JEE Journal of Ecological Engineering

Journal of Ecological Engineering 2023, 24(9), 333–344
https://doi.org/10.12911/22998993/169286
ISSN 2299–8993, License CC-BY 4.0

Received: 2023.06.12
Accepted: 2023.07.06
Published: 2023.07.24

Potency, Type, and Quality of Wood Waste Harvesting Timber of Lowland Natural Forest in Two Forest Concessions in South Papua

Soenarno[1], Yuniawati[1], Dulsalam[1], Sona Suhartana[1], Jamaludin Malik[1], I Wayan Susi Dharmawan[2], Titiek Setyawati[2], Eka Novrianti[1], Sarah Andini[1], Mutia Herni Ningrum[1], Totok Kartono Waluyo[1*], Pudja Mardi Utomo[3]

[1] Research Center for Biomass and Bioproducts, National Research and Innovation Agency, Republic of Indonesia, Jl. Raya Jakarta-Bogor KM. 46 Cibinong, Bogor 16911, Indonesia

[2] Research Center for Ecology and Ethnobiology, National Research and Innovation Agency-Republic of Indonesia, Jl. Raya Jakarta-Bogor KM. 46 Cibinong, Bogor 16911, Indonesia

[3] Research Center for Plant Conservation, Botanical Gardens and Forestry, National Research and Innovation Agency-Republic of Indonesia, Jl. Raya Jakarta-Bogor KM. 46 Cibinong, Bogor 16911, Indonesia

* Corresponding author's e-mail: waluyo60@yahoo.com

ABSTRACT

Papua Province has a natural production forest reaching 13.541 million ha, with log production achieving an average of 8.78% of the total national log production of 5.835 million m^3/year. The logs were obtained from selective logging activities using reduced-impact logging techniques. This paper aimed to determine the potency, type, and quality of wood harvesting waste in the two forest concessions lowland natural forests in the province of Papua. The average potential of wood harvesting waste is 4.012 m^3/ha or 16.25%. This figure comprises felling waste, which amounts to 2.529 m^3/ha or 10.24%, and waste due to skidding and grading scaling, which amounts to 1.483 m^3/ha or 6.01%. The types of logging waste consist of stump, end, and base waste with an average volume of 1.014 m^3/ha (40.88%), 0.825 m^3/ha (30.72%), and 0.690 m^3/ha (28.40%), respectively. The quality of logging waste is dominated by defects, with an average of 2.733 m^3/ha (69.10%). The waste broken due to the harvesting process averages 0.756 m^3/ha (18.84%), while that of good quality averages 0.484 m^3/ha (12.07%). The following measures should be taken to mitigate logging waste; (a) company management needs to train on reduced impact logging techniques for both chainsaw and tractor operators, (b) the piece rate system has to be reviewed, and (c) the monitoring function of logging activities in the field has to be improved.

Keywords: Papua province, log production, selective cutting, reduced impact logging, stump, base, end waste.

INTRODUCTION

Papua Province has a wealth of natural production forest resources, reaching 13.541 million ha, or 19.67% of Indonesia's total natural forest of 68.834 million ha (Badan Pusat Statistik Provinsi Papua, 2022; Badan Pusat Statistik, 2020a). Production forests have a vital role as a source of log production to support the raw material needs of the wood processing industry and the economy regionally and nationally. Log production in Papua is dominated by mixed forest species, Meranti and Merbau, with an average volume of 456,631–659,172 m^3/year (Badan Pusat Statistik Provinsi Papua, 2022) or an average of 8.78% of the total log production nationally at 5.835 million m^3/year (Badan Pusat Statistik, 2020b). The low supply of logs will affect the amount of Non-Tax State Revenue (PNBP). This is because the calculation of the provision of forest resources is based on the realization of log production (Kementerian Hukum dan Hak Asasi Manusia, 2014; Kementerian Lingkungan Hidup dan Kehutanan, 2017).

In timber harvesting, forest exploitation must be guided by low-impact logging technology. The guidelines for harvesting forest biomass help ensure the ecological sustainability of harvesting forest residues for bioenergy and bioproducts, thereby contributing to a social license for bioeconomic growth (Titus et al., 2021). This aligns with the globalization era, which demands more productive, efficient, and environmentally friendly forest management to ensure more sustainable forest management. However, wood biomass waste is difficult to avoid due to technical and non-technical factors. The study results revealed that the volume of harvesting waste in the exploitation of natural forests was still relatively high, reaching 45% of the logged timber volume (Budiaman & Audia, 2022). The wood harvesting waste that occurs needs to be measured, and its quality conditions must be known to make policies for its further utilization (Rotili et al., 2022).

Inefficient harvesting practices result in reduced log production from forests, potentially increasing forest carbon emissions and even threatening forest sustainability (Shearman, Bryan, & Laurance, 2012; Irland, 2011; Pearson et al., 2014; Damptey et al., 2021). Indonesia's forested region spans an area of 125.92 million hectares, with Production Forests accounting for approximately 55% of the total forest area of Indonesia. Implementing a logging system that causes minimal damage is a highly desirable approach to ensuring the sustainability of forest management. Implementing Reduced Impact Logging (RIL) as a logging technique can mitigate the negative impact of logging activities on the environment. The average emission factor for emission reduction estimation in RIL compared to conventional logging (CL) amounted to 30.03 tonC/ha and was equivalent to 110.2 tonCO2eq/ha or 55.71% (Dharmawan and Ridwan, 2022). Non-technical factors include natural defects in the felled trees (growth, crooked, heart rot, alligator eyes/notches) and company management policy factors oriented towards producing large logs. Technical factors include not mastering logging techniques and the chainsaw operator's habits (Soenarno et al., 2021). Logging techniques strongly influence operational efficiency and costs, and productivity is critical for commercial forest management (Soman et al., 2021).

