

RESEARCH PAPER

# Economic evaluation of hazard control technology in a wet process cement plant

Olasunkanmi Oriola Akinyemi<sup>1</sup>, Hezekiah Oluwale Adeyemi<sup>1</sup>, Adeshinaayomi Lawal Akintan<sup>1</sup>, Musediq Adedoyin Sulaiman<sup>1</sup>, Ademola Oluwafemi Sadiq<sup>1</sup>, Olaolu Folorunsho<sup>2</sup>

<sup>1</sup>Olabisi Onabanjo University, Department of Mechanical Engineering, Ago-Iwoye, Nigeria.

<sup>2</sup>Olabisi Onabanjo University, Department of Computer Engineering, Ago-Iwoye, Nigeria.

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## ABSTRACT

**Goal:** Retrofit technology has been suggested for the reduction of CO<sub>2</sub> emission in cement manufacturing but the economic justification of this retrofit technology is rarely or not available. This research study aimed to evaluate the beneficial value of retrofit technology aimed at reducing CO<sub>2</sub> emission in a wet process cement plant.

**Design / Methodology / Approach:** Engineering Economic and cost estimation techniques were used to evaluate the overall annual cost of combination of retrofit technology. The overall annual cost of retrofit technology was determined in terms of capital cost, operation and maintenance cost and energy cost savings of retrofit.

**Results:** The best strategy to reduce CO<sub>2</sub> emission is the combination of adjustable speed drive for kiln; kiln drive efficiency improvement for kiln and process control and management system for kiln at 6% reduction target, giving a cost savings of \$520,836 on retrofit for 10 years and 1.41% reduction in total cost.

**Limitations of the investigation:** Getting adequate plant data in Nigeria was a constraint during the research.

**Practical implications:** The results presented if implemented by Cement plant operators will ensure reduction in the CO<sub>2</sub> emission and government can enforce Cement plant operators to adhere to strict environmental and safety regulations while litigations and sanctions can be employed to implements this policy.

**Originality / Value:** The study established economic justification of retrofit technology for CO<sub>2</sub> emission reduction before eventual implementation.

**Keywords:** Cost Saving; Emission; Hazards; Kiln; Retrofitting; Wet Process.

## INTRODUCTION

Cement no doubt, is a much desired commodity and our development as a country isn't an extended way-fetched from our infrastructural power in terms of homes and awesome bodily infrastructure (Global Cement (2011). Cement consequently performs an important role in this regard. There are two techniques used for the manufacture of cement namely wet process and dry Process (Sidhi et. al., 2016). The decision among wet and dry techniques relies upon on positive factors specifically the physical condition of the raw substances; the cost of the fuel and the local climatic condition of the manufacturing unit. The particular feature of the wet system is that the raw materials are mixed in water while inside the dry technique the

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**Corresponding author:** [ooakinyemi@oouagoiwoye.edu.ng](mailto:ooakinyemi@oouagoiwoye.edu.ng)

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materials are ground and blended dry (International Energy Agency, 2010). Cement is among the most important commodities, as it serves as an excellent constituent inside the making of human refuge. Its manufacturing and availability can't be toyed with but unfortunately, an accompanying pollution is inevitable.

Nigeria is the most populated country in Africa with a population of 200 million individuals. Similarly, the nation has the quickest developing populace on the Africa's landmass with 2.6% yearly development rate in year 2016. The nation is positioned 44th producer of cement in the rundown of more than 200 World's nations. Be that as it may, with the pace at which the nation's populace is developing, the worry for increment in CO<sub>2</sub> emanations, which go with it, similarly develops. In that capacity, all things considered, the nations per capital emission will keep on ascending because of the quick populace development. This will expectedly expand the aggregate CO<sub>2</sub> discharges essentially. Along these lines, Nigeria is relied upon to devise maintainable methods for tending to CO<sub>2</sub> emanations (Sulaiman and Abdul-Rahim, 2018).

The cement industry has been lively in pursuing techniques to decreased CO<sub>2</sub> emanations long earlier than global warming have become a concern. Since 1999, with the launch of the Cement Sustainability Initiative (CSI) at the World Business Council for Sustainable Development (WBCSD), the industry has systematically amassed evidence and stepped forward its techniques. In 2009, the International Energy Agency/World Business Council for Sustainable Development (IEA/WBCSD) Roadmap presented several CO<sub>2</sub> emanations and mitigation strategies (IEA, 2018). The IEA study observed that the target 50% global emissions reduction purpose to preserve global warming at less than 2°C of pre-industrial stages might require an average reduction of 18% within the CO<sub>2</sub> emanations of the cement industry by 2050 (Farfan et al., 2019).

Nigeria CO<sub>2</sub> emanations data as reported in the World Bank study by Cervigni et al. (2013) indicated that agriculture and land use, oil and gas, power and transport sectors accounted for the majority of the CO<sub>2</sub> emanations to the environment. Surprisingly, manufacturing sector and cement industry in particular (with a percentage contribution of 8.14% to GDP of Nigeria economy in Q3 of 2013) was not included in the study. The Federal Government of Nigeria (FGN) has shown some commitments in combating CO<sub>2</sub> emanations. At the 2015 UN Climate Change Conference held in Paris, France; Nigeria presented a document which stated unconditional commitment to reduce CO<sub>2</sub> emanations by 20% in year 2030 and possibility of achieving 45% reduction outside aid is obtained (Ezema et al., 2016).

