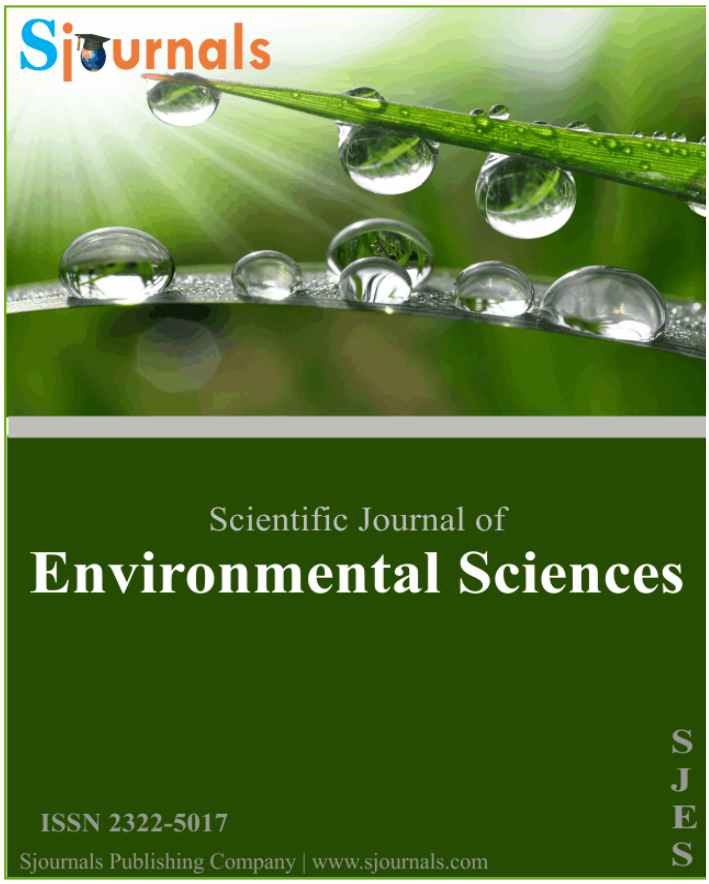
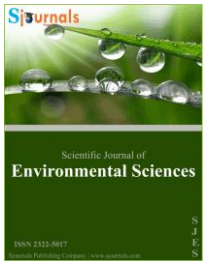


Sjournals
Scientific Journals
Scientific Journal of Environmental Sciences (2021) 10(2) 349-364
ISSN 2322-5017
doi: 10.14196/sjes.v10i2.1650



Contents lists available at Sjournals
Scientific Journal of **Environmental Sciences**
Journal homepage: www.sjournals.com

Original article

Assessment of wood waste management in timber industries in the forest areas of Man and Daloa (Côte d'Ivoire)

Sandotin Lassina Coulibaly[a,b,*], Drissa Sangare[a,b], Franck Michaël Zahui[a,b], Yao Emmanuel Konan[b], Lacina Coulibaly[b]

[a]Department of Agronomic, Forestry and Environmental Engineering, University of Man, (BPV 20 Man, Côte d'Ivoire).

[b]Department of Sciences and Environment Management, Biotechnology and Environmental Engineering Research Unit, University of NANGUI ABROGOUA, (02 BP 801 Abidjan 02, Côte d'Ivoire).

*Corresponding author: sandotin.coulibaly@univ-man.edu.ci

ARTICLE INFO

Article history,
Received 13 February 2021
Accepted 21 March 2021
Available online 27 March 2021
iThenticate screening 16 February 2021
English editing 19 March 2021
Quality control 26 March 2021

Keywords,
Timber industry
Wood waste
Wood generation
Sustainable management

ABSTRACT

The rapid growth in urbanization and population increasing the demand for manufactured wood products, thus putting pressure on the forest cover of the countries. Strategies adopted for the re-composition of the destroyed forest cover should take into account the activities of the timber industries, from the stage of tree felling to the management of the resulting wood waste. This paper assesses wood waste generation and its management practices in timber industries established in the west of the Cote d'Ivoire. The study was conducted through data collected during site visits of potential timber industries located respectively in the cities of Man (*Scierie et Menuiserie du Tonkpi* [SMT] and the *African Wood* company [Afr. Wood]) and Daloa (*Groupe Ivoirien des Bois Tropicaux* [GIBT] and *Etablissements Coulibaly* [Ets. Coul]). A total of sixty (60) wood species were pulled and processed in the industries of witch 44 species were recorded at GIBT, 37 at SMT, 33 at Ets Coul, 12 at African Wood Company. However, six species [*i.e.* Ako, Dabema, Fraké, Framiré, Lati, and Samba] were both registered in the four structures. Volumes of logs processed in the industries were 7026.5 m^3 (GIBT), 4686.8 m^3 (SMT), 3192.9 m^3 (Ets Coul) and 1816.6 m^3 (African Wood). The transformation of said volumes in the industries

generated waste volumes of 867.4 m^3 at Afri. Wood, 4186.6 m^3 at GIBT, 2768.9 m^3 at SMT and 1227.2 m^3 at Ets Coul, corresponding to 47.7%, 59.6%, 59.1% and 38.4% of the respective gross wood volume of each industry. Waste generated consisted of small sizes waste such as sawdust and, coarse elements (*i.e.* wood core and strip, slat ends, wood debris, barks, washers, etc.) The waste management methods practiced in the industries were summed up in collection, storage, sorting, and transport to the final place of use. Recovery actions were incineration through the boiler, carbonization with furnaces for the production of charcoal (energy recovery), burning, building fences, using as firewood for drying fish and preparing food, cuttings for the transformation of furniture, rafters, etc. Apart from these circuits, the waste is left abandoned in the industries.

1. Introduction

Waste from the transformation of raw materials used to manufacture products poses both an environmental and an economic challenge for producers in most countries of the world (Abdel-Shafy and Mansour, 2018). In timber industries, depending on the processing method, the companies in the sector produce different types of waste (*i.e.* sawdust, washers, strips, shavings, offcuts, bark, logs, etc.) (Sales, 2003). However, the characteristics of this waste depend on the grain size, density, humidity, type of raw material used (mainly solid wood or panel) as well as the type of adjuvant used (FAO, 1993). Wood waste, such as shavings or sawdust from machining, bark torn from trees, ash and debris from logs can cause problems in the environment through the release of particles into the atmosphere and contamination of soils and waterways where they are stored (James et al., 2012; Tamanna et al., 2020). This is because barks, log debris, and other wood waste can accumulate at the bottom of storage ponds and thus kill benthic organisms. Sawdust and dust produced by other processes present a risk of fire and explosion in factories. Added to these risks is that of the release of dioxins and furans in the kilns of sawmills where chlorophenols are used (Levin et al., 1976). Therefore, knowledge of the characteristics of the various by-products appears essential in order to assign each waste the appropriate recovery routes, whether internal or external to the company. The valorization of wood by-products, therefore, remains essential insofar as it would make it possible not only to minimize the quantity of wood to be transformed or to be used rationally but, above all, to exert less pressure on the forest, a carbon sink par excellence (De Cherisey et al., 2007). There are three (3) types, including material recovery, organic recovery, and energy recovery, which could be followed by wood waste from timber industries (Warken, 2004). Material recovery consists of reuse, recycling, and regeneration of waste, while organic recovery concerns composting and vermicomposting (generation of fertilizers) of waste. As for energy recovery from waste, it contributes to the production of biogas and digestate (anaerobic digestion), coal (carbonization), heat (pyrolysis) (Parmar and Ross, 2019; Sayara et al., 2020). Thus, wood by-products have the potential for bioenergy production that can reduce the high pressure on hydropower systems and produce energy for households. Wood waste can also be used to make plywood and other types of wood for household furniture and other furnishing work which will reduce the annual amount of wood to be harvested (FAO, 1990; Aina, 2006).

