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Energy and Cost Analysis of Cement Production Using the Wet and Dry Processes in Nigeria

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ABSTRACT

The study evaluates the energy consumption of both wet and dry processes cement manufacturing plant in Nigeria. Energy consumption data collected for the period 2003 to 2011 were used to estimate the energy consumption of the crushing, milling, agitation, burning, grinding and bagging operations. The total energy evaluation was based on the three primary energy sources which include electrical, combustion and human. The total estimated energy intensities were 6545 MJ/ton and 4197 MJ/ton for wet and dry processes respectively. The percentage consumption of energy in each operation is 93.68 and 90.34% (burning), 2.11and 4.33% (milling), 0.43 and 0.67% (crushing), 1.39 and 0% (agitation), 2.12 and 3.90% (grinding), and 0.27 and 0.75% (bagging) of the total energy inputs for the wet and dry processes respectively. Furthermore, the average total energy cost of production showed that wet process is approximately 40% more cost intensive in cement production than the dry process while at the same time it is cost effective to run production on energy through gas powered plant than the national grid.

Keywords: Wet Process; Dry Process; Cement; Crushing; Milling; Nigeria

1. Introduction

Cement and/or clinker (cement primary input) is a commodity being produced in over 150 countries of the world [1]. It is an essential input into the production of concrete needed for building purposes and other construction related activities. According to Madlool *et al*. [2], world demand for cement was predicted to increase from 2283 million tonnes in 2005 to about 2836 million tonnes in the year 2010 [2]. The growth witnessed in recent days is largely driven by rising production in emerging economies and developing countries, especially in Asia. In 2006, almost 70% of the world production was in Asia (47.4% in China, 6.2% in India, 2.7% in Japan and 13.2% in other Asian countries) and about 13.4% in Europe [3].

In Nigeria, cement production grew rapidly from 2 million tonnes in 2002 to 17 million in 2011 [4]. This has led to the Nigeria cement industry accounting for 63.6% of the West African region's cement output in 2011. Daily production is in excess of sales having recorded a zero importation from January 2012 to date and in the process of formalizing the exportation of cement to Eco-

nomic Community of West African States (ECOWAS) and other neighboring countries. With the new Ibeshe cement factory by Dangote Group (commissioned in February, 2012), the country's production capacity is expected to hit 39.4 million metric tonnes per annum thereby recognizing Nigeria as a cement producing country.

The cement sub-sector is one of the most energy consuming industries and it consumes approximately 12% - 15% of total industrial energy use [2,5]; since the industry sector plays a significant role in global energy consumption, its demand can be said to be majorly determined by population and socio-economic activities of a country. Large volumes of CO_2 are however being emitted during cement production and it is believed that this sector represents 5% - 7% of the total CO_2 anthropogenic emissions [6,7]. Since the associated energy used in the item production is extensively based on fossil fuels, environmental issues are further heightened and are of great importance. Therefore, a detailed review on the energy use and savings is necessary to identify energy wastage so that necessary measures could be implemented to reduce energy consumption in this sub-sector [2].

The escalating production of cement in the Nigeria

thus calls for a proportionate rise in energy need and cost, and environmental issues relating with the CO_2 emission. According to Fadare *et al.* [8], energy cost constitutes a major component of the overall production cost in manufacturing industries; it accounts for about 60.75% of the direct manufacturing cost of cement [9], hence energy utilization efficiency is a major determinant of the profitability of manufacturing system.

In Nigeria, approximately 40 to 50 per cent of cement manufacturing cost is energy related; each tonne of cement requires 60 - 130 kg of fuel oil or its equivalent and about 105 kWh of electricity, depending on the cement variety and process type employed [10]. Cement production spreads across five geo-political zones due to the vast deposit of raw materials (**Table 1**). Kilns are majorly being fired by the use of heavy fuel oil (LPFO), coal and natural gas. However, the dearth of natural gas supply in the northern part of the country has restricted its use in kiln firing to plants located in the southern region.

In Adeloye [11], the unit cost of fuel component for cement production is as low as $6 per tonne in China as opposed to $30 per tonne in Nigeria; this has contributed largely to the high and persistent rise in unit cost of cement production. There is thus the need for the adoption of energy efficiency in cement production in Nigeria. Recently, there has been an increasing interest in using energy analysis techniques for energy-utilization assessments in order to attain energy saving, and hence financial savings [5]. In this study, in-depth energy evaluation is carried out on a large scale cement production firm, whose mode of operation is based on both the wet and dry processes by evaluating specific energy consumption including electric, combustion, human as well as total energy of its various units of operation with a view to optimizing the plants' energy consumption. Various energy savings measures peculiar to the industry were also presented.

2. Methodology

The plant adopted for the study has a wet production capacity of 1 million tonnes per year and a dry process output of 1.2 million tonnes per year. Six operation units are identified for the wet process while five units are identified for the dry process. The operation units considered for the purpose of this work include crushing, milling, agitation, burning, grinding and bagging (**Figures 1** and **2**). For each of these operation units, energy input was accounted for by noting and quantifying the type of energy that was used. The primary energy sources being utilized in the plant are electrical, combustion and manual energy; combustion energy is consumed only during the burning operation in cement processing. An inventory of the electrical motors with their respective

Table 1. Locations, capacities and status of cement companies in Nigeria.

| Company name	Location (state)	Region
Sokoto cement	Sokoto	North-West
Ashaka cement	Gombe	North-East
Bauchi-Gwana cement	Bauchi	North East
Benue cement company	Benue	North-Central
Obajana cement plc	Kogi	North-Central
Unicem cement	Cross River	South-South
Wapco cement plc	Ogun	South West
Purechem cement	Ogun	South West
Wapco cement plc	Ogun	South West
Dangote cement plc	Ogun	South West
Ibeshe cement company	Ogun	South West
Ava cement	Edo	South-South
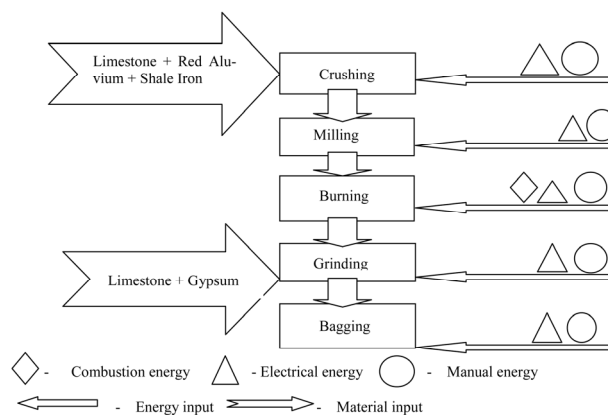
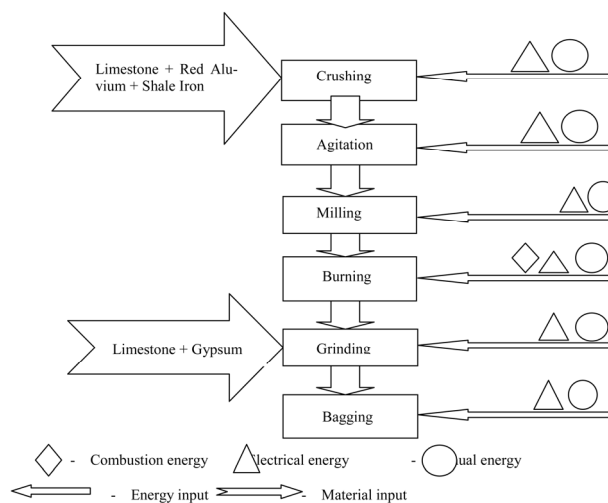**Figure 1. Material and energy flow diagram for dry process manufacturing of cement.**