Wood biomass waste is one of the problems that must be overcome, because harvesting wood in natural forests aims to maximize the product and value of logs to optimize the supply of raw materials for the wood processing industry (Sari & Ariyanto, 2018). From an ecological perspective, biomass wood waste in the forest has an essential meaning in sustainable forest management, because it not only plays a role in maintaining carbon stocks (Putz et al., 2008; Martin et al., 2015; Osone et al., 2016) but can also maintain forest biodiversity (Eräjää et al., 2010; Ranius et al., 2018) and supports tree growth (Helmisaari et al., 2011). Wood waste and timber harvesting are significant sustainable forest management components. Sustainable harvesting techniques entail selective tree-cutting, allowing healthy trees to flourish and preserve the natural balance of the forest. It is possible to collect timber and wood debris in a way that minimizes harm to the forest floor, safeguards wildlife habitats, and lowers erosion and water pollution. Logging should not significantly harm the future potential for an extensive range of forest uses with careful planning and operational procedures. However, logging is damaging no matter how well planned and carried out. Therefore, the first step in ecologically sound or "good" forest management is to practice responsible logging (Armitage, 1997).

Forest harvesting waste measures the efficiency level of forest harvesting (Matangaran et al., 2013; Sari & Ariyanto, 2018; Akay et al., 2010: Yguel et al., 2019). Wood harvesting waste is a potential source of energy for raw wood materials (Osman et al., 2014; Zamora-Cristales & Sessions, 2016; Pandey, 2022; Zbieć et al., 2022), and the pellet industry (Ruslandi et al., 2020; Dalya et al., 2021). It is a common wood harvesting waste that is still good and can be processed into laminated wood products (Malik et al., 2005).

In logging, at least three main technical aspects need attention, namely determining the direction of the felling of trees, making notches, and applying proper bucking (Klassen, 2006). Inaccuracies in creating cutting notches may lead to the formation of barber chairs at the stem's base, consequently causing the tree to fall in an unintended direction (Forestry Training Center Incorporated, 2010; Soenarno et al., 2019). The correct direction will increase the quantity and quality of wood, so that its utilization is efficient (Ward, 2011). In comparison, the correct distribution of logs will affect the quality and economic value of wood (Uusitalo et al., 2004; Greulich et al., 1999).

On the basis of the description above, this paper aimed to determine the potential and quality of wood biomass waste and wood harvesting efficiency in lowland natural forests in Papua Province. It is hoped that corrective action can be taken from the technical performance data and information on good timber harvesting. In addition, the data on the potential and quality of wood biomass waste is also important information in the efforts to utilize it further.

RESEARCH METHODS

Site of research

The research was conducted in two areas of forest concession, namely PT. INA in Merauke Regency, and PT. TTL in Boven Digoel Regency, South Papua Province. Schematically, the second location is presented in Figure 1.

Materials and tools

The materials used in this study were steel cable slings to help tie the logs, chalk, paint, markers, plastic for labels, diesel fuel, lubricating oil, and tally sheets. The tools used were a chainsaw, a skidder, a tree diameter measuring tape (Phiband) and a tape measure to measure the length of logs and felling residue, a clinometer, a compass and a GPS to make sample plots observation, and a digital camera for documentation.

Data collection

Primary data

Primary data is basic data obtained through direct observation and measurement in the field. The data collected included the potential of clear bole, felling waste, as well as wood waste along skid trails and after testing and measuring the wood by technical officers at the landing point.

1. Clear bole potency

Clear bole potency is the volume of wood expected to be utilized, which is calculated based on the length of the tree up to the limit of the first branch.

2. Logging waste

a) Felling waste

Residual timber, commonly called felling waste, comprises various wood materials such as stumps, deformed, rotted or hollow logs with a diameter reduction exceeding 40%, and twigs and branches that remain in the forest after logging activities (Kementerian Lingkungan Hidup dan kehutanan, 2019). Sari & Ariyanto (2018) stated that logging waste is part of commercial logs, short pieces of the remaining division of stems, stumps, branches, and twigs. However, in this paper, logging waste only includes stumps and short pieces of remaining stem division in the form of buttresses, bases, and ends that are deformed or broken (Soenarno et al., 2016). The stump waste is calculated based on the difference between the height of the arrears measured in the field and the allowable felling height of 30 cm (Ruslandi, 2013).

b) Skidding waste is measured by the damaged/broken wood left along the skid trails.

c) Grading and scaling waste is the residue from cutting the base or ends of logs that are skidded to the landing point by technical staff.

Secondary data

Secondary data collected includes the general condition of forest concession (forest condition and location, topography, climatic conditions, for instance), reports on the results of standing inventory before logging, log production report, wage system for logging and skidding, implementation

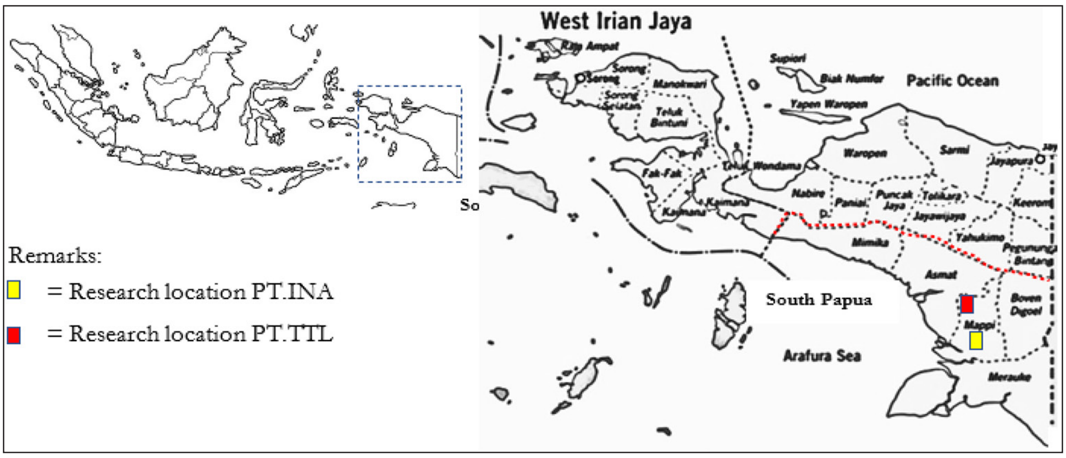

Figure 1. Research location

testing and measuring (grading scaling) of logs. Other secondary data were obtained from the literature studies related to research results.