In Côte d'Ivoire, after independence in 1960, timber activities intensified with the creation of a Ministry in charge of Water and Forests (1961), the establishment of a legal framework by passing laws (1965) and the ratification of treaties and conventions relating to the environment (Ministère des Eaux et Forêts, 2019). Wood was a driving force in the early economic activities undertaken in the country. In 1965, through its exports, it occupied second place, with eighteen (18) billion CFA francs (Mohamed, 2016). However, the demographic boom supported by immigration, extensive agriculture, rampant and anarchic urbanization, bush fires, contract sawing or illegal logging, illegal gold panning and the military-political crisis ten (10) years have led to the excessive shrinkage of forest capital (Arnaud and Sournia, 1979; Luc et al., 2015). In addition, the timber industry, the first unit of which was created in 1918 in the city of Grand Bassam continues to grow by diversifying to this day, its units (*i.e.* sawing, peeling, and slicing), much more (46.5%) in the western zone of the country (Luc et al., 2015; Salah, 2020).

If in 1972, only about thirty species were exploited, to date, exploitation involves more than fifty species. Thus, forest capital has fallen from 15 million to around 3 million hectares in less than 30 years, in connection with excessive exploitation, exceeding the rate of natural regeneration and the capacity for reforestation (Ministère des Eaux et Forêts, 2019). During the United Nations climate change assemblies in New York in 2014, the State of Côte d'Ivoire committed to a transition to zero-deforestation agriculture from 2017. The effort should also focus on restoring the country's forest cover. Thus, strategies relating to the preservation, rehabilitation, and extension of forests have been developed so as to contribute to the improvement of the country's forest cover from 11% in 2015 to a rate of at least 20% in 2045, in the interest of the populations (Ministère des Eaux et Forêts, 2019). This involves, among other things, protecting and restoring the forests of the protected forest domain (rural domain), protecting and restoring the forests of the classified domain by finding consensual solutions to the question of the agricultural occupation of classified forests, meeting ecological requirements of the country and the needs of the populations in terms of timber, fuelwood. However, the strategies adopted for the re-composition of the destroyed forest cover should take into account the activities of the timber industries, from the stage of tree felling to the management of the resulting wood waste. Indeed, the efficient management of waste from the activities of the timber industries would not only reduce the pressure exerted on forests, but also, protect the environment and the health of populations. However, the work carried out to date (De la Mensbruge, 1971; Tano, 2012) only deals with the boom in the timber industries in Côte d'Ivoire. No study has devoted its essence to the management of waste from timber industries as in the forest countries of the sub-region such as Ghana (Danquah et al., 2013; Asamoah et al., 2020), Nigeria (Owoyemi et al., 2013; Sambe et al., 2021), etc.

The study aims to assess the typology of wood waste and their management practices in potential timber industries located in western Côte d'Ivoire, in cities of Man and Daloa. Specifically, characterize the species used (*e.g.* species, quantity, and volume of wood) as well as the wood products in the timber industries. Then, determine the typology and quantity of wood waste produced in industries. And finally, examine the methods of wood waste management and recovery channels in said structures.

2. Overview and location of study sites

This study was carried out in four (4) industrial wood units, in particular, *Groupe Ivoirien des Bois Tropicaux* (GIBT) and *Etablissements Coulibaly* (Ets. Coul), located in Daloa (Center West, Ivory Coast) and, the *Scierie et Menuiserie du Tonkpi* (SMT) and the *African Wood* company (Afr. Wood), located in Man (West, Ivory Coast) (Figure 1). The choice of these industries in said localities is justified by their large expanses and frequentation.

2.1. Wood industries in the locality of Man

The city of Man is located between 7 ° 24'45 "North latitude and 7 ° 33'13" West longitude, in the mountainous west and is the capital of the Tonkpi region (Figure 1). The relief of the town is very rugged over most of its area, but generally made up of mountains whose altitudes exceed 1000 meters. However, there are some forest massifs between the plantations containing the exploited species such as Iroko (*Chlorophora exelsa*), Samba (*Triplocyton schleroxylon*), Koto (*Pterygota macrocarpa k Schum*), Kondroti (*Bombax brevicuspe, Sprague*), Ilomba (*Pycnanthus angolense Warb*), Dabema (*Piptadenistrum africanum*), Kotibé (*Nesogordonia papaverifera*) (Dieter, 1997). Locality of Man house twelve (12) industrial units, of which only four (04) are in operation (*i.e.* Scierie et Moulure de Côte d'Ivoire, Compagnie de Transformation de Bois de l'Ouest, Scierie et Menuiserie du Tonkpi and the African Wood Company) (Kouassi, 2015). Regarding the industries considered in the study, the African Wood company, created in 1995, is a structure that is part of the large FADOUL group. It has two units, a Sawmill focused on sawing and a Peeling plant for the production of plywood. African Wood employs a composite staff of one hundred and eleven (111) including thirty (30) permanent and eighty-one (81) casual. As for the Scierie et Menuiserie du Tonkpi (SMT), it was created in November 2013 and specialized in sawing wood. Apart from the Sawmill, it has carpentry for making furniture (tables-benches). The SMT has a staff of twenty (20) permanent employees and about fifty (50) casual (Kouassi, 2015).

2.2. Wood industries in the locality of Daloa

The city of Daloa is located in the West Center of the Ivory Coast between 6 ° 53 ' North latitude and 6 ° 27' West longitude and is the capital of the Haut Sassandra region (Figure 1). The relief of the municipality consists

mainly of the low plateau with an average altitude between 200 meters and 300 meters **(**Tiécoura, 2015). The vegetation consists mainly of tropical plant formations sheltering a wide variety of noble species suitable for timber such as Iroko (*Chlorophora excelsa Benth.*), Fraké (*Terminalia superba Engl. Et diels.*), Samba (*Triplochiton scleroxylon K. Schum*), and fromager (*Ceiba pentendra Gaertn.*) (Dieter, 1997). Daloa houses five (05) industrial units which are : Société de Transformation des Bois de l'Ouest, Société Mohamed Coulibaly, Groupe Ivoirien des Bois Tropicaux and Etablissements COULIBALY. The company Etablissements COULIBALY has been approved as an industrial timber company since 1996. It is located in the southern part of the city of Daloa. It specializes in sawing and carpentry and employs one hundred and fifty (150) people, including seventy (70) permanent and around eighty (80) daily. Regarding the Groupe Ivoirien des Bois Tropicaux (GIBT), it has existed since 1999, in the industrial zone of the city of Daloa on the Daloa-Zaibo road axis. This company is specialized in sawing and employs one hundred and twenty (120) people, including fifty (50) permanent and seventy (70) occasional (Tiécoura, 2015).