Figure 2. Material and energy flow diagram for wet process manufacturing of cement.

power ratings, power ratings of the other machines and heaters, personnel involved, time required for production and material flow in each of the units operation along-

side with the units capacities were all collated from the respective departments in the production plant. The production processes were monitored and data for an eight year period ranging from 2003 to 2010 were collected.

2.1. Estimation of Energy Input

Energy inputs which comprise electrical, combustion and manual energy for each unit of operations were cal- culated yearly for the eight year period. According to Fadare *et al.* [8], the electrical energy usage by the equipment in kWh, was obtained as the product of the rated power of each motor and the number of hours of operation expressed in Equation (1); a motor efficiency of 80% was assumed to compute the electrical inputs mathematically as:

$$E_p = nPt \qquad (1)$$

where E_p is the electrical energy input, n is the electric motor efficiency, t is time taken in hours and P is power rating of each electric motor.

In Odigboh [12], at 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 climate is approximately 0.075 kW and sustained for an 8 - 10 hours workday. Hence, employing the current minimum wage paid by the federal government (**Table 2**), the cost of manual energy per unit operation was calculated in Equation (2) as the product of the manual energy consumption and the unit cost of manual energy [12].

$$E_m = 27Nt \qquad (2)$$

where E_m is the manual energy in MJ, 27 is the average 9.46%, 11.73 and 14.8% of the total energy required by the wet and dry production processes respectively (**Table 5**).

The lowest energy intensities came from manual energy which occupied about 0.42 to 0.83% and 0.45 to 2.21% for the wet and dry processes respectively with the study period.

As shown in **Table 6**, among all the operations undertaken in the wet process of cement manufacturing, burning operation has the highest consumption of the total energy required for manufacturing, ranging from 91.60%

Table 2. Manual energy cost per kWh.

Years	Naira (₦)
2003	5500
2004	5500
2005	5500
2006	7500
2007	7500
2008	7500
2009	7500
2010	7500

power of a normal human labour in MJ, N is the number of persons involved in an operation while t in hours, is the useful time spent to accomplish a given task.

Combustion energy was estimated based on the volume of natural gas consumed in the burning operation and converted to appropriate energy units for analysis.

2.2. Estimation of Energy Intensity (EI_i)

The energy consumed per unit product (energy intensity) for each of the unit operation (EI_i) and the average energy intensity (EI_{tt}) for cement production by either the dry or wet process is expressed in (3) and (4) as given in [8]:

$$EI_i = \frac{Et_i(MJ)}{\text{Total weight of product output per kg}} \qquad (3)$$

$$EI_{tt} = \frac{E_{tt}(MJ)}{\text{Total weight of product}(kg)} \qquad (4)$$

where Et_i and E_{tt} are the sums of energy inputs per unit operation and sum of energy inputs for all operations respectively.

3. Results and Discussion

Production of cement by the dry and wet processes follows the energy and mass flow diagrams shown in **Figures 1** and **2** respectively. The electrical, manual and combustion energy consumption together with the material mass flow are allotted to each unit operations with the dry cement operation having five unit operations (crushing, milling, burning, grinding and bagging) and the wet cement process involves six units which includes crushing, agitation, milling, burning, grinding and bagging as indicated in the figures. Comprehensive description of cement manufacturing is given in [2]. The unit operations were carried out in continuous process and the energy inputs into each of the operations were accounted for by noting and quantifying the type of energy that was used. The energy consumption data that were obtained provided useful information on the source of energy requirement for each unit of operation.

Tables 3 and **4** show the computed total amount of energy requirement needed for cement production using the wet and dry processes respectively for year 2003; similar step is employed for the remaining study period (2004-2010) as summarized in **Tables 5** and **6**. The respective average total energy intensities were computed as 6545 MJ/ton and 4197 MJ/ton for the wet and dry processes from 2003 to 2010.It can further be deduced within the study period, that the overall combustion energy intensity ranged from approximately 90 to 92% for the wet process and 84 to 87% for the dry process whereas the proportion of electrical energy is between 7.28 and

Table 3. Time and energy requirement for the wet process year 2003.

			TIME AND ENERGY REQUIREMENT				
			Year 2003				
S/N(i)	Process	Time (h)	Electrical Energy $E_p = nPt\,(MJ)$	Manual Energy $E_m = 27Nt\,(MJ)$	Combustion Energy $E_c\,(MJ)$	Total Energy $Et_i\,(MJ)$	Percentage energy (Eti/Ett) × 100
1	Crushing	6853	17609030	5777404	0	23393288	0.43%
2	Milling	16018	1.09E + 08	6740305	0	1.16E + 08	2.11%
3	Agitation	8640	71457583	4814504	0	76280727	1.39%
4	Burning	13595	82991537	3851603	5.05E + 09	5.13E + 09	93.68%
5	Grinding	12213	1.09E + 08	7703206	0	1.16E + 08	2.12%
6	Bagging	8422.759	9079599	5777404	0	14865426	0.27%
	Total Etti		3.99E + 08	34664426	5.05E + 09		
	Ett(%)		7.28%	0.63%	92.09%		

Table 4. Time and energy requirement for the dry process year 2003.

			TIME AND ENERGY REQUIREMENT				
			Year 2003				
S/N(i)	Process	Time (h)	Electrical Energy $E_p = nPt\,(MJ)$	Manual Energy $E_m = 27Nt\,(MJ)$	Combustion Energy $E_c\,(MJ)$	Total Energy $Et_i\,(MJ)$	Percentage energy (Eti/Ett) × 100
1	Crushing	1124.39	4308677	6126693	0	10435370	0.67%
2	Milling	2731.06	63385954	3676016	0	67061969	4.33%
3	Agitation	0	0	0	0	0	0.00%
4	Burning	3422.88	63681998	4901354	1.33E + 09	1.4E + 09	90.34%
5	Grinding	6195.13	53769764	6739362	0	60509126	3.90%
6	Bagging	3441.739	3710139	7964701	0	11674840	0.75%
	Total Ett		1.89E + 08	29408125	1.33E + 09		
	Ett(%)		14.18%	2.21%	85.92%		

Table 5. Primary energy consumption pattern for wet and dry processes for year 2003-2010.