Research procedure

In each forest concession location (PT. INA and PT. TTL), three logging sites were selected, and then 3 sample plots of 2 ha (200 x 100 m) were made for each selected felling site. Before logging began, all trees with a diameter at breast height (dbh) >20 cm were measured and mapped, along with the topography of each plot, stand density, and the number and type of trees to be felled. After felling and skidding were conducted, the volume of clear bole logs and felling waste in the cutting plots and wood waste left along the skid trails were recorded. However, the wood waste was recorded after the grading scaling activities at the Landing Point.

Data analysis

Calculation of the volume of wood used and wood harvesting waste uses the Brereton formula (National Standardization Agency, 2020), which is as follows:

$$I = \frac{\frac{1}{4}\pi \times d^2 \times p}{10000} \quad (1)$$

and

$$I = \frac{du + dp}{2} \quad (2)$$

where: I – wood volume (m^3);
d – average of wood diameters (cm);
dp – base diameter (cm);
du – end diameter (cm);
p – length of wood (m);
π – Constanta (3.14)

Wood waste volume per tree, calculated by the formula:

$$\mathrm{WWVT} = \frac{\mathrm{WWV}\ (\mathrm{m}^3)}{\mathrm{NFT}\ (\mathrm{tree})} \quad (3)$$

Wood waste volume per ha, calculated by the formula:

$$\mathrm{WWVH} = \frac{\mathrm{WWV}\ (\mathrm{m}^3)}{\mathrm{AOSP}\ (\mathrm{ha})} \quad (4)$$

Potency of wood waste (%), calculated by the formula:

$$\mathrm{WWVH} = \frac{\mathrm{WWV}\ (\mathrm{m}^3)}{\mathrm{AOSP}\ (\mathrm{ha})} \quad (5)$$

where: WWVT – wood waste volume per tree;
WWV – wood waste volume;
NFT – number of felled trees;
WWVH – wood waste volume per ha;
AOSP – area of observation sample plots.

Data analysis

The data from average waste measurement results were then statistically analyzed with the F-test using the program PAWSTAT 23.0.

RESULTS AND DISCUSSION

General site conditions

Table 1 provides an overview of the overall state of the research site. Table 1 presents the topographical characteristics of PT. INA and PT. TTL. The terrain at PT. INA is relatively flat, whereas PT. TTL is predominantly sloping, with a slight inclination towards steepness. The two

Table 1. Characteristic of the study area in PT. INA and PT. TTL

Description	Forest Concessions	
	PT. INA	PT. TTL
Area	99.665 ha	214.935 ha
Annual allowable cut (AAC)	117.112 m^3/year	118.641 m^3/year
Geographical location	140°31’42”–140°50’46” East Longitude and 06°40’56”–05°05’26” South Latitude	140°21’00”–140°59’00” East Longitude and 05°50’50”–06°42’00” South Latitude
Administration location	Ulilin District, Merauke Regency, Papua Province	District of Jair, Mindiptana, and Waropko, Boven Digoel Regency, Papua Province
Topography	Flat (0–8%)	Dominated with Sloping (8–15%)
Area height	25–50 m asl	30–300 m asl
Climate	Type B (Schmidt and Ferguson)	Type B (Schmidt and Ferguson)
Forest condition	Logged over area	Logged over area

forest conditions under consideration are logged forest areas with an Annual Allowable Cut (AAC) of 117.112 m^3/year at PT. INA and 118.641 m^3/year at PT. TTL.

Logging waste

Felling waste

The recapitulation of felling waste is presented in Table 2. Table 2 shows that the average volume of felling waste is 0.297 m^3/tree (2.529 m^3/ha), namely at PT. INA of 0.285 m^3/tree (2.509 m^3/ha) is relatively lower than PT. TTL of 0.310 m^3/tree (2.550 m^3/ha). Concerning the clear bole volume, the logging waste at PT. INA is 10.16% while at PT. TTL is 10.33%. To determine the difference in logging waste between PT. INA and PT. TTL is done by F test using PWSTAT version 23, as presented in Table 3.

The statistical test results are presented in Table 3, indicating that the F-count value is $0.679 < F_{0.05(1.4)} = 7.71$. Therefore, the null hypothesis (H_0) is accepted, and the alternative hypothesis (H_1) is rejected, concluding no statistically significant difference in logging waste between PT. INA and PT. TTL. Thus, it can be inferred that the amount of logging waste is 0.279 m^3/tree or 2.259 m^3/ha (10.24%) of the potential value of branch-free wood. The results of this study were lower than those obtained in the studies in East Kalimantan and Central Kalimantan which showed that felling waste ranged from 0.859–1.419 m^3/tree or 27–28% (Soenarno et al., 2016; Soenarno et al., 2021). The research volume of natural forest felling waste wood in Malaysia is 43% (Osman et al., 2014). Meanwhile, the felling waste in Central Kalimantan ranged from 12.81–18.09 m^3/ha with an average of 15.45 m^3/ha (Surasana et al., 2020), and in North Kalimantan and West Papua shows the potential for logging waste ranges from 3.21–3.64 m^3/ha (Budiaman et al., 2020). The difference in the volume of felling waste from the research results was caused by factors such as tree diameter and field topography. The average diameter of the trees felled in this study ranged from 48.7–55.3 cm, and the topography was flatter, but in Central Kalimantan, North Kalimantan,

Table 2. Recapitulation of felling waste measurement results

Forest concessions	Felling site	Number of trees felled	Tree diameter	Clearbole potency	Wood felling waste		
		(Tree/ha)	(Cm)	(m³/tree)	(m³/tree)	(m³/ha)	(%)
PT. A	1	7	52.1	21.959	0.245	1.712	6.93
	2	11	48.7	30.426	0.325	3.576	14.48
	3	8	50.3	24.112	0.280	2.240	9.07
	Average	9	50.4	25.499	0.285	2.509	10.16
	St.deviations	2.1	1.7	4.401	0.057	0.177	5.34
PT. B	1	10	55.2	27.720	0.266	2.660	10.77
	2	8	51.7	23.184	0.341	2.728	11.05
	3	7	55.3	20.755	0.323	2.261	9.16
	Average	8	54.1	23.886	0.310	2.550	10.33
	St.deviations	1.5	2.1	3.535	0.039	2.712	1.02
Grand average		9	52.2	24.693	0.297	2.529	10.24

Table 3. Results of felling waste F test analysis

Dependent Variable: Wood felling waste					
Source	Type III sum of squares	df	Mean square	F	Sig.
Corrected Model	0.001[a]	1	0.001	0.679	0.456
Intercept	0.528	1	0.528	336.205	0.000
Forest Concession	0.001	1	0.001	0.679	0.456
Error	0.006	4	0.002		
Total	0.535	6			
Corrected Total	0.007	5			

Note: a – *R* Squared = .145, (Adjusted *R* Squared = -.069).