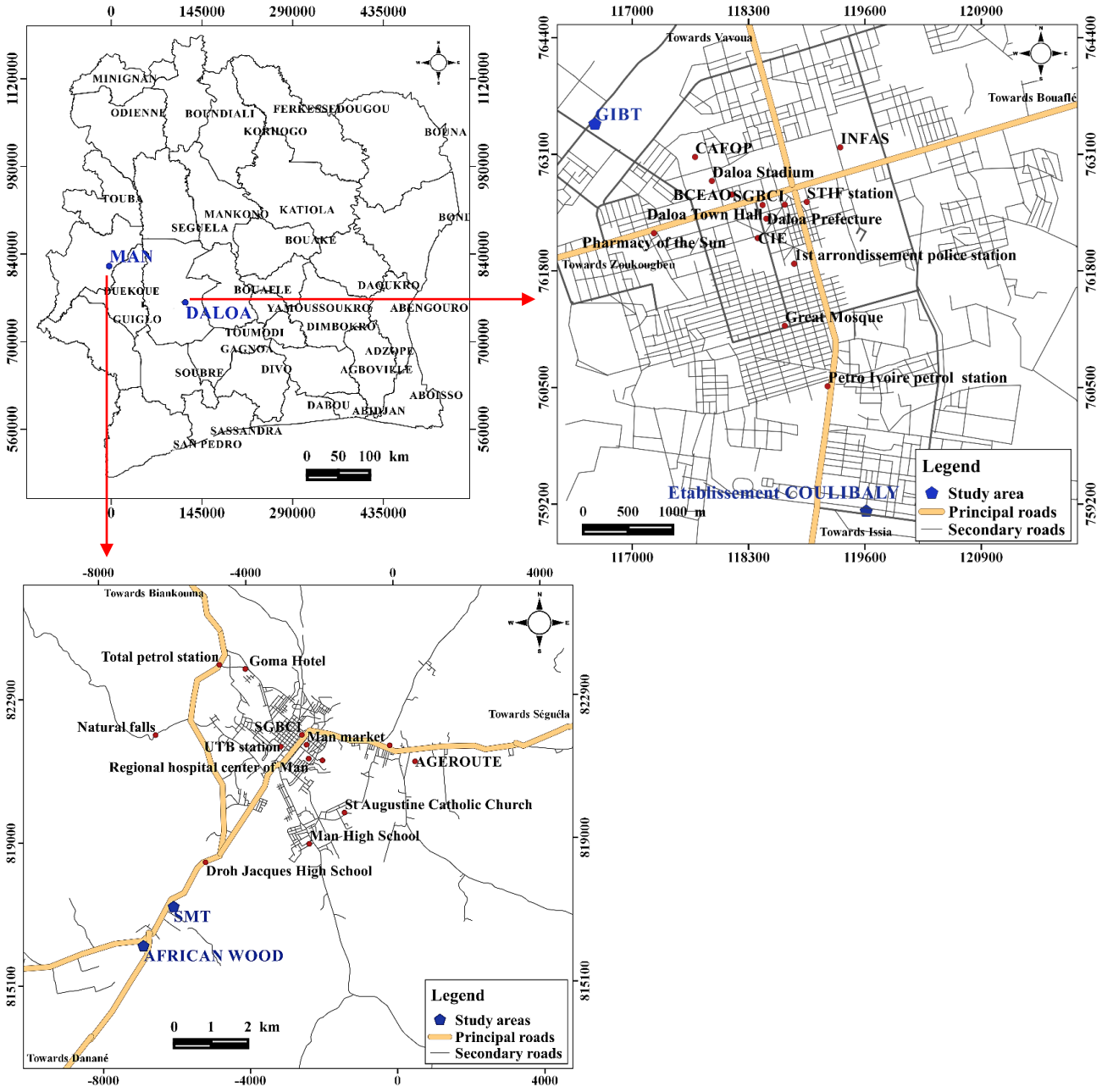


Fig. 1. Location of study area.

3. Materials and methods

Data collection for this study carried out in four (4) industrial wood units in the cities of Daloa and Man. Survey sheet were addressed to the staff of the different units. Global Positioning System (GPS) was used to obtain the position of the various sites and a digital camera to take pictures of the environment of the sites of the industrial wood units.

3.1. Data Collection

Data collection was performed from February to August 2019. It consisted of two joint activities, namely, field observation and conduct of the survey itself, with company managers, site directors, and employees.

3.1.1. Field observation

This technique provided a comprehensive overview of wood processing industries in the cities of Daloa and Man. It consisted in visiting the sites considered, in order to identify the cuts produced in the timber industries, the typology of waste generated, and assess their management method as well as the recovery channels used. During the site visit, pictures were taken to illustrate the observations made.

3.1.2. Survey

The actual survey consisted of filling in the forms prepared for this purpose, by interviewing the first site managers, the administrative staff and the various heads of activities. This made it possible to consult traceability documents such as approved waybills and log entry diaries to get out the gross monthly volumes and the number of logs entering the factory. In addition, the consultation of the production sheets and the monthly declaration sheets made it possible to have the volumes of the cuts produced in each timber industry and the volumes of waste produced by the site.

3.2. Calcul and statistics

The calculation of log volumes was obtained after measurements per meter of timber cubing on the site or in the lumber yard, with a scaling scale (Cirad-Forêt, 1995). Obtaining the wood waste volumes is only possible through the volumes of wood products in the industries. Thus, volumes of wood waste produced by site were obtained making the difference between the volumes of logs (gross volume) and that of wood products (finished products) according to relation (1):

$$V_W = V_L - V_P \quad (1)$$

Where:
V_W = volume of wood waste;
V_L = gross volume or volume of logs;
V_P = volume of wood products.

In addition, the waste characterization process in this study consisted of a sampling of a wood waste stream which is a motley material composed of fine elements like sawdust and coarse elements of medium and large sizes like debris, chips, logs, strips, twigs, bark, offcuts, and wood cores. The operating mode at the site level consisted of sampling by bulldozer buckets to fill the dump trucks with a capacity of four (4) cubic meters. The monthly volumes of wood logs, wood products, and wood wastes in the different timber industries followed a normal distribution, thus, the ANOVA test was used for their comparison. The difference was considered statistically significant when $p < 0.05$.

4. Results

4.1. Wood used in the timber industries

Wood is received in industries in the form of logs (Figure 2). During the study period, 4,507 wood logs were recorded in the four timber industries visited, including 80 at African Wood (Afr. Wood), 1,611 at Groupe Ivoirien

des Bois Tropicaux (GIBT), 1,256 at Scierie et Menuiserie du Tonkpi (SMT) and 1,560 at Etablissements COULIBALY (Ets. Coul) (Figure 3).