Energy Input			2003	2004	2005	2006	2007	2008	2009	2010
Wet	Electrical	Total X 108 (MJ)	3.99	3.81	3.81	4.34	4.0	3.67	3.1	3.24
		Percentage (%)	7.28	7.82	8.77	8.37	8.40	8.56	9.46	8.60
	Manual	Total (MJ)	34664426	38460177	35988149	27690052	20216244	27580086	25273040	24487280
		Percentage (%)	0.63	0.79	0.83	0.53	0.42	0.64	0.77	0.65
	Combustion	Total X 109 (MJ)	5.05	4.45	3.93	4.72	4.34	3.89	2.94	3.42
		Percentage (%)	92.09	91.39	90.40	91.09	91.17	90.79	89.76	90.75
Dry	Electrical	Total X 108 (MJ)	1.89	2.72	3.44	4.15	3.6	3.43	3.23	3.85
		Percentage (%)	14.18	11.73	12.55	13.08	14.14	13.83	13.83	12.17
	Manual	Total (MJ)	29408125	28467870	27211923	27370359	20718599	18229617	17008677	14282744
		Percentage (%)	2.21	1.23	0.99	0.86	0.81	0.74	0.73	0.45
	Combustion	Total X 109 (MJ)	1.33	2.02	2.37	2.73	2.16	2.12	2.0	2.76
		Percentage (%)	85.92	87.04	84.46	86.05	85.04	85.44	85.45	87.38

of the total energy in 2009 to 93.68% in 2003. Crushing operation ranged from about 0.19 to 0.48% while milling, agitation, grinding, and bagging operations ranged from 1.94 to 2.34%, 1.39 to 2.30%, 2.12 to 3.25% and 0.27 to 0.45% of the total energy respectively within the period. Similarly with the dry process (**Table 6**), burning consumed 89.02 to 90.34% of the energy representing the highest share, whereas milling and grinding consumed

3.95 to 4.35% and 3.70 to 5.78% respectively whilst 0.54 to 0.70% and 0.42 to 0.75% of the energy used for cement production were used for crushing and bagging respectively.

In addition, the wet cement processing is also found to consume approximately 5995.59 MJ/ton of overall energy intensity and employ about 35% of combustion energy per tonnage of cement more than the dry operation

Table 6. Energy consumption pattern of different operations for the wet and dry processes in the cement plant for the year 2003 to 2010.

	Process	Energy	2003	2004	2005	2006	2007	2008	2009	2010
Wet	Crushing	Total (MJ)	23393288	23255197	24980322	25582237	20039612	3126011	3086831	7341077
		Percentage (%)	0.43	0.48	0.57	0.49	0.42	0.07	0.09	0.19
	Milling	Total (MJ)	1.16×108	1×108	97639578	1.22×108	1.06×108	1.04×108	75114668	73269419
		Percentage (%)	2.11	2.06	2.25	2.36	2.23	2.43	2.30	1.94
	Agitation	Total (MJ)	76280727	76325960	76013045	75665798	75004293	76231060	75409746	75248501
		Percentage (%)	1.39	1.57	1.75	1.46	1.58	1.78	2.30	2.00
	Burning	Total x 109 (MJ)	5.13	4.54	4.01	4.81	4.42	3.97	3.00	3.49
		Percentage (%)	93.68	93.16	92.28	92.88	92.83	92.66	91.60	92.70
	Grinding	Total x 108 (MJ)	1.16	1.17	1.21	1.3	1.26	1.15	1.06	1.05
		Percentage (%)	2.12	2.41	2.79	2.51	2.64	2.69	3.25	2.78
	Bagging	Total (MJ)	14865426	15969908	15886454	15521178	14486826	15586156	14742614	14525860
		Percentage (%)	0.27	0.33	0.37	0.30	0.30	0.36	0.45	0.39
Dry	Crushing	Total (MJ)	10435370	14619994	17498493	22252421	16265416	14476562	12934127	17224976
		Percentage (%)	0.67	0.63	0.64	0.70	0.64	0.58	0.55	0.54
	Milling	Total (MJ)	67061969	94422875	1.16×108	1.38×108	1.08×108	1.07×108	94189047	1.25×108
		Percentage (%)	4.33	4.07	4.24	4.35	4.24	4.33	4.03	3.95
	Agitation	Total (MJ)	0	0	0	0	0	0	0	0
		Percentage (%)	0	0	0	0	0	0	0	0
	Burning	Total x 109 (MJ)	1.4	2.11	2.49	2.86	2.27	2.22	2.08	2.88
		Percentage	90.34	91.03	90.73	90.31	89.12	89.42	89.02	91.10
	Grinding	Total (MJ)	60509126	85866789	1.06×108	1.31×108	1.37×108	1.26×108	1.35×108	1.26×108
		Percentage (%)	3.90	3.70	3.87	4.12	5.39	5.09	5.78	3.98
	Bagging	Total (MJ)	11674840	13223341	14458648	16411750	15459365	14339406	14556926	13222404
		Percentage (%)	0.75	0.57	0.53	0.52	0.61	0.58	0.62	0.42

whereas the dry cement process consumes 3609.75 MJ/ton. The high energy consumption of the wet process over the dry can be attributed to the mix preparation method adopted prior to burning of clinker in the kiln (water being added to the raw materials to form raw thick slurry), whereas the dry process is only based on the preparation of fine powdered raw meal by grinding raw material followed by drying. The required evaporation of wet slurry before calcinations makes the wet process more energy intensive and expensive than the dry process. This is further reflected in **Figure 3**.

3.1. Electrical Energy Intensities Per Unit Operation

Figures 4 and **5** depict the electrical energy intensities per unit operation for the wet and dry processes respectively. It can be observed that grinding operation consumes the highest electrical energy input of 146 MJ per tonnage of product in the wet manufacturing process of cement production, followed by burning, milling, agitation, crushing and bagging with 118, 90, 22, 19 and 15 MJ/ton in that order. However, in the dry process, burning has the highest electrical intensities among all the operations with an approximate value of 170 MJ/ton whereas grinding, mill-
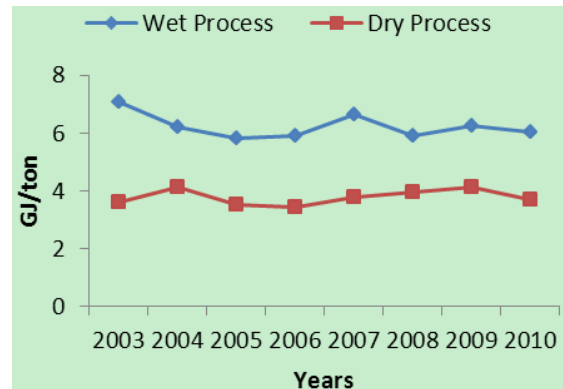
Figure 3. Combustion energy intensities.

ing, crushing and bagging consume 141, 115, 18 and 15 MJ/ton of electrical energy input respectively. Dry process is not subjected to agitation operation.