Table 4. Types of wood harvesting waste

Forest concessions	Felling site	Buttress height (cm)	Felling height (cm)	Type of wood felling waste							
				Stump		Base		End		Total	
				(m³/ha)	(%)	(m³/ha)	(%)	(m³/ha)	(%)	(m³/ha)	(%)
PT. A	1	33.3	66.1	0.886	51.74	0.417	23.90	0.409	23.90	1.712	100.00
	2	85.2	77.2	1.170	32.72	0.676	48.38	1.730	48.38	3.576	100.00
	3	30.5	70.7	0.932	41.59	0.884	18.94	0.424	18.94	2.240	100.00
	Average	49.7	71.3	0.996	42.02	0.659	30.41	0.855	30.41	2.509	100.00
	St. deviations	30.8	5.6	0.153	9.52	0.234	15.76	0.759	15.76	0.961	0.00
PT. B	1	75.1	69.3	1.200	45.11	0.590	32.71	0.870	32.71	2.660	100.00
	2	100.6	84.1	1.304	47.80	0.528	32.84	0.896	32.84	2.728	100.00
	3	35.0	68.5	0.595	26.32	1.043	27.55	0.623	27.55	2.261	100.00
	Average	70.2	74.0	1.033	39.74	0.720	31.04	0.796	31.04	2.550	100.00
	St. deviations	33.1	8.8	0.383	11.71	0.281	3.02	0.151	3.02	0.252	0.00
Grand average		60.0	72.7	1.014	40.88	0.690	28.40	0.825	30.72	2.529	100.00

and West Papua had tree diameters ranging from 60.7–92.9 cm with topographical conditions ranging from sloping to steep. However, the intensity of tree felling can determine the amount of logging waste (Numazawa et al., 2017; Rozak et al., 2018).

From observations in the field, the potential for felling waste is still scattered within the felling site with various types, as shown in Table 4. The proportion of felling waste in the felling plots is mostly stump waste, with an average of 1.014 m^3/ha (40.88 %). The average base and end waste volumes were 0.690 m^3/ha (28.40%) and 0.825 m^3/ha (30.72%).

The amount of stump waste is attributed to the stump that still exceeds the minimum allowable height of 30 cm above the ground, as stipulated by the reduced impact logging carbon guidelines (Ruslandi, 2013).

The results of measurements in the field showed that the average cutting height ranged from 71.3–74 cm with an average of 72.7 cm or there was a difference in the average cutting height of 42.7 cm compared to the allowable cutting height of 30 cm. Therefore, it is necessary to pay attention to the height of the stump because it will indirectly provide an additional volume of wood per tree. In fact, if the diameter of the tree is large, it will make a significant contribution to the volume of logs produced. The felling height was still higher, ranging from 3.8–22.6 cm or an average of 12.7 cm compared to the average buttress height of 60 cm. This excessive felling height is caused by the habits of the chainsaw operator for ease of work and not removing buttresses, so that the size of the cutting notch becomes inaccurate. Facts in the field show that the notch angle is often less than 45º with consideration of reducing the volume of felled timber (Figure 2). As a result, a barber chair is formed at the base of the stem, producing excessive waste. Another fact, the saw operator, when cutting the end of the stem, is sometimes still far from the first branch, so a large amount of tip waste occurs. It is even

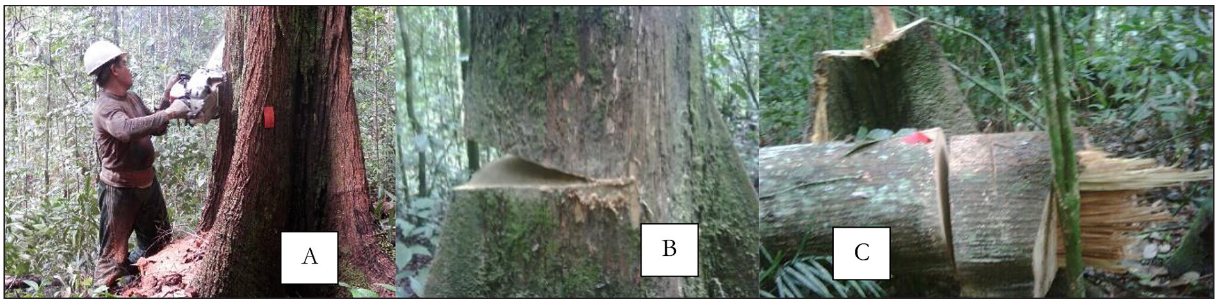

Figure 2. Technical errors in logging trees in natural forest: A = cutting too high, B = small notch size < 450), C= uprooted fiber at the base of the stem

suspected that logging waste is also influenced by the forest concession management policies that apply a piece rate wage system based on a unit volume of felled timber without adequate supervision in the field.

Therefore, technically the occurrence of logging waste can still be minimized by improving the skills of the saw operator, changing their habit of loggers in a standing position, and cutting the tip of the trunk as close to the first branch as possible. Applying the lowest possible felling technique can reduce the risk of splitting the wood at the base of the trunk, allowing for greater precision in the direction of the felling. Ward (2011) explains that the success of logging is determined mainly by the direction of logging and the skills of the loggers. Correct logging techniques reduce the risk of waste generation, increasing the volume and quality of wood used (Garland & Jackson, 1997; Uusitalo, Kokko, & Kivinen, 2004). Greulich et al., (1999) also stated that proper stem division can increase the resulting log value. For this reason, efforts from the company's management are needed to conduct low-impact logging technical training for chainsaw operators.