Fig. 2. Wood log illustration images received in industries at GIBT (A) [Daloa] and at SMT (B) [Man]

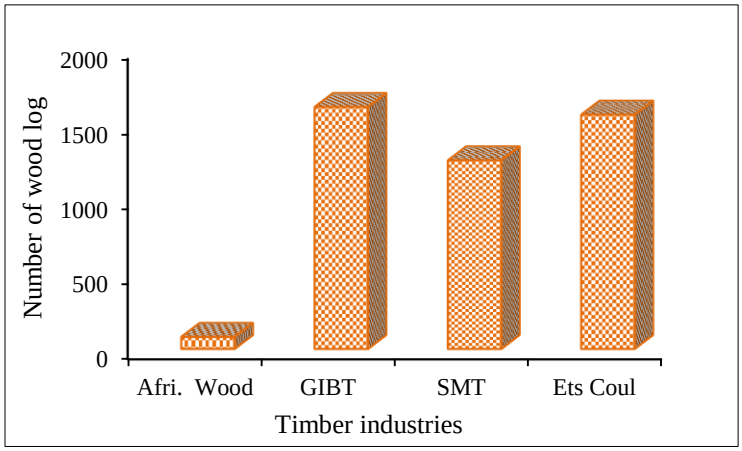


Fig. 3. Wood logs quantities recorded in timber industries.

4.1.1. Wood species used

The logs pulled and processed by the industries are divided into sixty (60) species including six (06) [*i.e.* Ako, Dabema, Fraké, Framiré, Lati and Samba] were both registered in the four (04) structures (Table 1). We noted more species in GIBT (44) followed respectively by those of SMT (37), Ets. COUL (33) and Afr. Wood (12).

Table 1
Species machined in the four timber industries, (***** = presence of the species considered).

Wood species		**Timber industries**			
Vernacular names	**Scientific names**	**Afri. Wood**	**GIBT**	**SMT**	**Ets. COUL**
Abalé	*Petersianthus macrocarpus*	*	*	*	
Aboudikro	*Entandrophragma cylindricum*			*	
Acajou	*Khaya ivorensis*			*	*
Aiélé	*Canarium schweinfurthii Engl.*	*		*	*
Akatiou	*Chrysophyllum africanum*		*		*
Ako	*Antiaris toxicaria*	*	*	*	*
Akossika	*Scottellia klaineana*		*		
Akoui	*Triplochiton scleroxylon*		*		*
Amazakoué	*Guibourtia ehie*		*	*	*
Aniégré	*Chrysophyllum giganteum*		*		
Assan	*Celtis zenkeri*		*	*	*
Avodiré	*Turraeavkthus africanus*			*	

Azobe	*Lophira alata*			*	
Badi	*Nauclea diderrichii.*			*	*
Bahé	Fagava macrophylla		*		*
Bahia	*Mitragyna ciliata*		*		
Bété	*Mansonia altissima*		*		
Boborou	*Irvingia gabonensis*		*		
Bodo	*Detarium senegalense*		*		*
Bossé	*Guarea cedrata*		*	*	
Codabema	*Piptadenia africana*		*	*	*
Dabema	*Piptadeniastrum africanum*	*	*	*	*
Difou	*Morus mesozygia*		*		*
Emien	*Alstonia congerzsis*		*	*	
Etimoé	*Copaifera salikounda*				
Eyong	*Eribroma oblonga*		*	*	*
Faro	*Daniellia thurifera*	*	*		
Fraké	Terminalia superba	*	*	*	*
Framiré	Terminalia ivorensis	*	*	*	*
Fromager	*Bombax ceiba*	*	*		
Iatandza	Albizia ferruginea		*	*	*
Ilomba	*Pycnanthus angolensis*	*	*		
Iroko	*Milicia excelsa*		*	*	*
Kapokier	*Ceiba pentandra*	*	*		
Kekelé	*Holoptelea grandis*		*	*	*
Kondroti	*Bombax brevicuspe*			*	
Kosipo	*Entandro+hragma candollei.*				*
Kotibé	*Nesogordonia eapaverifera*		*	*	*
Koto	Pterygota macrocarpa		*	*	*
Kroma	*Klainedoxa gabonensis*			*	
Lati	*Amphimas Pterocarpoides*	*	*	*	*
Lingué	*Afzelia africana*		*		*
Loloti	*Lannea welwitschii*		*	*	
Lohonfé	*Celtis adolfi frederici*		*		*
Lotofa	Sterculia *rhinopetala*		*		
Makoré	*Tieghemella heckelii*				*
Movingui	*Distemonanthus benthamianus*			*	*
Néré	*Parkia biglobosa*			*	
Pépé	*Ficus bongouanouensis*		*	*	*
Pocouli	*Berlinia occidentalis*		*	*	*
Pouo	*Funtumia elastica*		*		
Jumbo	*Pin Sylvestre*			*	
Rikio	*Uapaca guineensis*			*	
Samba	*Triplochiton scleroxylon*	*	*	*	*
Sipo	*Entandrophragma utile*		*	*	*
Sougué	*Parinari excelsa*			*	
Taly	*Erythrophleum ivorense*		*		
Tam-tam	*Cordia senegalensis*		*		
Tiama	*Entandrophragma angolense*		*	*	*
Zaizou	*Gymnostemon zaizou*		*	*	*
Total	60	12	44	37	33
Wood species encountered both in the four industries			6		

Considering the most machined wood species in the four industries, there were nine (09), including Ako, Dabema, Emien, Fraké, Framiré, Fromager, Lati, Pépé, and Samba (Table 1). However, the most used species in Afri. Wood were Fromager and Samba, with 50 and 10 logs respectively recorded. Regarding GIBT, they were six (6) species (*i.e.* Ako [194], Emien [227], Fromager [132], Lati [75], Pépé [61] and Samba [193]) which were most used. Regarding the industry SMT, there were five (5) species including Ako (93), Dabema (85), Fraké (137), Framiré (9) and Samba (573). As for Ets Coul, three (3) species including Ako, Fraké, and Samba have been frequently recorded there, with 83, 1102 and 133 logs respectively. However, Samba remains the wood species used by all industries and the most in SMT.

Table 2
Wood species most used in the timber industries.

Timber industries	Wood species								
	Ako	**Dabema**	**Emien**	**Fraké**	**Framiré**	**Fromager**	**Lati**	**Pépé**	**Samba**
Afr. Wood						55			10
GIBT	194		227			132	75	61	193
SMT	93	85		137	90				573
Ets. Coul	83			1102					133

4.1.2. Volumes of wood used

The quantification of logs (April-August) in timber industries allowed to record monthly volumes ranging from 247.8 to 472.6 m^3 in Afr. Wood, 1269.5 to 1613.9 m^3 at GIBT, 309.7 to 2074.9 m^3 at SMT and from 342.4 to 984.7 m^3 at Ets. Coul, with respective mean values of 363.3 m^3, 1405.3 m^3, 937.4 m^3, and 638.6 m^3. These volumes varied significantly from each other (ANOVA, $p < 0.05$) (Figure 4A). Thus, the GIBT industry exploited the highest volume of logs while the lowest volume was recorded at Afr. Wood. Considering the total volume of logs processed in industries during the period, 7026.5 m^3 were recorded at GIBT, 4686.8 m^3 at SMT, 3192.9 m^3 at Ets. Coul and 1816.6 m^3 at Afr. Wood (Figure 4B).