Furthermore, going by **Figures 4** and **5**, electrical energy intensity consumed in the burning operation of dry process is about 31% higher than that in the wet process of cement. The dry process cement kiln consumes more electrical energy per ton because of the multiple induced draft fans used in the control of air movement through the cyclones and the length of the kiln; the wet process
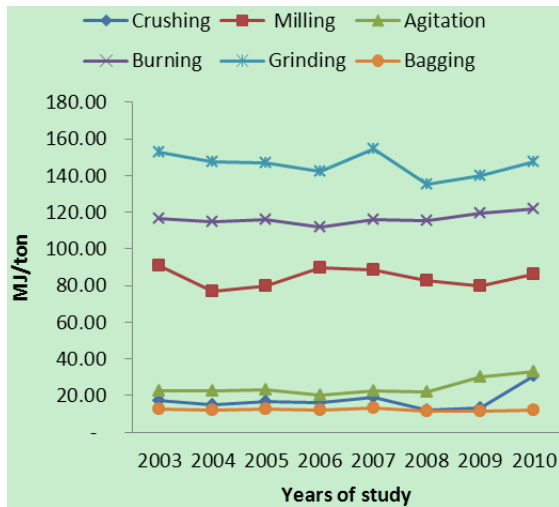
Figure 4. Electrical energy intensities for different process in wet process plant.
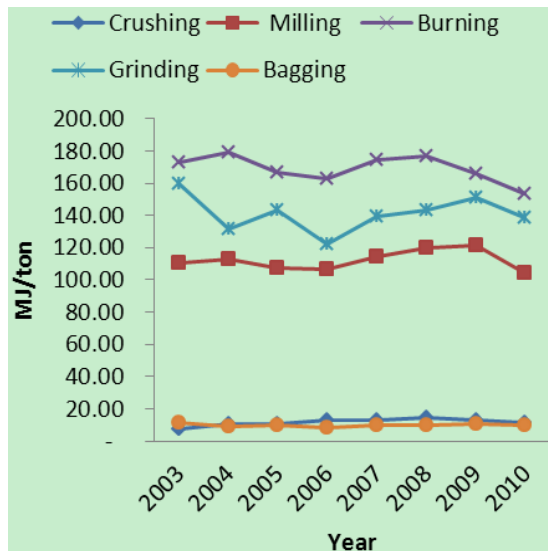

Figure 5. Electrical energy intensities for different process in dry process plant.

cement kiln only makes use of one induce draft fan along the length of the kiln with no cyclones attached.

3.2. Manual Energy Intensities

Manual energy is required for both wet and dry manufacturing process of cement. **Figure 6** shows manual energy intensities for the different operating units in cement production; over the study period, crushing operation requires the highest manual energy intensities for the wet process and bagging for the dry process, followed by the grinding operation and the lowest being the crushing for the dry process and agitation for the wet process. It was also observed during the course of the research work that kiln operation has the highest level of skilled labour, because of the level of system and process so-
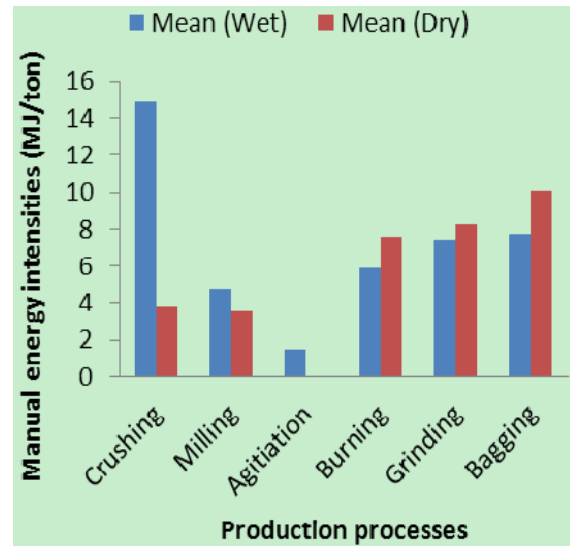

Figure 6. Manual energy intensities for the wet and dry processes within the study period.

phistication, while bagging operation has the highest level of unskilled labour.

3.3. Cost Analysis

The national grid and gas turbine power plant are the two primary sources of electrical energy utility in the cement plant under study. The use of natural gas fired power plant by manufacturers during production is very necessary to ensure smooth production operations and protection of sensitive manufacturing equipment due to the persistent power outages (energy crisis) being witnessed in all sector of the country. A situation whereby 0% power outage involving the use of national grid for the total production time, and situation of 100% power outage involving only the use of electrical power from the gas turbine power plant are considered in calculating the cost of energy inputs of the plant.

The cost of electrical energy based on the national grid was calculated as the product of the energy consumption per unit operation and unit cost of energy (**Tables 7** and **8**) while the electrical energy cost based on the gas powered plant was computed as the product of the gas consumption of the power plant in standard cubic feet (scf) and the unit cost of gas (Naira per standard cubic feet) as listed in **Table 9**. The current minimum wage per month by the Federal Government (**Table 2**) was used to compute the unit cost of manual energy and the appropriate cost/kWh generated in accordance with Equation (2).

The energy costs of the different unit operations for the production of cement by wet and dry process, with the use of national grid and gas turbine power plant as separate sources of electrical energy for year 2003 are given in **Tables 10-13** while **Tables 14-17** depict the summary of cost values for the duration of study.

Table 7. Electrical energy tariff schedule from July 1st. 2009 from Power Holding Company of Nigeria (PHCN).

			Industrial Class			
Class	Demand Level	Demand Charge/KVA	Minimum Charge /Month	Fixed Charge	Meter Main Charge/Month	Energy Charge/KWH
D1	>5 < 15 kVA	00.00	136.00	136.00	151.00	7.90
D2	>15 < 45 kVA	00.00	181.00	181.00	755.00	10.30
D3	>45 < 500 kVA	278.88	7550.00	362.00	2416.00	10.30
D4	>500 < 2 MVA	303.13	47,188.00	0.00	3322.00	10.30
D5	>2 MVA	327.38	2,265,011.00	0.00	3322.00	10.30

Table 8. Electrical energy tariff schedule from February 1st. 2002 to June 30th. 2009 from Power Holding Company of Nigeria (PHCN).

			Industrial Class			
Class	Demand Level	Demand Charge/KVA	Minimum Charge /Month	Fixed Charge	Meter Main Charge/Month	Energy Charge/KWH
D1	>5 < 15 kVA	200.00	90.00	90.00	100.00	6.50
D2	>15 < 45 kVA	200.00	120.00	120.00	500.00	8.50
D3	LV: >45 < 500 kVA	230.00	5000.00	240.00	1600.00	8.50
D4	HV: >500 < 20 MVA	250.00	31,250.00	0.00	2200.00	8.50
D5	>20 MVA	270.00	1,500,000.00	0.00	2200.00	8.50

Table 9. Price of natural gas in Naira per standard cubic feet.