Skidding and grading scaling waste

The recapitulation of the results of the average measurement of wood waste due to the skidding process and the scaling of grading in the landing point is presented in Table 5. From Table 5, it can be seen that the average amount of skidding and scaling of the grading of wood waste is 0.173 m^3/tree (1,483 m^3/ha) or 6.01% higher than Central Kalimantan with an average of 0.093 m^3/tree or 4.0% (Soenarno et al., 2021). Skidding and grading scaling wastes are unavoidable due to industrial demands for sorting with a specific size, such as sizes with a minimum diameter and length limits. The two forest companies have signed cooperation contracts with the plywood industry following specific log quality requirements.

On the basis of the wood waste calculations in Tables 2 and 5, the calculation of logging waste is presented in Table 6. Table 6 shows that the potential for logging waste is quite large, varying between 3,634–4,391 m^3/ha with an average of 4,012 m^3/ha or 15.18–18.19% with an average of 16.25%. In the results of the research in Central Kalimantan, the amount of wood harvesting waste ranged from 13.65–15.12% with an average of 14.21% depending on the type and diameter of the tree (Abidin et al. (2018). With AAC in PT. INA and PT. TTL of 117.112 m^3/year and 118.641 m^3/year, the logging waste at PT. INA and PT. TTL reached 17,777.60 m^3/year and 21,580.80 m^3/year, respectively. This waste occurs due to the size required by the plywood industry not being met even though, technically, it can still be processed or utilized.

The logging waste is lower than the research results in the sub-regions of East Kalimantan and Central Kalimantan, which ranged from 17–18% (Soenarno et al., 2016; Soenarno et al., 2021) and in East Luwu Regency of 5.75 m^3/ha (Dalya et al. 2021). The amount of waste is much smaller than the research in the Caspian hardwood forests of Pakistan at 15.6% (Behjou et al. 2016) and North Kalimantan at 11.06 m^3/ha (Muhdi et al., 2016). The waste differences are caused by differences in how waste is measured. In this study, only branch-free wood waste up to 30 cm in

Table 5. Recapitulation of skidding and grading scaling waste

Forest concessions	Felling site	Type of wood skidding and grading scaling waste								
		Base			End			Total		
		(m³/tree)	(m³/ha)	(%)	(m³/tree)	(m³/ha)	(%)	(m³/tree)	(m³/ha)	(%)
PT. A	1	0.059	0.413	1.88	0.120	0.840	3.83	0.179	1.253	5.71
	2	0.066	0.726	2.39	0.052	1.582	5.20	0.118	1.298	4.27
	3	0.042	0.336	1.39	0.061	0.488	2.02	0.103	0.824	3.42
	Average	0.056	0.492	1.89	0.078	0.970	3.68	0.133	1.125	5.57
	St. deviaton	0.012	0.207	0.50	0.037	0.559	1.59	0.040	0.262	1.16
PT. B	1	0.257	2.570	9.27	0.041	0.410	1.48	0.298	2.980	10.75
	2	0.111	0.888	3.83	0.059	0.472	2.04	0.170	1.360	5.87
	3	0.067	0.469	2.26	0.102	0.714	3.44	0.169	1.183	5.70
	Average	0.145	1.309	5.12	0.067	0.532	2.32	0.212	1.841	7.44
	St. deviation	0.099	1.112	3.68	0.031	0.161	1.01	0.074	0.990	2.87
Grand average		0.100	0.900	3.50	0.073	0.751	3.00	0.173	1.483	6.01

Table 6. Recapitulation of wood harvesting waste

Forest concessions	Felling site	Clear bole potency (m^3/ha)	Origin of wood waste					
			Wood felling waste		Wood skidding and grading scaling waste		Wood harvesting waste	
			(m^3/ha)	(%)	(m^3/ha)	(%)	(m^3/ha)	(%)
PT. A	1	3.137	1.712	6.93	1.253	5.07	2.965	13.50
	2	2.766	3.576	14.48	1.298	5.26	4.874	16.02
	3	3.014	2.240	9.07	0.824	3.34	3.064	12.71
	Average	2.952	2.509	10.16	1.125	4.56	3.634	15.18
	St.deviations	0.262	1.318	5.34	0.262	1.06	1.350	1.78
PT. B	1	2.772	2.660	10.77	2.980	12.07	5.640	20.35
	2	2.898	2.728	11.05	1.360	5.51	4.088	17.63
	3	2.965	2.261	9.16	1.183	4.79	3.444	16.59
	Average	2.878	2.550	10.33	1.841	7.46	4.391	18.19
	St.deviations	0.098	0.252	1.02	0.990	4.01	1.129	1.94
Grand average		2.915	2.529	10.24	1.483	6.01	4.012	16.25

Figure 3. Timber harvesting waste: (A, B, and C) = due to felling, (D) = due to grading scaling

diameter was measured, while in North Kalimantan, branch-wood waste up to 10 cm in diameter was measured. Some examples of types of wood harvesting waste are presented in Figure 3.