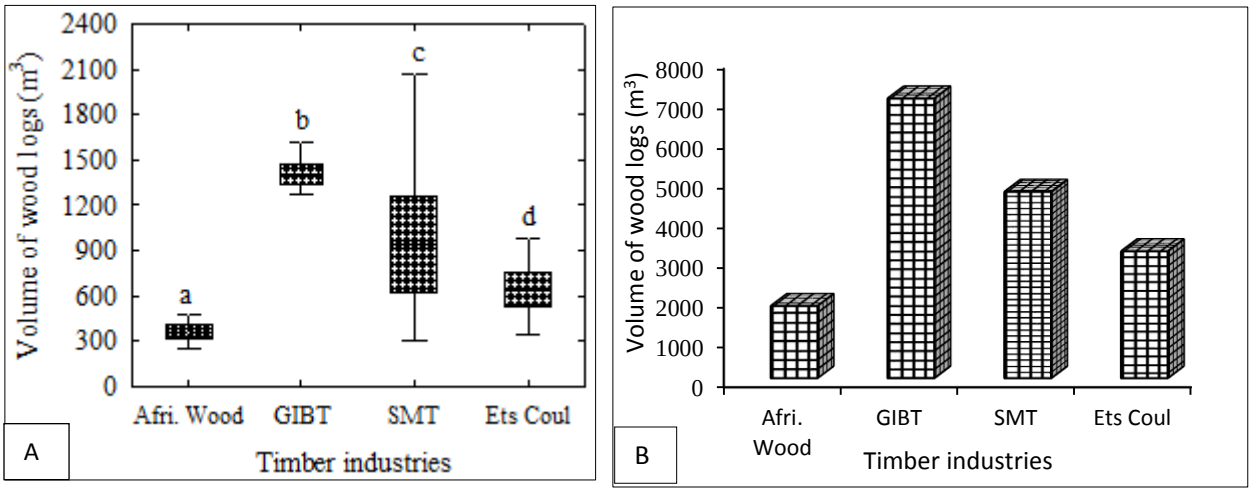


Fig. 4. Volume of wood logs in timber industries, A = monthly processed wood logs volume variations, B = total processed logs volumes, Box-plots no bearing one alphabetical letter-identical are significantly different (ANOVA test; $p < 0.05$).

4.2. Wood products in the industries (Entity + volume)

At the end of wood processing in industries, the products obtained consist of flitch plates, planks, studs, boards, rafters, plywood, slats, battens and pallets (Figure 5). Analysis of timber industries, monthly productions showed that volume remained largely high in GIBT, compared to those of other industries (Figure 6A) [ANOVA, $p < 0.05$]. The average monthly productions recorded were 568 m^3 at GIBT, 393.1 m^3 at Ets. Coul, 383.6 m^3 at SMT

and 189.9 m^3 at Afri. Wood. Total productions amounted to 2839.9 m^3 at GIBT, 195.7 m^3 at Ets. Coul, 1918 m^3 at SMT and, at 949.3 m^3 at Afri. Wood (Figure 6B).

Fig. 5. Illustrations of the products obtained in timber industries, A = boards at Ets Coulibaly, B = rafters at Afr. Wood, C = plywood in Afr. Wood, D = slats at GIBT, E = pallets at SMT, F = battens at GIBT.

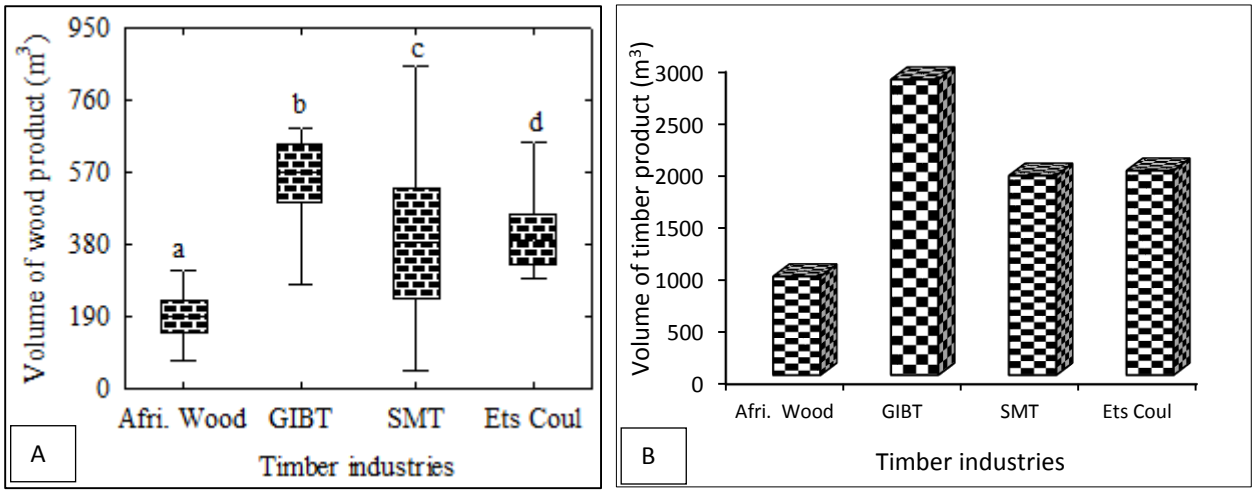


Fig. 6. Volume of wood Products in timber industries, A = monthly wood products volume variations, B = total wood products volumes, Box-plots no bearing one alphabetical letter-identical are significantly different (ANOVA test; $p < 0.05$).

4.3. Wood waste generated in the timber industries

4.3.1. Typology of wood waste generated

Most of the wood waste comes from peeling in the industry at African Wood. These are logs, sawdust, bark, washers, overcuts, wood cores, and veneer and plywood debris (Figure 7). Regarding the other timber industries, wood waste comes mainly from sawing. These include waste such as logs, washers, sawdust, slabs to be recovered, shavings, offcuts, bark, debris (Figure 8).

Fig. 7. Illustrations of peeling wood waste, A = unwinding slats, B = wood core and strip, C = bark.

Fig. 8. Illustrations of sawmill waste, A = sawdust at GIBT, B = slat ends at SMT, C = wood debris at Ets Coul.

4.3.2. Volume of wood waste generated

The quantities of waste obtained from the gross volumes of wood entered in the industries and the different productions are denoted in figure 9. As seeing, the highest volume in the industries is recorded at GIBT, on the other hand, that of Ets Coul appear lowest. In the industry Afri. Wood, 1816.6 m^3 of gross volumes from which 949.3 m^3 of wood products were deducted, correspond to 867.4 m^3 of waste, or 47.7% of the gross volume. Regarding the GIBT industry, the volume of waste was 4186.6 m^3 corresponding to 59.6% of the gross volume of wood entered into the industry. This quantity results from the difference between the estimated productions of 7026.5 m^3 from which 2839.9 m^3 of wood products were extracted. As for the SMT industry, 2768.9 m^3 of waste was obtained for 4686.8 m^3 of raw wood entered in the industry, which represents 59.1% of the latter. Regarding the Ets Coul industry, the final volume of wood products was 1965.7 m^3, for a volume of raw wood of 3192.9 m^3, hence the volume of waste of 1227.2 m^3, or 38.4% gross volume. Thus, in view of the volume of wood entering the different industries, there is less waste produced in Afri. Wood (47.7%) and Ets Coul (38.4%) compared to their wood products, unlike the GIBT (59.6%) and SMT (59.1%) industries. The figure 9 show the monthly volumes of waste produced in the industries. One could observed that the latter varied from 119.9 to 213.5 m^3 in Afri. Wood, from 80.9 to 1227.2 m^3 at GIBT, from 256.4 to 1227 m^3 for the SMT industry and from 50.5 to 420.3 m^3 at Ets Coul, with respective averages of 173.5 m^3, 837.3 m^3, 553.8 m^3 and 245.4 m^3. These volumes differ significantly from one industry to another in the different sites visited (ANOVA, $p < 0.05$).