Years	₦/standard cubic feet (scf)
2003	0.2364
2004	0.4955
2005	0.4959
2006	0.4431
2007	0.7300
2008	0.7340
2009	0.9534
2010	0.6383

3.4. Total Energy Cost Using Combustion Energy, Manual Energy and Electrical Energy from National Grid and Gas Turbine Plant for Wet and Dry Processes

It can be observed as computed in (**Table 14**) that the average total energy cost of cement production by the wet process using power from national grid and manual energy during the study period has the highest in 2009 and the least in 2003. Among the constituents of the estimated total cost of energy, combustion cost records the highest average followed by electrical cost and the least being manual energy as 63, 25 and 13% respectively. It can also be seen from the table that the highest in combustion energy cost is obtained in 2009 representing 73.31% for the year while manual energy cost representing 14.22% in 2003 gave the lowest in the study period. In the same vein, for the cost of producing cement using the dry process, the largest portion is obtained in 2010 and the lowest in 2003. However, cumulative average of the constituent costs gave combustion energy as the highest of the total cost with 51% and the lowest as 15% with the manual energy for the whole duration of study. All the study year gave the largest cost estimate as combustion energy and the least estimate as manual energy in both the dry and wet technique of cement production.

Table 15 depicts the total energy cost using power supply from gas turbine plant and manual energy for the wet and dry processes. It shows similar trend in cost with **Table 14**; for the two production processes, cumulative average of combustion energy cost has the highest values having 67 and 59% while that for manual energy has the least values with 14 and 17% for the wet and dry techniques respectively; also, across the study duration, cost of combustion energy is the highest in 2009 and electrical energy is the least in 2003 for the two processes. Furthermore, the average total energy cost of production showed that wet process is approximately 40% more cost intensive in cement production than the dry process. However, comparing the two tables, it is cheaper to run production on energy based on gas powered plant than the national grid.

Table 16 consists of energy cost for each production operations for the wet and dry processes using power supply from national grid. It can be observed that burning operation consumes the largest energy as reflected in the cost with 70 and 64% for the wet and dry processes in that order, followed by grinding, milling, agitation (wet), bagging whereas the least is in crushing operation with 2.5 and 3.3% for the wet and dry techniques respectively for the study period; the dry process is not employ agitation operation. On the yearly basis within the study period,

Table 10. Total energy cost using combustion energy, manual energy and electrical energy from national grid supply for wet process.

		Year 2003							
S/N	Process	Energy from National Grid		Combustion Energy		Manual Energy		Total Energy	
		Electrical Energy $E_p = nPt(MJ)$	Energy Cost N	Energy Consumption SCF	Energy Cost N	Energy Consumption Em = 27 Nt(KWh)	Energy Cost N	Energy Cost N	Percentage of energy cost
1	Crushing	4,891,397.28	41,576,876.88			1,604,834.54	55,784,048.77	97,360,925.65	4.14
2	Milling	30,272,738.56	257,318,277.76			1,872,306.97	65,081,390.23	322,399,667.99	13,70
3	Agitation	19,849,328.64	168,719,293.44			1,337,362.12	46,486,707.31	215,206,000.75	9.14
4	Burning	23,053,204.64	195,952,239.44	4,556,863,878.96	1,077,242,620.99	1,069,889.70	37,189,365.85	1,310,384,226.27	55.68
5	Grinding	30,182,719.68	256,553,117.28			2,139,779.39	74,378,731.69	330,931,848.97	14.06
6	Bagging	2,522,110.84	21,437,942.15			1,604,834.54	55,784048.77	77,221,990.92	3.28
	Total		941,557,746.95		1,077,242,620.99		334,704,292.63	2,353,504,660.56	
	Percentage Total		40.01%		45.77%		14.22%		100

Table 11. Total energy cost using combustion energy, manual energy and electrical energy from national grid supply for dry process.

		Year 2003							
S/N	Process	Energy from National Grid		Combustion Energy		Manual Energy		Total Energy	
		Electrical Energy $E_p = nPt(MJ)$	Energy Cost N	Energy Consumption SCF	Energy Cost N	Energy Consumption Em = 27 Nt(KWh)	Energy Cost N	Energy Cost N	Percentage of energy cost %
1	Crushing	1,196,854.69	10,173,264.84			1,701,859.09	59,156,622.00	69,329,886.84	6.84
2	Milling	17,607,209.37	149,661,279.61			1,021,115.45	35,493,973.20	185,155,252.81	18.26
3	Agitation								0.00
4	Burning	17,689,443.84	150,360,272.64	1,202,122,588.97	284,181,780.03	1,361,487.27	47,325,297.60	481,867,350.27	47.52
5	Grinding	14,936,045.42	126,956,386.08			1,872,045.00	65,072,284.20	192,028,670.28	18.94
6	Bagging	1,030,594.29	8,760,051,49			2,212,416.82	76,903,608.60	85,663,660.09	8.45
	Total		445,911,254.65		284,181,780.03		283,951,785.60	1,104,044,820.29	
	Percentage Total		43.9%		28.02%		28.00%		100

Table 12. Total energy cost using combustion energy, manual energy and electrical energy from gas turbine power plant supply for wet process.

		Year 2003							
S/N	Process	Energy from National Grid		Combustion Energy		Manual Energy		Total Energy	
		Electrical Energy $E_p = nPt(MJ)$	Energy Cost N	Energy Consumption SCF	Energy Cost N	Energy Consumption Em = 27 Nt (KWh)	Energy Cost N	Energy Cost N	Percentage of energy cost %
1	Crushing	45,046,356..35	10,648,958.64			1,604,834.54	55,784,048.77	66,433,007.41	4.02
2	Milling	278,790,801.62	65,806,145.50			1,872,306.97	65,081,390.23	130,987,535.74	7.92
3	Agitation	182,798,468.41	43,213,557.93			1,337,362.12	46,486,707.31	89,700,265.24	5.43
4	Burning	212,303,931.10	50,188,649.31	4,556,863,878.96	1,077,242,620.99	1,069,889.70	37,189,365.85	1,164,620,636.15	70.45
5	Grinding	277,961,790.54	65,710,167.28			2,139,779.39	74,378,731.69	140,088,898.98	8.4
6	Bagging	23,226,881.24	5,490,834.72			1,604,834.54	55,784,048.77	61,274,883.50	3.71
	Total		241,158,313.40		1,077,242,620.99		334,704,292.63	1,653,105,227.01	
	Percentage Total		14.59%		65.16%		20.25%		100

Table 13. Total energy cost using combustion energy, manual energy and electrical energy from gas turbine power plant supply for dry process.