Quality of logging waste

A recapitulation of the results of observations and measurements of the quality of wood harvesting waste is presented in Table 7. Table 7 shows that the quality of logging waste is dominated by an average defect of 2,733 m^3/ha (69.10%) consisting of waste due to logging of 1,424 m^3/ha (35.49%) and waste due to skidding and grading scaling of 1,349 m^3/ha (33.61%). The waste damaged by logging is generally in the form of remaining supports, holes/growth and rot in the heartwood, alligator eyes/notches and/or crooked but is also commonly found in bottom waste due to logging. Meanwhile, the waste deformed due to skidding and grading scaling is in the form of

Table 7. Distribution of wood harvesting waste quality

Logging activity	Forest concession	Clear bole potency	Wood waste quality							
			Good		Defects		Broken		Total	
			(m^3/ha)	(%)	(m^3/ha)	(%)	(m^3/ha)	(%)	(m^3/ha)	(%)
Felling	PT. A	25.499	0.181	7.21	1.834	73.07	0.495	19.71	2.509	100.00
	PT. B	23.886	0.787	30.88	1.014	39.79	0.748	29.33	2.550	100.00
Average		24.693	0.484	19.14	1.42	56.30	0.62	24.56	2.529	100.00
Skidding and grading scaling	PT. A	25.499			0.981	87.20	0.144	12.80	1.125	100.00
	PT. B	23.886			1.716	93.21	0.125	6.79	1.841	100.00
	Average	24.693			1.349	90.93	0.135	9.07	1.483	100.00
Grand average		24.693	0.484	12.07	2.773	69.10	0.756	18.84	4.012	100.00

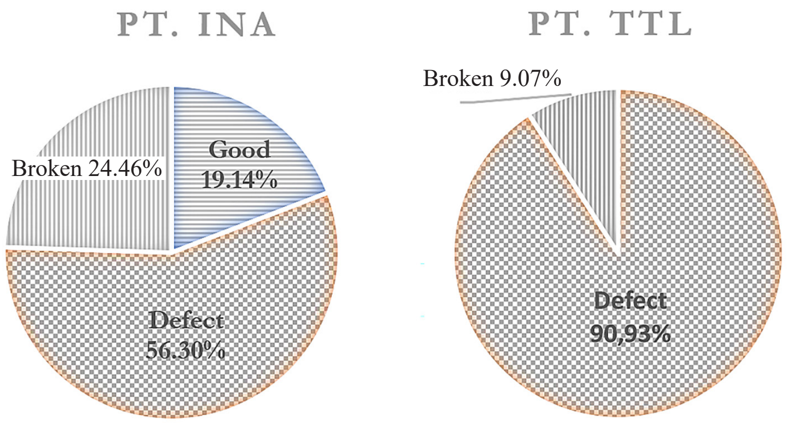

Figure 4. Distribution of logging waste quality

bent wood, notch, and sizes that do not meet the minimum length requirements of 1.3 m.

Broken waste due to timber harvesting averaged 0.756 m^3/ha (18.84%), in the form of the waste due to felling amounting to 0.621 m^3/ha (15.48%) as well as due to skidding and grading scaling equaling 0.135 m^3/ha (3.35%). The broken logging waste occurs both in the end and base stems. Observations in the field indicated that the cause of the broken waste was caused by imperfect felling techniques, especially in narrow undercut (< 30º). According to chainsaw operators, making narrow undercut will reduce the potential for logging waste to occur. The correct width of the mouth of the falling notch ranges from 30–45º (Ruslandi, 2013), and for the trees with inclined conditions it is greater than 45º. (Forestry Training Center Incorporated, 2010; International Tropical Timber Organization, 2012; Lilly et al., 1996). Facts in the field show that the cutting notch is too small, causing the fibers to be uprooted at the base of the tree trunk, and the direction of the fall is incorrect. Even if wrong estimates of the height of the tree with the length of the slope, it can result in the end of the stem breaking. Since there are still many broken logging wastes, chainsaw operators should receive technical education and training to be skilled at mastering the correct felling techniques in the field. However, split waste due to skidding and grading scaling is thought to have occurred during the stacking of logs at the landing point and occurred in certain types of wood which naturally break easily after being logged, such as *Anisoptera marginata* Korth, *Octomeles sumatrana* Miq. and *Pometia pinnata*. The amount of logging waste that was still good was only found due to felling with an average of 0.484 m^3/ha (12.07%) but was not found due to skidding and grading scaling.

Until now, the logging waste has not been utilized and is still left in the forest due to many technical and economic considerations. The difficulty of extracting logging waste from the forest, the diverse types and quality, and the high cost of provision of forest resources that must be paid are the primary considerations related to the profit calculation. The provision of forest resources rate for wood harvesting waste is still the same as Small Logs, IDR 320,000/m^3 or USD 21.4/m^3 (Kementerian Lingkungan Hidup dan Kehutanan, 2017; Kementerian Hukum dan Hak Asasi Manusia, 2014). Meanwhile, the distance between the location of the wood harvesting waste and the wood processing industry is very far, even > 50 km, so transportation costs and standard wages for collecting wood harvesting waste must be considered.

CONCLUSIONS

The potential for wood harvesting biomass waste is enormous, varying between 3,634–4,391 m^3/ha with an average of 4,012 m^3/ha or 15.18–18.19% with an average of 16.25%.), consisting of logging waste an average of 2.529 m^3/ha (10.24%), and waste due to skidding and grading scaling an average of 1.483 m^3/ha (6.01%). The types of logging waste consist of stump, end, and base waste with an average volume of 1.014 m^3/ha (40.88%), 0.825 m^3/ha (30.72%), and 0.690 m^3/ha (28.40%). The quality of wood harvesting waste is dominated by an average defect of 2.733 m^3/ha (69.10%) consisting of waste due to logging of 1.424 m^3/ha (35.49%) and due to skidding and grading scaling of 1.349 m^3/ha (33.61%). Broken waste due to timber harvesting averaged

0.756 m^3/ha (18.84%), in the form of waste due to felling of 0.621 m^3/ha (15.48%) as well as due to skidding and grading scaling of 0.135 m^3/ha (3.35 %) while the average logging waste is 0.484 m^3/ha (12.07%).

Technically, the occurrence of wood harvesting waste is caused by the low skill of the chainsaw operator, namely not applying the correct RIL technique, the felling height being far above the allowable cutting height, and making the wrong cutting notches. Meanwhile, non-technical activities are suspected to be triggered by the forest concession management policies that apply a piece rate wage system based on the unit volume of timber produced by logging and inadequate supervision in the field.

The following measures should be taken to mitigate logging waste; (a) company management needs to provide training on low-impact timber harvesting techniques for both chainsaw and tractor operators, (b) the piece rate system has to be reviewed, and (c) the monitoring function of timber harvesting in the field must be improved.

Acknowledgements

The author would like to thank all parties, especially the leaders of PT INA and PT TTL, who have funded and supported field staff and equipment so that the research runs smoothly. This research is a collaborative activity between the Center for Research and Development of Forest Products, the Ministry of Environment and Forestry, and PT INA and PT TTL in South Papua.

