Energy Analysis of Timber Log Processing in Nigerian Sawmill

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Logging encompasses all activities involved in the processing of fully developed tree for production of finished and intermediate planks of varying sizes. Energy is a major input for logging. In this study, energy audit and analysis was used to determine the specific energy and cost of production. Primary data for the study included site visits and use of questionnaire to collect data on the wood species, energy use pattern and types of equipment used for logging. Measuring instruments such as wattmeter, stop watch and measuring tape were used to measure the current, voltage and power factor; time of operation and size of timber log used in sawmilling in the selected study area. The study covered 24 sawmills spread across 5 states in the south-western part of Nigeria. The study showed that there are seven wood species in the study area. The specific energy (kWh/m^3) and average processing costs per unit volume (\$/m^3) of the seven species measured in the study area are respectively as follows - *Afara (Terminalia superba)*: 1.65 and 0.094; *Iroko (Milicia excelsa)*: 4.48 and 0.260; Mahogany *(Khaya ivorensis)*: 1.47 and 0.084; *Opepe (Naulea diderrichii)*: 1.77 and 0.100; *Omo (Cordia millenii)*: 0.75 and 0.043; *Obeche (Triplochyton scleroxylon)*: 0.58 and 0.033; *Igba (Parkia biglobosa)*: 1.01 and 0.058. The study showed that the *Iroko* was the most common wood species processed in the study area and has the highest specific energy for processing. The *Iroko* was also the most expensive wood specie for log processing in the study area.

Keywords: *Log processing, Energy audit, Energy analysis, Specific energy, Specific cost.*

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1. Introduction

Logging is the act of processing matured trees into marketable sizes and making them available for sale; all in a sawmill. It encompasses all activities involved in the processing of fully developed tree for production of finished and intermediate planks of varying sizes using different kinds of equipment for onward transmission to factories or other places for further processing [1]. It involves tree felling, trimming of the branches, cutting into standard length (logs) and transportation for sale or further processing.

Unlike in the past when logging is done in a prepared pit, equipment such as power-driven chain and more sophisticated machines are now available for both the primary, intermediate and final processing as the case may be. The authors in [2] and [3] described logging as the comprehensive activities performed on matured trees to produce wood of standard and marketable sizes for different end users. The use of major machineries in log processing makes energy a major ingredient in the log processing industry. Energy in the industry is used for a wide range of activities such as sawing, lighting, saw sharpening and other maintenance activities.

This study examines, using the technique of energy auditing, the total amount of energy, the pattern of energy use, quantity of energy used per unit of log processed and the cost of energy used per unit of log processed in selected saw mill across the south western part of Nigeria.

The study is divided into five sections. Section 2 is the history and operation of the log processing industry in Nigeria. Section 3 reviews the energy auditing method used for the study. Section 4 presents and discusses the result of the study, while Section 5 concludes.

2. History and operations of the log processing (sawmill) industry in Nigeria

Log processing or sawmill industry is one of the major wood product industry in Nigeria. The predominant machines used in this industry are the CD series machines. Currently, sawmill industry accounts for 93.2% of the total number of wood-based industries in Nigeria [4].

Log processing in Nigeria started since 1782 with earlier pit-sawing technique [5]. The recent power sawing method was introduced in Nigeria in 1902 and it began in the Niger Delta area of the country [6]. The industry has grown rapidly over the years according to the report of [7] shown in Table 1.

Table 1. Installed Capacity and Utilization in the Nigerian Sawmill Industry [7]

Year	No. of Sawmills	Total Installed Capacity (M^3/year)	Utilization Capacity (M^3/year)	Capacity Utilization (%)
1988	N/A	8,831,750	6,994,660	79
1992	910	15,793,188	6,031,922	38
1996	1252	10,900,000	4,200,000	39
2002	1259	14,684,000	5,177,700	35
2010	1325	11,734,000	3,800,000	32

The importance of log processing cannot be overemphasized because it has contributed to providing revenue to government through fees and royalties paid by the stake holders in the business; various categories of employment is also generated and the development of the rural communities is also enhanced while locating the sawmills close to the source of raw material [7], [3] and [8].

Energy is a major input to sawmilling not only to power the machines and equipment used in sawmilling, but also to provide lighting, saw sharpening, maintenance services and transportation of the logs from one place to another. Energy analysis is a veritable tool to help reduce operational costs, enhance product management and reduce waste in all aspects of the process. section presents an overview of the geographical location of Kaveh, clustering and principle analysis component. Finally, comparative strainer clustering is introduced and the procedures of this algorithm are described.