		Year 2003							
S/N	Process	Energy from National Grid		Combustion Energy		Manual Energy		Total Energy	
		Electrical Energy $E_p = nPt\,(MJ)$	Energy Cost N	Energy Consumption SCF	Energy Cost N	Energy Consumption Em = 27 Nt(KWh)	Energy Cost N	Energy Cost N	Percentage of energy cost %
1	Crushing	11,147,448.88	2,635,256.92			1,701,859.09	59,156,622.00	61,791,878.92	9.04
2	Milling	163,992,729.09	38,767,881.16			1,021,115.45	35,493,973.20	74,261,854.36	10.86
3	Agitation								0.00
4	Burning	164,758,657.16	38,948,946.55	1,202,122,588.97	284,181,780.03	1,361,487.27	47,325,297.60	370,456,024.19	54.19
5	Grinding	139,113,632.35	32,886,462.69			1,872,045.00	65,072,284.20	97,958,746.89	14.33
6	Bagging	9,598,907.31	2,269,181.69			2,212,416.82	76,903,608.60	79,172,790.29	11.58
	Total		115,507,729.00		284,181,780.03		283,951,785.60	683,641,294.64	
	Percentage Total		16.90%		41.57%		41.54%		100.00

Table 14. Total energy cost using combustion energy, manual energy and electrical energy from National grid supply for wet and dry processes.

Energy Input		2003	2004	2005	2006	2007	2008	2009	2010
Wet / Electrical	Total X 108 (N)	941,557,756.95	899,044,769.39	900,356,387.01	1,024,596,014.60	944,855,808.32	865,898,402.97	731,067,479.99	927,042,555.51
	Percentage (%)	40.01	27.56	29.94	29.72	21.25	20.25	16.01	26.75
Wet / Manual	Total (N)	334,704,292.63	371,354,375.70	347.485,576.61	534,110,331.87	389,948,885.02	531,989,215.44	487,488,850.80	567,451,891.67
	Percentage (%)	14.22	11.39	11.55	15.49	8.77	12.44	10.68	16.37
Wet / Combustion	Total X 109 (N)	1,077,242,620.99	1,991,217,397.96	1,759,565,452.97	1,888,732,302.40	3,111,655,564.78	2,877,123,473.11	3,346,853,110.42	1,970,958,208.83
	Percentage (%)	45.77	61.05	58.51	54.79	69.98	67.30	73.31	56.87
	Total energy cost (N)	2,353,504,660.56	3,261,616,543.06	3,007,407,416.59	3,447,438,648.87	4,446,460,258.12	4,275,011,091.52	4,565,409,441.21	3,465,452,656.01
Dry / Electrical	Total X 108 (N)	445,911,254.65	642,657,551.69	812,580,451.96	978,683,285.38	849,561,050.34	809,637,699.10	762,476,425.67	1,100,770,853.21
	Percentage (%)	43.97	35.29	39.76	37.68	30.22	31.56	27.15	36.40
Dry / Manual	Total (N)	283,951,785.60	274,873,104.47	262,746,230.04	527,943,813.60	399,638,744.40	351,629,056.80	328,078,480.80	330,978,776.04
	Percentage (%)	28.00	15.09	12.86	20.33	14.21	13.71	11.68	10.95
Dry / Combustion	Total X 109 (N)	284,181,780.03	903,467,378.11	968,565,978.51	1,090,693,044.66	1,562,479,185.18	1,403,808,051.83	1,718,015,421.18	1,592,050,821.00
	Percentage (%)	28.02	49.61	47.39	41.66	55.57	54.73	61.17	52.65
	Total energy cost (N)	1,014,044,820.29	1,820,998,034.27	2,043,892,660.51	2,597,320,143.64	2,811,678,979.91	2,565,074,807.73	2,808,570,327.65	3,023,800,450.26

Table 15. Total energy cost using combustion energy, manual energy and electrical energy from gas turbine power plant supply for wet and dry processes.

	Energy Input	2003	2004	2005	2006	2007	2008	2009	2010
Wet	Electrical — Total X 108 (N)	241,158,313.40	482,650,524.11	483,744,859.09	497,473,042.06	755,794,167.99	865,898,402.97	889,043,662.52	622,868,966.55
	Electrical — Percentage (%)	14.59	16.96	18.67	17.03	17.75	20.25	18.82	17.97
	Manual — Total (N)	334,704,292.63	371,354,375.70	347,485,576.61	534,110,331.87	389,948,885.02	531,989,215.44	487,488,850.80	567,451,891.67
	Manual — Percentage (%)	20.25	13.05	13.41	18.29	9.16	12.44	10.32	16.37
	Combustion — Total X 109 (N)	1,077,242,620.99	1,991,217,397.96	1,759,565,452.97	1,888,732,302.40	3,111,655,564.78	2,877,123,473.11	3,346,853,110.42	1,970,958,208.83
	Combustion — Percentage (%)	65.16	69.98	67.92	64.68	73.09	67.30	70.86	56.87
	Total energy cost (N)	1,653,105,227.01	2,845,222,297.77	2,590,795,888.67	2,920,315,676.34	4,257,398,617.78	4,275,011,091.52	4,723,385,623.75	3,465,452,656.01
Dry	Electrical — Total X 108 (N)	115,507,729.00	348,930,082.50	242,302,380.76	475,180,992.56	679,567,486.95	651,181,300.93	796,556,722.86	635,358,151.41
	Electrical — Percentage (%)	16.90	22.85	16.44	22.69	25.72	27.06	28.02	24.83
	Manual — Total (N)	283,951,785.60	274,873,104.47	262,746,230.04	527,943,813.60	399,638,744.40	351,627,056.80	328,078,480.80	330,978,776.04
	Manual — Percentage (%)	41.54	18.00	17.83	25.21	15.13	14.61	11.54	12.94
	Combustion — Total X 109 (N)	284,181,780.03	903,467,378.11	968,565,978.51	1,090,693,044.66	1,562,479,185.18	1,403,808,051.83	1,718,015,421.18	1,592,050,821.00
	Combustion — Percentage (%)	41.57	59.16	65.73	52.09	59.15	58.33	60.44	62.23
	Total energy cost (N)	683,641,294.64	1,527,270,565.08	1,473,614,589.31	2,093,817,850.83	2,641,685,416.53	2,406,618,409.57	2,842,650,624.84	2,558,387,748.46

burning operation had the highest cost in 2009 representing 77.96% while crushing represents 0.74% for 2010 for the wet process. However, using power supply from turbine power plant based on natural gas for the two processes (**Table 17**), burning operation consumes the largest energy as reflected in the total average cost for the study period with 72 and 69% respectively for the wet and dry processes while the least energy is consumed in bagging (wet) and crushing operation (dry) with 3.3% and 3.2% respectively. Furthermore, on the yearly basis within the study period, burning operation had the highest cost in 2009 with 75.96% while crushing represents 1.16% of the cost computed for 2010 for the wet process; dry process has the highest portion of cost in burning as 72.39% in 2010 while the least cost is given by the crushing operation as 1.69% in 2010.