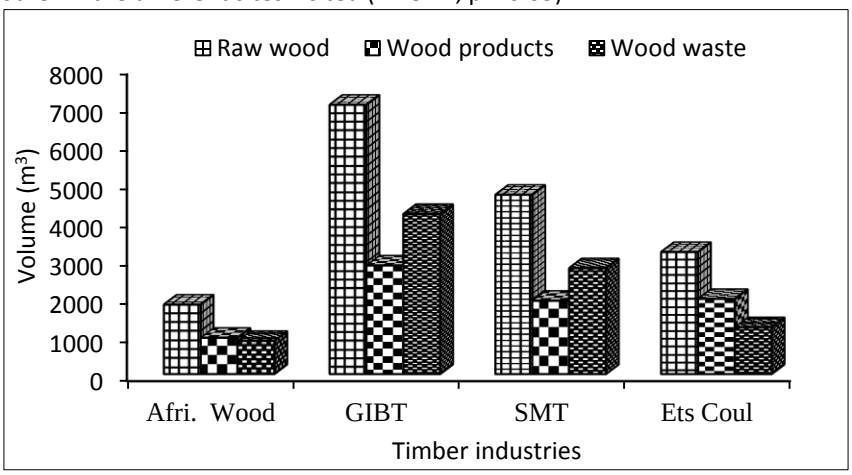


Fig. 9. Volume of raw wood, wood products and wood waste generated in the timber industries.

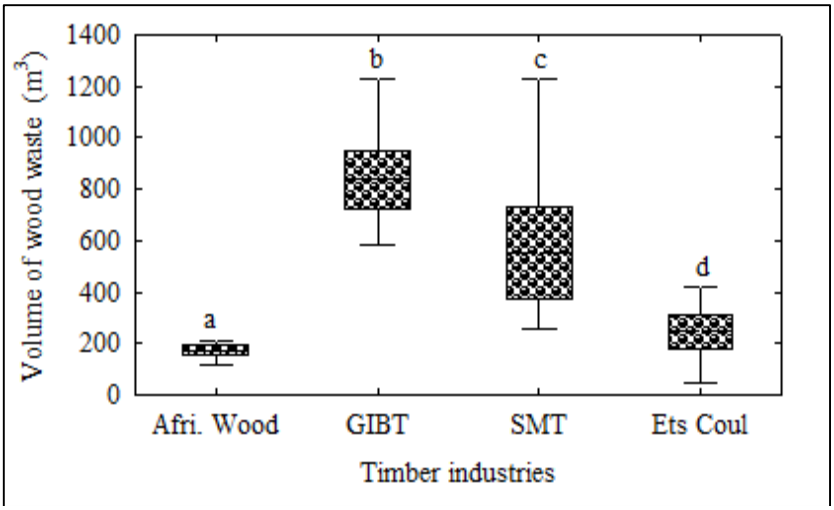


Fig. 10. Monthly volumes of waste production in the industries, Box-plots no bearing one alphabetical letter-identical are significantly different (ANOVA test; $p < 0.05$).

4.4. Wood waste management and recovery channels

4.4.1. African wood (Afri. Wood)

In industry, African Wood, waste management method comes down to collection, storage, sorting and transport (Figure 11). However, Afri. Wood company has a boiler whose waste feed promotes the drying of the veneers. This process is part of the energy recovery of the waste produced. In addition to this process, the company burns builds fences, or simply leaves them in the wild (Figure 12).

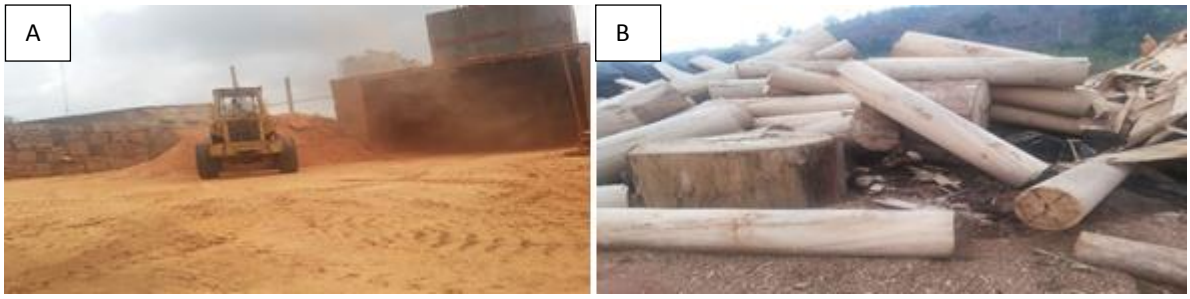


Fig. 11. Illustrations of the actions carried out in African Wood company's, A = transport of sawdust to the bull, B = storage of logs and wood cores.

Fig. 12. Illustrations of recovery channels African Wood company's, A = boiler, B = waste burning, C = fences made with wood waste.

4.4.2. Groupe Ivoirien des Bois Tropicaux (GIBT)

Just like in African Wood Company's, the operations carried out at the Groupe Ivoirien des Bois Tropicaux (GIBT) are collection, storage, sorting and transport. However, the waste is transferred either to Etablisements

COULIBALY (Ets Coul), or to a recovery site near GIBT. Specifically, the sawdust is placed in crates and transported out of the place of production (Figure 13). Regarding the recovery channels, GIBT has signed a waste recovery contract with Ets Coul with the maintenance of the site as a bonus. Part of the waste is transferred to the site of this contracting company for further processing and the other part to a site adjacent to the GIBT industry for the production of coal (energy recovery) (Figure 31). Apart from these two circuits, the waste is left abandoned.

Fig. 13. Illustrations of the actions carried out in Groupe Ivoirien des Bois Tropicaux (GIBT), A = put into storage, B = transport of waste, C = crating.

Fig. 14. Illustrations of the recovery channels in Groupe Ivoirien des Bois Tropicaux (GIBT), A = setting up a furnace, B = furnace in operation.

Fig. 15. Illustrations of the actions carried out in Scierie et Menuiserie du Tonkpi (SMT), A = waste removal, B = storage of slabs, C = setting up a furnace, D = furnace in operation.

4.4.3. Scierie et Menuiserie du Tonkpi (SMT)

On this site, the Scierie et Menuiserie du Tonkpi (SMT) also collects, sorts, and stores its wood waste. The transfer out of the place of production depends on the type of waste. Only those with don't go into salvage fall

into the sale, are sent to the city of Man. As for the rest, it is transported to a site adjacent to the industry, for coal (Figure 15AB). The disposal of wood waste from SMT is carried out through a private individual who has a site within the structure for making charcoal (Figure 15C, D). The unit has carpentry which collects a good part of the cuttings for the transformation of furniture.