3. Materials and Methods

3.1. Study Area

A total of 24 sawmill spread across five states across south – west zone of Nigeria was selected for the study. Five sawmills were selected in the three senatorial districts of Osun, and Ondo states, while eight sawmills and four sawmills were selected in Ogun and Oyo States respectively. Two sawmills were selected in Lagos State. The selection of sawmills in the study area was based on the various wood species that have been processed.

3.2. Data Collection

In the selected sawmills for study, the production process was monitored to measure the time it takes to complete one production circle of converting the wood from the forest into logs for secondary use

Primary data collection of electricity consumption was from two main sources. These are electricity from the national grid and electricity from self – generation. Electricity data for public supply involved in the power rating of the electrical devices and capacity of each power equipment, as well as daily availability of public electricity was recorded, in addition for self-generation the type and amount (in liters) of fossil fuels used such as gasoline, diesel and natural gas were monitored and recorded. Manual energy usage for log processing was also monitored.

3.3. Methodology

The methodology for data collection of the energy usage for the production of one cycle of log was done using energy auditing. The energy auditing was done in two phases. The first phase was the Pre-Audit Phase. This phase involved an initial study of the site and equipment used in log processing and was done over a period of two weeks. This phase provided the opportunity to meet the personnel concerned, get familiarize with them and to assess the procedures necessary in carrying out the energy audit. During the initial site visit, the following actions were carried out:

a. Discussions with the sites management on the aims of the energy analysis.

b. Analysis of the major energy consumption data.

c. Identification of the power rating of various logs' processing equipment.

d. Identification of the main energy consuming facility(ies)

e. Identification of any existing instrumentation or additional metering required

This phase of the energy audit also provided an opportunity to know, based on observed conditions, where it was necessary to install metering devices prior to the analysis; identify the instrumentation required for the audit; plan the time frame for the study and collect micro data on energy resources and major energy consuming point.

The second phase of the energy audit which lasted between 4 to 6 weeks depending on the nature and complexity of each site involved detailed studies of the energy and material balances for specific plants and items of process equipment used in each sawmill. This analysis included a description of energy inputs and product outputs by major processing functions and the efficiency of each step of the product chain.

The apparatus used at the selected sawmill included Digital Power Clamp Meter to measure electrical energy usage, stop watch to measure production time and measuring tape to measure the size of log processed.

The log length was measure directly using measuring tape; the volume of the log was calculated using Newton formula [9], shown in (1); a motor efficiency of 80% was assumed to compute the electrical inputs [10] as shown in (2); manual energy was obtained using the work of [11] shown is (3), according to his work, at the maximum continuous energy consumption rate of 0.30 kW and conversion efficiency of 25%, the physical power output of a normal human labourer in tropical climates is approximately 0.075 kW sustained for an 8–10 h workday. The number of people working in each sawmill per operation was counted and recorded.

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$$V = \frac{\pi\left[db^2 + 4dm^2 + ds^2\right]l}{24} \quad (1)$$

Where, V is volume of log (m³), db is diameter at the large end of log, dm is diameter at midpoint of log, ds is diameter at small end of log, l is Log length (m), and π is equal to 3.142 or 22/7.

$$E_P = \eta P t \quad (2)$$

where, E_P is the electrical energy consumed in kWh, P is the rated power of the motor in kW, t is the hours of operation in hours and η is efficiency of the motor or power factor usually taken as 80% or 0.8.

$$E_m = 0.075 N t \quad (3)$$

where E_m is the manual energy in kWh, 0.075 is the average power of a normal human labour in kW, N is the number of persons involved in an operation and t is the useful time spent to accomplish a given task in hours.

4. Results and Discussion

4.1. Location Characteristics of the Study Area

Table 2 shows the name and locations of sawmills selected for the study. The sawmills in the selected area were small holder operators with private ownership. The location characteristics also showed that most operational sawmills in the south western part of Nigeria are located around the predominant rain forest zone.