3.5. Energy Cost Per Tonnage of Cement Produced by the Wet and Dry Process

The average energy cost per tonnage of cement by wet and dry processes for the period of study (2003-2010) is represented in **Figures 7** and **8**.

Approximate values of ₦5551.72and ₦3174.13 per ton for electrical energy supplied from national grid were computed for wet and dry processes in that order while ₦5,382.46 and ₦2,960 per ton for the electrical energy supplied from gas turbine power plant were calculated

for wet and dry processes respectively. The comparative analysis of average cost per tonnage gave reduction in ₦/ton of approximately ₦169.26/ton and ₦214.13/ton for the wet and dry process based on electrical energy from national grid and gas turbine power plant respectively; a resulting change in source price of electrical energy by 55.85% more on the dry process than wet process was obtained.

3.6. Energy Efficiency Options Available in the Industry

Various aspects of the cement manufacturing processes has been found to consume and/or waste energy. Opportunities for either reducing this energy consumption or recycling them where appropriate are being continuously sort out for. The following are considered necessary in optimizing energy consumption in a cement manufacturing process: 1) plant retrofits (process modification and design modification) as included in **Table 18**) energy efficient best practices in cement manufacturing. Burning operation takes place in the kiln and has been discovered from the study as the most energy intensive operation in this research work.This is followed by grinding, milling, agitation (wet), bagging and crushing respectively; these operations can be targeted for energy consumption reduction with the application of economically viable energy efficient tech-

Table 16. Total energy cost using combustion energy, manual energy and electrical energy from National grid supply for wet and dry processes.

| Process		Energy	2003	2004	2005	2006	2007	2008	2009	2010
Wet	Crushing	Total (N)	97,360,925.65	115,278,680.40	115,471,574.21	165,831,370.21	101,349,870.54	52,272,163.30	33,696,770.66	45,977,246.38
		Percentage (%)	4.14	3.53	3.84	4.81	2.28	1.22	0.74	1.33
	Milling	Total (N)	322,399,667.99	286,167,929.72	277,059,281.97	359,750,545.67	305,203,317.56	326,556,618.25	256,579,336.91	303,282,985.54
		Percentage (%)	13.70	8.77	9.21	10.44	6.86	7.64	5.62	8.75
	Agitation	Total (N)	215,206,000.75	215,726,176.44	212,704,809.47	249,891,076.40	237,131,378.53	260,794,349.96	244,952,117.84	292,296,285.78
		Percentage (%)	9.14	6.61	7.07	7.25	5.33	6.10	5.37	8.43
	Burning	Total x 109 (N)	1,310,384,226.27	2,223,148,574.46	1,979,083,016.89	2,164,668,995.82	3,345,873,592.52	3,138,209,855.72	3,559,220,301.42	2,263,751,459.88
		Percentage (%)	55.68	68.16	65.81	62.79	75.25	73.41	77.96	65.32
	Grinding	Total x 108 (N)	330,931,848.97	333,871,508.18	339,057,660.21	385,166,568.92	350,651,601.69	352,638,326.10	330,518,286.88	393,716,528.29
		Percentage (%)	14.06	10.24	11.27	11.17	7.89	8.25	7.24	11.36
	Bagging	Total (N)	77,221,990.92	87,423,673.85	84,031,073.84	122,130,091.86	106,250,497.28	144,539,778.19	140,442,627.50	166,428,150.12
		Percentage (%)	3.28	2.68	2.79	3.54	2.39	3.38	3.08	4.80
Dry	Crushing	Total (N)	69,329,886.84	77,962,379.85	81,184,712.44	134,182,615.84	79,762,925.31	52,789,026.60	47,900,866.56	63,171,020.24
		Percentage (%)	6.84	4.28	3.97	5.17	2.84	2.06	1.71	2.09
	Milling	Total (N)	185,155,252.81	249,008,669.49	300,058,555.30	386,546,383.12	304,358,557.99	299,855,768.21	265,795,694.92	398,859,001.61
		Percentage (%)	18.26	13.67	14.68	14.88	10.82	11.69	9.46	13.19
	Agitation	Total (N)	-	-	-	-	-	-	-	-
		Percentage (%)	-	-	-	-	-	-	-	-
	Burning	Total x 109 (N)	481,867,350.27	1,156,669,956.81	1,278,883,175.82	1,490,827,832.35	1,873,870,527.06	1,698,970,760.51	1,972,715,946.21	1,990,648,431.57
		Percentage	47.52	63.52	62.57	57.40	66.65	66.23	70.24	65.83
	Grinding	Total (N)	192,028,670.28	249,659,415.13	294,490,005.06	414,344,809.45	409,653,667.29	378,807,603.16	393,743,371.35	436,072,906.82
		Percentage (%)	18.94	13.71	14.41	15.95	14.57	14.77	14.02	14.42
	Bagging	Total (N)	85,663,660.09	87,697,612.98	89,276,211.89	171,418,502.88	144,033,302.27	134,651,649.26	128,414,448.61	135,049,906.02
		Percentage (%)	8.45	4.82	4.37	6.60	5.12	5.25	4.57	4.47
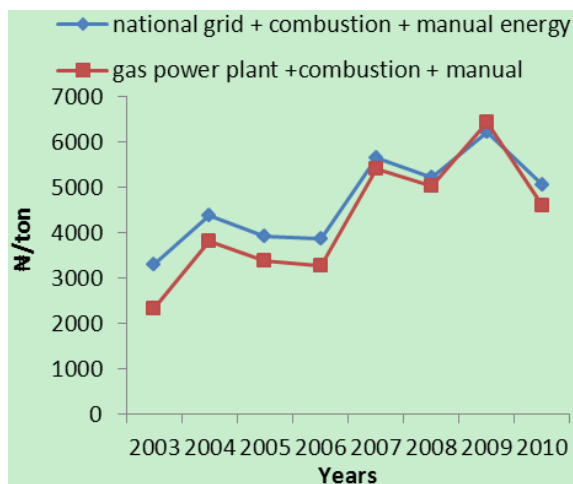
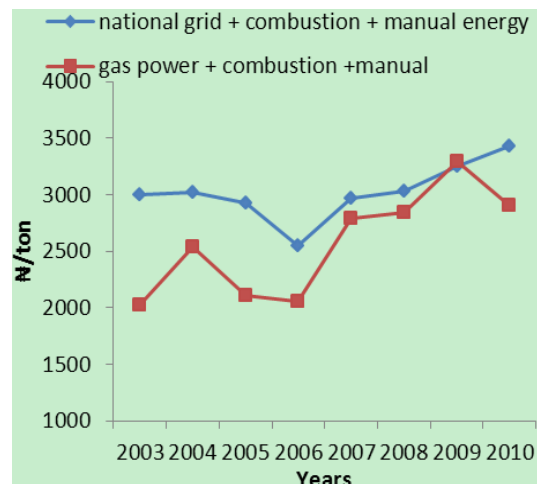**Figure 7. Energy cost per tonnage of wet process cement in Naira (₦).**

Figure 8. Energy cost per tonnage of dry process cement in Naira (₦).