4.4.4. Etablissements COULIBALY (Ets Coul)

In Ets Coul company, the actions carried out are collection, storage, sorting, and transport to the final place of use (Figure 16AB). The industry is cleaning up its site by collecting waste, and through installations (*i.e.* carpentry), it recycles waste (Figure 16CD). The company donates and sells waste to individuals who in turn use it for drying fish and preparing cassava meal.

Fig. 16. Illustrations of the actions carried out in Etablissements COULIBALY (Ets Coul), A = sorting and storage at the trimmer, B = transport of sawdust, A and B = products resulting from gluing in the carpentry.

5. Discussion

It emerges from this study that sixty (60) species of wood were processed in the four (04) timber industries visited in the towns of Man and Daloa. These wood species remain regulatory with regard to the regulations in force in Côte d'Ivoire. However, Ivorian regulations prescribe 100 species of wood that can be exploited by the wood industries, in the country (Durand, 1977). This inferiority of the wood species exploited by the timber industries visited, compared to the Ivorian prescription would be explained by the scarcity of the precious raw material [*e.g*. Aningueri (*Chrysophyllum Perpulchrum*), Bon (*Cordia platythyrsa*), Dibetou (*Lovoa trichilioides*), Movingui (*Distemonanthus benthamianus*), Mutibganayé (*Guarea thomsonii*), Naiangon (*Tarrietia utilis*), etc.] (Louppe et al., 2018). The wood species listed in the study areas were mostly identified by Martin and Vernay (2016) during the study focused on the use of eco-certified African woods in Europe. In addition, nine (09) species (*i.e.* Ako, Dabema, Emien, Fraké, Framiré, Fromager, Lati, Pépé and Samba) were the most used in the timber industries visited. This strong demand for the same species could be due to their remarkable ability for peeling and sawing. The use of these same species is mainly based on the production of veneers for the plywood industry. According to Martin and Vernay (2016), the predominant use of certain woods is due to the exceptionally varied properties they possess, which naturally meet all the use criteria recommended for works carried out. Moreover, it is thanks to their remarkable properties that these wood species have conquered the European markets. The amount of wood used in the industries varied from site to site, with 80 at Afri. Wood, 1611 at Groupe Ivoirien des Bois Tropical (GIBT), 1256 at SMT and 1560 at Ets. Coul, with respective volumes of 1816.6 m^3, 7026.5 m^3, 4686.8 m^3 and 3192.9 m^3. These volumes of wood used to indicate an exhaustion of the current raw material (Arnaud and Sournia, 1979). Regarding typology of waste generated in the various companies, it consisted of small sizes waste such as sawdust, coarse elements such as wood core and strip, slat ends, wood debris, barks, washers etc. These

types of waste were also recorded by ORDIMIP (2015) and Hermeline and Lavarde (2020) during the evaluation of the recovery channels of wood waste. However, differences recorded in wood waste generation in the timber industries would be explained by the fact that most of the wood waste comes from peeling in the Afri. Wood industry, while in the other industries, wood waste comes mainly from sawing. The quantification of the waste produced on the research sites gives volumes of 867.4 m^3, 4186.6 m^3, 2768.9 m^3, and 1227.2 m^3, respectively at Afri. Wood, GIBT, SMT, and Ets Coul. However, less waste was produced in Afri. Wood (47.7%) and Ets Coul (38.4%) in relation to their wood products, unlike the GIBT (59.6%) and SMT (59.1%) industries. These figures recorded by site would depend on the interest and financial resources of the structure. The wood waste management methods practiced on the sites were generally summed up in collection, storage, sorting, and transport. As for the recovery actions identified, these were incineration through the boiler, carbonization with furnaces for the production of charcoal (energy recovery), butting and jointing for slats, rafters, etc. Indeed, Afri. Wood company has a boiler whose waste feed promotes the drying of the veneers. In addition to this process, the company burns, builds fences, or simply leaves it in the wild. As for, GIBT wastes were transferred to the site of a contracting company for further processing and the other part to a site adjacent to the company, for the production of charcoal. Apart from these circuits, the waste is left abandoned. Wood waste from SMT is carried out through a private individual who has a site within the structure for making charcoal. The unit has carpentry which collects a good part of the cuttings for the transformation of furniture. Ets Coul Company donates and sells waste to individuals who in turn use it for drying fish and preparing cassava meals. These types of valuation practiced on the sites have been highlighted in several studies, in particular those of Bouchard (2004), Nazaret (2013) and that of ORDIMIP (2015). However, the wood cores from wood processing in Afri. Wood company could be sawn and used as formwork in road construction and buildings. Likewise, sawdust could be used in making briquettes, in market gardening, or in stable breeding (Laurent, 1977). Finally, the boiler should be put into operation to meet export standards and that there be an addition of a head saw, to optimize the processing of wood waste. These practices could be considered as those of the French company Veolia, in the recovery of wood waste, which was able to treat 500,000 tons of wood waste in 2014. Also, the ADEME structure showed interest in waste treatment because 79% of wood waste was recovered, with 57% for material and organic recoveries and 22% for energy recovery (Guinard et al., 2015; De Cherisey et al., 2007).

6. Conclusion

Sixty (60) wood species were pulled and processed in the industries of which 44 species were recorded at GIBT, 37 at SMT, 33 at Ets Coul, 12 at Afri. Wood company. However, six (06) species [*i.e.* Ako, Dabema, Fraké, Framiré, Lati and Samba] were both registered in the four (04) structures. The total volumes of logs processed in the industries were 7026.5 m^3 (GIBT), 4686.8 m^3 (SMT), 3192.9 m^3 (Ets Coul) and 1816.6 m^3 (Afri. Wood). The transformation of said volumes of wood in the industries generated waste volumes of 867.4 m^3 at Afri. Wood, 4186.6 m^3 at GIBT, 2768.9 m^3 at SMT and 1227.2 m^3 at Ets Coul, corresponding to 47.7%, 59.6%, 59.1%, and 38.4% of the respective gross wood volume of each industry. However, at the end of wood processing in industries, the products obtained consist of flitch plates, planks, studs, boards, rafters, plywood, slats, battens, and pallets. Wood waste generated in the industries consisted of small sizes waste such as sawdust, coarse elements such as wood core and strip, slat ends, wood debris, barks, washers. However, most of the wood waste from the Afri. Wood industry is sawdust, bark, washers, overcuts, wood cores, and veneer and plywood debris. On the other hand, those of the other wood industries, consist of wastes such as logs, washers, sawdust, slabs to be recovered, shavings, offcuts, bark, and debris. The waste management methods practiced in the industries were summed up in collection, storage, sorting, and transport to the final place of use. Recovery actions were incineration through the boiler, carbonization with furnaces for the production of charcoal (energy recovery), burning, building fences, using as firewood for drying fish and preparing food, cuttings for the transformation of furniture, rafters, etc. Apart from these circuits, the waste is left abandoned in the industries.

References

Abdel-Shafy, H.I., Mansour, S.M., 2018. Solid waste issue: Sources, composition, disposal, recycling, and valorization. Egypt. J. Pet., 27, 1275-1290.