REFERENCES

1. Abidin Z., Thamrin G.A.R., Silaban C. 2018. Potensi limbah pemanenan kayu di lokasi penebangan IUPHHK-HA PT. Dasa Intiga Kalimantan Tengah. Jurnal Hutan Tropis, 5(2), 174–181.
2. Akay A.E., Sessions J., Serin H., Pak M., Yenilmez N. 2010. Applying optimum bucking method in producing taurus fir (*Abies cilicica*) logs in mediterranean region of Turkey. Baltic Forestry, 16(2), 274–279.
3. Armitage I.P. 1997. Practical Steps Contributing to Sustainable Tropical Forest Management for Wood Production With Special Reference to Asia. Special Paper to XIth World Forestry Congress, Antalya, Turkey.
4. Badan Pusat Statistik. 2020a. Statistik Perusahaan Hak Pengusahaan Hutan. BPS-Statistik Indonesia, Jakarta, 52.
5. Badan Pusat Statisti 2020b. Statistik Produksi Kehutanan. Badan Pusat Statistik. BPS-Statistik Indonesia, Jakarta, 68.
6. Badan Pusat Statistik Provinsi Papua. 2022. Provinsi Papua dalam Angka. Badan Pusat Statistik Propinsi Papua, Jayapura, 673.
7. Badan Standardisasi Nasional. 2020. Pengukuran dan Penetapan Isi Kayu Bundar. Jakarta, 1–54.
8. Behjou F., Ramezan M., Esfahan E.Z., Eftekhari A. 2016. Wood waste during full-length and cut-to-length harvesting systems in caspian forests. International Journal of Advanced and Applied Sciences 3(8), 52–56.
9. Budiaman A., Audia L. 2022. Kayu Sisa setelah Penebangan Hutan Alam Di Indonesia: Suatu Tinjauan Sistematis. Jurnal Ilmu Lingkungan, 20(2), 427–436.
10. Budiaman A., Mubarak F.M., Lismaya W. 2020. Kayu limbah penebangan intensitas rendah di Izin Usaha Pemanfaatan Hasil Hutan Kayu-Hutan Alam. Jurnal Ilmu Pertanian Indonesia, 25(1), 145–151.
11. Dalya N., Wahyuni., Muin A.V.F. 2021. Utilization of community forest wood harvesting waste in Bone Pute Village, Burau District, East Luwu Regency. IOP Conference Series: Earth and Environmental Science, 886, 012021. DOI: 10.1088/1755-1315/886/1/012021
12. Damptey F.G., Adofo E., Duah-Gyamfi A., Adusu D., Opuni-Frimpong E. 2021. Logging effects on seedling regeneration and diversity in a tropical moist semi-deciduous forest in Ghana. Geology, Ecology, and Landscapes, 00, 1–12.
13. Darmawan I.W.S., Ridwan M. 2022. Emission factor for emission reduction estimation in reduced impact logging. IOP Conference Series: Earth and Environmental Science 1115 012038. DOI: 10.1088/1755-1315/1115/1/012038
14. Erajaa S., Halme P., Kotiaho J.S., Makkanen A., Toivanen T. 2010. The volume and composition of dead wood on traditional and forest fuel harvested clear-cuts. Silva Fennica, 44(2), 203–211. DOI: 10.14214/sf.150
15. Finley J. 2016. Forest Stewardship: Timber Harvesting: An Essential Management Tool. Update: April 8th, 2016. https://extension.psu.edu/forest-stewardship-timber-harvesting-an-essential-management-tool. FORESTRY TRAINING CENTRE INCORPORATED. 2010. Course in reduced impact logging : chainsaw use, safety practices & directional tree felling techniques (Issue March).
16. Garland J., Jackson D. 1997. Felling and bucking techniques for woodland owners (Issue January). The Woodland Workbook.
17. Greulich F., Hanley D. Mcneel L. 1999. A primer for timber harvesting. Washington State University, Washington.

