Caloric value			Amount of consumption		GHG emissions		Amount of GHG emissions		Reduction amounts
	Woody biomass ^{a)}	Kerosene ^{b)}	Equivalent value of kerosene	Woody biomass for fuel	Equivalent amount of kerosene	Woody biomass	Kerosene ^{c)}	Woody biomass	Kerosene	
	MJ/t	MJ/L	L/t	t	L	kg CO ₂ eq/t	kg CO ₂ eq/t	t CO ₂ eq		
Unit										
Total reduction	-	-	-	-	-	-	-	-	-	1,261
Chip for fuel	12,950	36.7	352.9	267	94,214	30.1	3,001	8	283	275
Bark	3,500	36.7	95.4	3,897	371,649	33.0		129	1,115	987

^{a)} The caloric value for woody biomass was set according to NEDO (2010).

^{b)} The caloric value for kerosene was set based on RIETI (2005).

^{c)} GHG emissions of unit of kerosene were set to 3.001kg CO₂eq/t based on JEMAI (2010).

Figure 1 Map of Maniwa city

Figure 2 Process flow diagram of woody biomass utilization in Maniwa

Figure 3 GHG emissions (left) and unit benefit (right) changes by utilization rate of logging residues under the three scenarios

Figure 4 The number of full-time jobs created in the three scenarios

Figure 5 Effects of GHG emissions and expenditure by changing the proportion of logging and mill residue utilization

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