Aina, O.M., 2006. Wood waste utilization for energy generation. In Proceedings of the International Conference on Renewable Energy for Developing, Ann Arbor, MI, USA.

Arnaud, J.C., Sournia, G., 1979. Les forêts de Côte-d'Ivoire: une richesse naturelle en voie de disparition. Cah. Outre-Mer., 127, 281-301.

Asamoah, O., Kuittinen, S., Danquah, J.A., Quartey, E.T., Bamwesigye, T., Boateng, C.M., Pappinen, A., 2020. Assessing wood waste by timber industry as a contributing factor to deforestation in Ghana. Forest, 11, 939. https://doi:10.3390/f11090939

Bouchard, M., 2004. Gestion et valorisation des déchets et produits connexes de la filière bois. CRIQ-Centre de recherche industrielle du Québec.

Cirad-Forêt, 1995. Barème de cubage. Bois et forêts des tropiques. Département forestier. 2è édition BP 5015 34032 Montpellier, CEDEX, France.

Danquah, J.A., Sarpong, D.B., Pappinen, A., 2013. Causal relationships between African mahoganies exports and deforestation in Ghana: Policy implications. Environ. Dev. Sustain., 15, 51-66.

De Cherisey, H., Roy, C., Pouet, J.C., 2007. La valorisation de la biomasse. Guide d'information à l'attention des administrations et des établissements publics ADEME, France.

De la Mensbruge, G., 1971. Les industries du bois en Côte d'Ivoire: Les sciages. Bois et Forêts des Trop., 135, 21-37.

Dieter, S., 1997. Préface d'AKE A.L. In: Bois de Côte d'Ivoire. Précis de reconnaissance des arbres commercialisés. CEDA, Côte d'Ivoire, Abidjan.

Durand, P.Y., 1977. Liste des essences forestières de Côte d'Ivoire devant faire l'objet d'essais technologiques d'investigation ou de complément. Nogent-sur-Marne: GERDAT-CTFT, 11p.

FAO, 1993. Les panneaux à base de bois, Etude FAO forêts 116 Rome.

FAO, 1990. The potential use of wood residues for energy generation. In Energy Conservation in the Mechanical Forest Industries; FAO, Rome.

Guinard, L., Deroubaix, G., Roux, M.L., Levet, A.L., Quint, V., 2015. Évaluation du gisement de déchets bois et son positionnement dans la filière bois/bois énergie, ADEME, France.

Hermeline, M., Lavarde, F., 2020. La valorisation des gros bois. Rapport n° 18130, Conseil Générale de l'Alimentation de l'Agriculture et des Espaces Ruraux, Paris, 98p.

James, A.K., Thring, R.W., Helle, S., Ghuman, H.S., 2012. Ash management review applications of biomass bottom ash. Energ., 5, 3856-3873, https://doi.org/10.3390/en5103856.

Kouassi, A., 2015. Monographie de Man. Rapport d'activités. CEF. Direction régionale des Eaux et Forêts de Man. Côte d'Ivoire.

Laurent, D., 1977. Revalorisation des déchets d'exploitations forestières et des industries du bois en Côte d'Ivoire. Nogent-sur-Marne: GERDAT-CTFT, 147p.

Levin, J.O., Rappe, C., Nilsson, C.A., 1976. Use of chlorophenols as fungicides in sawmills. Scand. J. Work Environ. Health, 2, 71-81. https://doi:10.5271/sjweh.2816

Louppe, D., Herault, B., Zobi, I.C., Kouadio, K.B., 2018. Révision des normes d'aménagement des forêts classées de Côte d'Ivoire-Rapport d'expertise scientifique. Montpellier: CIRAD-INPHB, 37p. https://agritrop.cirad.fr/588695/

Luc, D.M., Pulchérie, E.G., Tomini, B.B., 2015. Gestion durable des ressources forestières. Ernest & Advisory / BNETD, Côte d'Ivoire.

Martin, P., Vernay, M., 2016. User guide for eco-certified African timbers in Europe. Tome 1, ATIBT, Paris.

Ministère des Eaux et Forêts, 2019. Politique Nationale de Préservation, de Réhabilitation et d'Extension des Forêts et Stratégies. Côte d'Ivoire.

Mohamed, B.B., 2016. L'industrie du bois en Côte d'Ivoire: quelle capacité de résilience, in les Actes du forum des Etats généraux de la Forêt, de la Faune et des Ressources en Eaux. MINEF, ETINCEL, 157p.

Nazaret, P., 2013. Bannissement du bois de l'élimination: le cas du secteur CRD, des ici et des zones urbaines et municipales de l'Estrie. M. Env. - IMEDD, Université de Sherbrooke, Québec, Canada, 136p.

ORDIMIP, 2015. Evaluation des gisements de «déchets bois» en Midi-Pyrénées. Positionnement dans la filière bois énergie. ADEME, France.

Owoyemi, J.M., Zakariya, H.O., Elegbede, I.O., 2016. Sustainable wood waste management in Nigeria. Environ. Socio-Econ. Stud., 4, 1-9.

Parmar, K.R., Ross, A.B., 2019. Integration of hydrothermal carbonisation with anaerobic digestion; opportunities for valorisation of digestate. Energ., 12, 1586. https://doi.org/10.3390/en12091586

Salah, B.B., 2020. Etat des lieux des acteurs de la filière foret-bois en Côte d'Ivoire, rapport d'étude de l'activité de la composante 2 des projets FLEGT-REDD et FLEGT-IP, Côte d'Ivoire.

Sales, C., 2003. Innovation technologique et valorisation des sous-produits des filières bois. Bois. Forêt. Des. Trop., 2, 36-43.

Sambe, L.N., Origbo, B., Gbande, S., Ande, P.U., 2021. Assessment of wood waste generation and utilization in makurdi metropolis: implication for sustainable management of forest resources. J. Res. For. Wildl. Environ., 13, 188-196.

Sayara, T., Basheer-Salimia, R., Hawamde, F., Sánchez, A., 2020. Recycling of organic wastes through composting: Process Performance and Compost Application in Agriculture. Agron., 2020, 10, 1838.

Tamanna, K., Raman, S.N., Jamil, M., Hamid, R., 2020. Utilization of wood waste ash in construction technology: A review. Constr. Build. Mater., 237, 1-10.

Tano, K.P., 2012. Naissance et essor de l'industrie du bois dans l'entre-deux-guerres mondiales. Rev. Hist. Archéol. Afr., 22, 106-116.

Tiécoura, C., 2015. Monographie de Daloa. Rapport d'activités. CEF. Direction régionale des Eaux et Forêts de Daloa, Côte d'Ivoire, 25p.

Warken, M., 2004. Optimal recovery of resources: A case study of wood waste in the Greater Sydney region. Master of Engineering Research Thesis, Chemical Engineering, Universityof Sydney.

How to cite this article: Coulibaly, S.L., Sangare, D., Zahui, F.M., Konan, Y.E., Coulibaly, L., 2021. Assessment of wood waste management in timber industries in the forest areas of Man and Daloa (Côte d'Ivoire). Scientific Journal of Environmental Sciences, 10(2), 349-364.