18. Helmisaari H.S., Hanssen K.H., Jacobson S., Kukkola M., Luiro J., Saarsalmi A., Tamminen P., Tvite B. 2011. Logging residue removal after thinning in Nordic boreal forests: Long-term impact on tree growth. Forest Ecology and Management, 261(11), 1919–1927.
19. International tropical Timber Organization. 2012. Tracking sustainability (Issue October).
20. Irland L.C. 2011. Timber productivity research gaps for extensive forest management. Small-scale Forestry, 10, 389–400. DOI: 10.1007/s11842-011-9155-1
21. Kementerian Hukum Dan Hak Asasi Manusia. 2014. Peraturan Pemerintah Nomor 12 Tahun 2014 tentang jenis dan tarif atas jenis penerimaan negara bukan pajak yang berlaku pada Kementerian Kehutanan. Kementerian Hukum dan Hak Asasi Manusia. Jakarta.
22. Kementerian Lingkungan Hidup dan Kehutanan. 2017. Peraturan menteri lingkungan hidup dan kehutanan tentang penetapan harga patokan hasil hutan untuk perhitungan provisi sumber daya hutan dan ganti rugi tegakan.
23. Kementerian Lingkungan Hidup dan Kehutanan. 2019. Peraturan menteri lingkungan hidup dan kehutanan No. P.1/MENLHK/SETJEN/KUM.1/1/2019 tentang izin usaha industri primer hasil hutan. Jakarta.
24. Klassen A. 2006. Operational considerations for reduced impact logging. International Tropical Timber Organization (ITTO).
25. Lilly S., Palmer K., Tompkins R. 1996. Chainsaw Cutting Techniques.
26. Malik J., Santoso A., Roliad H. 2005. Characteristics of laminated wood of logging waste of three natural forest wood species. Indonesian Journal of Forestry Research, 2(1), 37–48. DOI: 10.20886/ijfr.2005.2.1.37-48
27. Martin P.A., Newton A.C., Pfeifer M., Khoo M.S., Bullock J.M. 2015. Impacts of tropical selective logging on carbon storage and tree species richness: A meta-analysis, 356, 224–233.
28. Muhdi., Elias., Murdiyarso D., Matangaran J.R. 2016. Wood waste caused by reduced impact logging in Indonesian selective cutting and planting system, North Borneo, Indonesia. International Journal of Sciences: Basic and Applied Research (IJSBAR), 30(1), 86–92.
29. Numazawa C.T.D., Numazawa S., Pacca S., John V.M. 2017. Logging residues and CO2 of Brazilian Amazon timber: Two case studies of forest harvesting. Resources, Conservation and Recycling, 122, 280–285. https://doi.org/10.1016/j.resconrec.2017.02.016
30. Osman N.B., Othman H.T. Karim R.A., Mazlan M.A.F. 2014. Biomass in Malaysia : Forestry-Based Residues. International Journal of Biomass & Renewables, 3(1), 7–14. https://myjms.mohe.gov.my/index.php/ijbr/article/view/13872/7153
31. Osone Y., Toma T., Warsudi, Sutedjo, Sato T. 2016. High stocks of coarse woody debris in a tropical rainforest, East Kalimantan: Coupled impact of forest fires and selective logging. Forest Ecology and Management, 374, 93–101. https://doi.org/10.1016/j.foreco.2016.04.027
32. Pandey S. 2022. Wood waste utilization and associated product development from under-utilized low-quality wood and its prospects in Nepal. SN Applied Sciences, 4, 168.
33. Pearson T.R.H., Brown S., Casarim F.M. 2014. Carbon emissions from tropical forest degradation caused by logging. Environmental Research Letters, 9, 034017. DOI: 10.1088/1748-9326/9/3/034017
34. Putz F.E., Sist P., Fredericksen T., Dykstra D. 2008. Reduced-impact logging: Challenges and opportunities. Forest Ecology and Management, 256(7), 1427–1433.
35. Ranius T., Hamalainen A., Egnell G., Olsson B., Eklof K., Stendahl J., Rudolphi J., Stern A., Felton A. 2018. The effects of logging residue extraction for energy on ecosystem services and biodiversity: A synthesis. Journal of Environmental Management, 209, 409–425.
36. Rotili W.O., Brandelero C., De Oliveira Fortes F., Peripolli J.L.Z., De Vargas F., Werner V. 2022. Quality Control of logs in semi-mechanized harvest. Floresta, 52(2), 351–358. DOI: 10.5380/rf.v52 i2.80555
37. Rozak A.H. Rutishauser E., Raulund-Rasmussen K., Sist P. 2018. The imprint of logging on tropical forest carbon stocks: A Bornean case-study. Forest Ecology and Management, 417, 154-166. DOI: 10.1016/j.foreco.2018.03.007
38. Ruslandi. 2013. Penerapan pembalakan berdampak rendah-carbon (RIL-C). The Nature Conservancy.
39. Ruslandi R., Novita N., Malika A. 2020. Utilization of timber harvesting residues for wood pellet production: A green strategy to improve timber concession's profitability. IOP Conference Series: Earth and Environmental Science, 415, 012018. DOI: 10.1088/1755-1315/415/1/012018
40. Sari D.R., Ariyanto. 2018. The potential of woody waste biomass from the logging activity at the natural forest of Berau District, East Kalimantan. IOP Conference Series: Earth and Environmental Science 144 012061. DOI: 10.1088/1755-1315/144/1/012061
41. Soenarno, Dulsalam, Yuniawati. 2019. Teknik penebangan pohon hutan alam. IPB Press, Bogor.
42. Soenarno., Endom W., Basari Z., Dulsalam., Suhartana S., Yuniawati. 2016. Faktor eksploitasi hutan di Sub Region Kalimantan Timur. Jurnal Penelitian

Hasil Hutan, 34(4), 335–348. DOI: 10.20886/jphh.2016.34.4.335-348

43. Soenarno, Yuniawati, Dulsalam. 2021. Penetapan angka standard faktor eksploitasi hutan alam dan potensi limbah pemanenan kayu sub region provinsi kalimantan tengah. Jurnal Penelitian Hasil Hutan, 39(3),155–169. DOI: 10.20886/jphh.2021.39.3.155-169
44. Soman H., Kizha A.R., Delgado B.M., Kenefic L.S., Kanoti K. 2021. Production economics: Comparing hybrid tree-length with whole-tree harvesting methods. Forestry, 93(3), 389–400.
45. Surasana I.N., Kristiani D.I, Yosep. 2020. Limbah penebangan kayu di perusahaan PT. Dwimajaya Utama. Journal of Environment and Management, 1(3), 253–258.
46. Titus B.D., Brown K. Helmisaari H.S., Vanguelova E., Stupak I., Evans A., Clark N., Guidi C., Brugman V.J., Kabasinskiene I.V., Srmolaitis K., De Vries V., Hirai K., Kaarakka L., Hogg K., Reece P. 2021. Sustainable forest biomass: a review of current residue harvesting guidelines. Energy, Sustainability and Society, 11(10), 1–32.
47. Uusitalo J., Kokko S., Kivinen V.P. 2004. The effect of two bucking methods on Scots pine lumber quality. Silva Fennica, 38(3), 291–303. https://doi.org/10.14214/sf.417
48. Warde E. 2011. Chain saws — safety, operation, tree felling techniques. Kansas State University Agricultural Experiment Station and Cooperative Extension Service, Kansas.
49. Yguel B., Piponiot C., Mirabel A., Dourdain A., Herault B., Gourlet-Freury S., Forget P.M., Fontaine C. 2019. Beyond species richness and biomass: Impact of selective logging and silvicultural treatments on the functional composition of a neotropical forest. Forest Ecology and Management, 433, 528–534. https://doi.org/10.1016/j.foreco.2018.11.022
50. Zamora-Cristales R., Sessions J. 2016. Modeling harvest forest residue collection for bioenergy production. Croatian Journal of Forest Engineering, 37(2), 287–296.
51. Zbiec M., Franc-Dabrowska., Drejerska N. 2022. Wood waste management in Europe through the lens of the circular bioeconomy. Energies, 15(12), 4352.