Table 17. Total energy cost using combustion energy, manual energy and electrical energy from gas turbine power plant supply for wet and dry processes.

Process		Energy	2003	2004	2005	2006	2007	2008	2009	2010
Wet	Crushing	Total (N)	66,4433,007.41	98,898,398.62	96,640,692.30	142,321,608.88	93,390,262.54	52,272,163.30	34,475,745.29	40,239,904.02
		Percentage (%)	4.02	3.48	3.73	4.87	2.19	1.22	0.73	1.16
	Milling	Total (N)	130,987,535.74	184,108,578.12	177,352,910.33	216,430,384.95	256,453,499.31	326,556,618.25	292,515,843.93	238,828,516.19
		Percentage (%)	7.92	6.47	6.85	7.41	6.02	7.64	6.19	6.89
	Agitation	Total (N)	89,700,265.24	137,583,524.09	134,635,276.51	163,090,216.14	203,371,363.41	260,794,349.96	281,410,626.30	225,214,459.40
		Percentage (%)	5.43	4.84	5.20	5.58	4.78	6.10	5.96	6.50
	Burning	Total x 10⁹ (N)	1,164,620,636.15	2,133,146,281.48	1,893,790,514.51	2,056,116,396.29	3,309,958,732.92	3,138,209,855.72	3,587,770,534.55	2,198,843,656.85
		Percentage (%)	70.45	74.97	73.10	70.41	77.75	73.41	75.96	63.45
	Grinding	Total x 10⁸ (N)	140,088,898.98	214,072,422.05	214,734,076.10	232,946,687.29	292,807,774.52	352,638,326.10	382,432,242.21	299,589,747.91
		Percentage (%)	8.47	7.52	8.29	7.98	6.88	8.25	8.10	8.65
	Bagging	Total (N)	61,274,883.50	77,413,092.40	73,642,418.92	109,410,382.78	101,416,985.09	144,539,778.19	144,780,631.21	158,562,782.91
		Percentage (%)	3.71	2.72	2.84	3.75	2.38	3.38	3.07	4.59
Dry	Crushing	Total (N)	61,791,878.92	68,612,231.74	58,301,835.34	113,010,737.07	73,232,657.17	46,607,388.52	49,157,618.70	43,161,172.44
		Percentage (%)	9.04	4.49	3.96	5.40	2.77	1.94	1.73	1.69
	Milling	Total (N)	74,261,854.36	150,968,231.74	115,009,408.46	223,575,916.15	254,773,647.19	251,544,794.58	275,465,261.49	250,316,704.00
		Percentage (%)	10.86	9.88	7.80	10.68	9.64	10.45	9.69	9.78
	Agitation	Total (N)	-	-	-	-	-	-	-	-
		Percentage (%)	-	-	-	-	-	-	-	-
	Burning	Total x 10⁹ (N)	370,456,024.19	1,061,969,516.29	1,095,183,682.07	1,332,831,783.49	1,826,650,368.00	1,655,036,483.36	1,981,152,705.37	1,851,893,344.61
		Percentage	54.19	69.53	74.32	63.66	69.15	68.77	69.69	72,39
	Grinding	Total (N)	97,958,746.89	163,937,526.62	127,374,501.41	263,396,422.30	347,298,012.00	322,652,802.03	407,510,642.38	288,171,811.55
		Percentage (%)	14.33	10.73	8.64	12.58	13.15	13.41	14.34	11.26
	Bagging	Total (N)	79,172,790.29	81,782,761.59	77,745,162.04	161,002,991.82	139,730,732.17	130,776,941.06	129,364,396.91	124,844,715.86
		Percentage (%)	11.58	5.35	5.28	7.69	5.29	5.43	4.55	4.88

nologies.

A lot of energy has been observed to be lost in the form of waste heat through the kiln exhaust gas and the air discharged from the clinker cooler stack where the temperature could be as high as 315 and 215˚C respectively [2]. Re-direction of these high temperature gases through a wasteheat recovery steam generator for electricity production has been considered as a means of making the process more efficient. Energy consumption can also be reduced through the addition of pre-calciner to lower the specific fuel consumption and reduce thermal NOx emission. Improvement in the efficiency of electric motors, replacement of all old/obsolete devices together with the use of adjustable speed drives (ASDs) for various electric motors can result into large energy and cost savings. Various other energy efficient best practices adopted to save energy and hence GHG emissions reduction in a cement industry were comprehensively discussed in

Table 18. Process and design modifications.

Raw material preparation	Replace traditional mills with roller mills and high pressure pressing milling
	Improve ball mills
	Apply efficient separators
	Insulate the hot air piping entering mills in order to dry materials
	Utilize pre-crusher
	Continuous control of raw material level in mills
	Adjust raw material size
Clinker production	Combustion system improvement
	Heat loss reduction by insulation
	Improve cooler operation and replace satellite coolers by grates ones
	Adopt mechanical transportation system (elevator instead of airlift)
	Add multistage pre-heaters and pre-calcinator
	Re-adapt wet type to dry type or semi-dry type
	Use low pressure cyclones
	Install eefficient fans
	Recycle waste heat
	Ensure air-tight system (good air draft control)
	Utilize variable speed drives for proper motor utilization
	Improve ball mills
Finished grinding	Replace traditional mills with roller mills and high continuous control of cement level in mills
	Control the size of input clinker and softness of cement according to standards
	Apply grinding aid materials to increase grinding capacity and reduce energy intensity
	Immediate grinding of clinker from kiln is encouraged to reduced the crushing strength, thereby reducing the electrical energy per ton required for grinding
Preventive maintenance	Correct plant maintenance schedule should be encouraged in order to operate plant in optimal capacity

[2,13,14].

4. Conclusions

An investigation of the energy consumption for the production of cement by wet and dry processes in Nigeria was carried out. From the study, the following observations were made:

- Combustion, electric and human energy constituted the major portion of the energy input in the production of cement by the wet and dry processes.
- The total estimated energy intensities were 6545 and 4197 MJ/ton for wet and dry process respectively. Furthermore, energy utilization is less intensive for the dry process than the wet cement manufacturing technique.
- The most energy intensive operation of all the operations in cement production was the burning operation consuming about 93% and 90% of the total energy input for the wet and dry processes respectively. Significant amount of heat is wasted in burning. Therefore, improvements can be made in this section to reduce heat loss or recycle heat.
- It has been observed that dry process is more efficient compared to wet process. It has been proved to reduce the energy consumption by 40% than wet process

because extra energy is needed in wet techniques to remove moisture contained in wet slurry.

- Wet process plants which are energy inefficient and still available in the country should be replaced or upgraded to reduce its overall energy consumption.

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