Table 2. Name and Location of Selected Sawmills for the Study

S/N	Name of Sawmill	Location	State
1.	Bisi Abass	Ife	Osun
2.	Adegoke	Ikirun	Osun
3.	Olorunda	Osogbo	Osun
4.	Alhaji Kabiru	Ede	Osun
5.	Ojebola	Ejigbo	Osun
6.	St. Luke	Okeigbo	Ondo
7.	Sesan	Okitipupa	Ondo
8.	Alawiye	Akure	Ondo
9.	Oluwabamise	Ikare	Ondo
10.	Olukayode	Akungba	Ondo
11.	Ranmilowo Oluwa	Osiele	Ogun
12.	Olorunwa	Lafenwa	Ogun
13.	Alhaji Isiaka Olaoluwa	Aiyetoro	Ogun
14.	Ogo Oluwa	Ipokia	Ogun
15.	Iyanu Oluwa	Ijebu – igbo	Ogun
16.	Oremeji	Ogere – remo	Ogun
17.	Gawan	Abeokuta	Ogun
18.	Pakoto	Ifo	Ogun
19.	EDMED	Atiba	Oyo
20.	Iyanu Oluwa	Sabo	Oyo
21.	Ai – wajud	Ido	Oyo
22.	Owonikoko	Igbo – ora	Oyo
23.	Okegbegun	Ikorodu	Lagos
24.	Oke – Baba	Ebute – Meta	Lagos

4.2. Wood and Energy Parameters in the Study area

Table 3 shows the wood species, average log length, volume of log, operating time, electrical power and electrical energy consumption, and manual energy used in the selected sawmills. From Table 3 it can be seen that there are seven main types of wood species that are processed into logs for secondary uses in the study area. These are *Afara* (Terminolia Superba); *Opepe* (Naulea diderrichii); *Iroko* (milias excels); *Omo* (cordia millenii); *obeche* (Tripochyton scleroxylon); *mahogany* (Khaya Ivorensis) and *Igba* (Parkia biglobose). Table 4 which is derived from work of [12] shows the density of wood species. The Table shows that hardness of wood affects the amount of power consumed in their processing. This accounts for the varying energy results obtained from each of the seven species irrespective of their location. Table 4 also shows that based on density, wood can be classified as high, medium and low-density wood. *Opepe* is high density wood, while *Iroko*, *Afara* and *Mahogany* are medium density wood and *Omo* and *Obeche* are low density wood. High and medium density woods are also called hard wood and low-density wood are called soft wood.

Table 3. Wood Species and Energy Parameters of Selected Sawmills

S/N	Wood Species	Average log length (m)	Volume of log (m^3)	Operating time (hr)	Electrical Power (kW)	Electrical Energy (kWh)	Manual Energy (kWh)
1a	*Afara* (Terminalia superba)	3.32	2.58	0.24	17.65	4.24	0.07
b.	*Afara* (Terminalia superba)	3.41	3.81	0.28	19.15	5.36	0.08
c.	*Afara* (Terminalia superba)	3.06	2.15	0.29	16.96	4.92	0.09
2.	*Opepe* (Naulea diderrichii)	3.11	2.14	0.36	6.28	2.26	0.11
3.	*Iroko* (Milicia excelsa)	2.99	2.99	0.38	47.15	17.92	0.11
4.	*Omo* (Cordia millenii)	3.61	2.22	0.22	7.61	1.67	0.07
5.	*Obeche* (Tripochyton scleroxylon)	3.83	2.18	0.22	5.78	1.27	0.07
6a.	*Mahogany* (khaya Ivorensis)	3.49	2.48	0.29	12.09	3.51	0.09

b.	*Mahogany* (khaya Ivorensis)	3.51	2.58	0.31	13.1	4.06	0.09
7.	*Iroko* (Milicia excelsa)	2.72	4.54	0.36	52.36	18.85	0.11

Table 4. Density of Wood Species [12]

S/N	Wood Species	Density (kg/m^3)
1.	Terminalia superba (*Afara*)	555.08
2.	Naulea diderrichii (*opepe*)	739.45
3.	Milicia excelsa (*Iroko*)	653.66
4.	Cordia millenii (*Omo*)	436.51
5.	Triplochiton Scleroxylon (*Obeche*)	407.50
6.	Khaya ivorensis (*mahogany*)	468

4.3 Energy consumption pattern

Nigeria generates its electricity majorly from hydropower plants and gas-powered plants. These plants are run by the Federal government and private investors, making it a source of revenue for the investors. The electricity consumed is being paid for by end users that consume this energy and the cost of usage is determined from a fixed tariff rate of usage. Electric meters are installed in almost every home and companies to monitor the kWh usage and at the end of the month payment is being made for the kWh used.

4.4 Energy and Cost Analysis

Table 5 shows the energy analysis of power consumed in log processing and the energy use per volume, while Table 6 shows the cost of energy per volume for the seven species of wood in the study area. For the purpose of the cost analysis, the electricity tariff, (at the time of this study) used for sawmills in Oyo, Osun and Ogun states was \$0.059/kWh and that of Ondo state was \$0.054/kWh.

From Table 5, the *Iroko* wood, a hard wood, of wood density of 653.66 kg/m^3 is the most predominant wood specie that is processed for log in the study area and has the highest average energy per unit volume of 4.48 kWh/m^3, while the *Omo* and *Obeche* wood are the least wood processed with the smallest average energy per unit of 0.75 kWh/m^3 and 0.58 kWh/m^3 respectively. The only noticeable contrast is that *Opepe* wood, which is a hard wood like *Iroko* and high density of 739.45 kg/m^3 had an average energy per unit of 1.77 kWh/m^3. The other hard wood, *Afara* with wood density of 653.66 kg/m^3 had an average energy per unit of 1.65 kWh/m^3.

The reason *Opepe* wood, though higher density than *Iroko* and *Afara*, consumes less energy *Iroko* may be due to the micro structural arrangement and the characteristics of the wood's fibrous cell [13].

Table 5. Energy Analysis of logging in study area

Wood Species	No. of Sawmill	Power Consumed (kW)	Equivalent Energy (kWh)	Log Volume (m^3)	Energy/Unit Volume (kWh/m^3)
Afara (Terminalia superba)	1	17.65	4.24	2.58	1.64
	3	19.15	5.36	3.81	1.40
	4	16.96	4.92	2.15	2.28
	19	13.10	4.06	3.16	1.28
	Average energy per unit volume				**1.65**
Iroko (Milicia excelsa)	5	47.00	17.92	2.99	5.99
	10	52.36	18.85	4.54	4.15
	15	47.15	17.92	4.58	3.91
	20	52.36	18.85	4.86	3.88
	Average energy per unit volume				**4.48**
Mahogany (Khaya ivorensis)	8	12.09	3.51	2.48	1.41
	9	13.10	4.06	2.58	1.53
	Average energy per unit volume				**1.47**
Opepe (Naulea diderrichii)	2	6.28	2.26	2.14	1.05
	16	13.88	4.44	3.79	1.17
	18	12.09	3.51	2.66	1.31
	Average energy per unit volume				**1.77**
Omo (Cordia millenii)	6	7.61	1.67	2.22	**0.75**
Obeche (Triplochyton scleroxylon)	7	5.78	1.27	2.18	**0.58**
Igba (Parkia biglobosa)	11	17.65	4.24	4.44	0.96
	13	14.64	4.10	4.22	0.97
	14	16.96	4.92	4.81	1.02
	17	24.36	5.36	4.97	1.07
	Average energy per unit volume				**1.01**

From Table 6, it can be seen that *Iroko* wood specie is the most expensive to process, while the *Obeche* and *Omo* woods are the least to process, while most of the other wood species fall within the medium rate of \$0.055/m^3 and \$0.10/m^3.

Table 6. Cost Analysis of processing wood species

Wood Species	Energy/unit Volume (kWh/m^3)	Cost of Processing per unit volume (\$/m^3) for *Oyo*, *Osun* and *Ogun* states	Cost of Processing per unit volume (\$/m^3) For *Ondo* state	Average cost of processing per unit volume (\$/m^3)
Afara (Terminalia superba)	1.65	0.098	0.090	0.094
Iroko (Milicia excelsa)	4.48	0.270	0.240	0.260
Mahogany (Khaya ivorensis)	1.47	0.087	0.080	0.084
Opepe (Naulea diderrichii)	1.77	0.110	0.097	0.100
Omo (Cordia millenii)	0.75	0.045	0.041	0.043
Obeche (Triplochyton scleroxylon)	0.58	0.034	0.032	0.033
Igba (Parkia biglobosa)	1.01	0.060	0.055	0.058

5. Conclusions

The result of the study showed that there are seven major wood species in the study area with the *Iroko* wood been the most predominant. The study also showed that electricity supply from distribution companies in the study area is the major source of electrical energy used by the sawmills in the area of study. The energy analysis of the seven wood species in the study area, the *Iroko* wood specie had the highest energy per unit volume of wood processed and was also the most expensive wood to process. The contributions to knowledge of the work are: (1) it established specific energy for timber log processing and (2) energy conservation was instituted for saw milling industry. The specific energy and cost generated in this work should be used to check an arbitrary charge that are being charged on customer in the sawmill industry to serve as a good customers' protection. A benchmark should be established for processing of various species of wood. This will create a good manager – customer relations in the industry and will enable a good consumer protection policy in the industry.

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