Summerbell et al. (2016) and Maddalena et al. (2018) stated that reducing CO<sub>2</sub> emanations from cement manufacturing depend largely on raw material mix and fuel type. Summerbell et al. (2016) further stated that the type of manufacturing technology used for cement production also contribute to CO<sub>2</sub> emanations. In order to achieve the target of less than 2°C global average temperature and environmental gains, it is necessary to implement mitigation strategies for the reduction of CO<sub>2</sub> emanation. Also Naqi and Jang (2019) investigated the use of different alternative fuels and binders in cement production to mitigate carbon dioxide emissions. Farfan et al. (2019) and Jessica (2018) proposed carbon capture and utilization (CCU) techniques as a means of reducing CO<sub>2</sub> emanations and the possible use of the captured CO<sub>2</sub> for the production of synthetic hydrocarbon. Adebisi et al. (2015) identified four technological approaches (namely adjustable speed drive for kiln, kiln drive efficiency improvement for kiln, process control and management system for kiln and reciprocating grate coolers for kiln) and eighteen combinations (for two production line of kilns) of these technological approaches to reduce CO<sub>2</sub> emanations. Gardarsdottir et al., (2019) also identified four CO<sub>2</sub> capture technologies namely (chilled ammonia process (CAP), membrane-assisted CO<sub>2</sub> liquefaction, oxyfuel technology and two different configurations of calcium looping technology (tail-end and integrated)). Other mitigating strategies for CO<sub>2</sub> reduction in cement manufacturing have been compiled by Leeson et al. (2017).

However, while an 18% reduction target of CO<sub>2</sub> emission was achieved in the work done by Adebisi et al. (2015); the economic implications of the retrofit technologies have not been

proven. So, it is the main objective of this research work to evaluate the economic viability of combination of retrofit technology in a wet process cement plant.

**METHODOLOGY**

In order to evaluate the economic viability of retrofit technology for mitigating CO<sub>2</sub> emanations in a wet process cement plant; the following methodologies were used:

1. Cost estimation; and
2. Engineering Economic techniques.

The cost estimation approach was used to estimate the capital cost, operations and maintenance cost and energy savings of retrofit technology in year 2008 while the engineering economic techniques was used to evaluate all cost parameters from the estimated cost in 2008 to year 2019 i.e. discounting the value estimated in year 2008 to year 2019 value and subsequently annualized over a 10-year period.

**Cost Estimation of Retrofit Technology**

Staudt (2008) provided a means of estimating the capital costs for the energy efficiency measures using the following equation:

$$Capital\ Costs\ (\$2008) = Scaleup\ factor \times \left( \frac{tons}{year} - cement\ capacity \right)^m \tag{1}$$

where *m* is the scale-up factor exponential.

Retrofits are carried out on a wet kiln and hence scale-up factors were extracted for wet kiln column from Staudt (2008). Meanwhile, scale-up factor using calculations from payback period was adopted. These costs however are subject to revalidation as this method only provides an estimation of equipment’s capital cost only. The equation provided by Staudt (2008) is for 2008-dollar value. This value was normalized into present year using engineering economics techniques for finding a present worth of a future cost (past or later year).

For the purpose of this research, the equation above was used to model the case study plant. The case study cement plant is a wet process plant located in south western Nigeria. The plant runs a double firing system with natural gas and heavy oil as its sole kiln fuel. Carbon capture technology hasn’t been discovered running on any cement plant everywhere throughout the world, the innovation is said to be in pilot stage at different research focuses yet notwithstanding, it has been exhibited in power plants and the prospects that it will work in a cement plant is high. Find below the details of the wet kiln used for this study (Table 1):

**Table 1:** Details of the wet kiln used for this study (Lafarge Nigeria, 2019)

Indicators	Plant Unit	Data Accumulated Average
Cement Output	Tonne/Year	680,087
Clinker Output	Tonne/Year	568,470
Cement-Clinker Ratio	Tonne/Tonne	1.20
Annual Cement Turnout	Tonne	700,000
Type of Fuel	N	Natural Gas
Emission Tonne of Cement	Tonne/Tonne	0.84
Raw Material to Clinker Ratio	Tonne/Tonne	1.54
Total Emission	Tonne	300,137
CO <sub>2</sub> to CaCO <sub>3</sub>	Stoichiometric Ratio	0.44
CaCO <sub>3</sub> to Raw Material Ratio	Tonne/Tonne	0.78
Total Heat Consumed	GJ	3,420,105
Heat Consumed	GJ	976310

**Table 1:** Continued...

Indicators	Plant	Data
	Unit	Accumulated Average
Total Power Consumed	MWh	82,530
Operating Cost	\$	27,835,961
Total Heat Expenditure	\$	14,001,196
Total Power Expenditure	\$	14,042,662
Overall Operating Cost	\$	27,835,961
Average Power Cost	\$/MWh	170.15
Power Cost in Cement	\$/Tonne	19.89
Fuel Cost in Cement	\$/Tonne	210.88
Energy Cost in Cement	\$/	40.97
Expenditure up to Clinker	\$	48,060,980
Production Cost up to Clinker	\$/Tonne	84.55
Cement Cost in Bin	\$/Tonne	91.45
Maintenance Cost	\$	6,377,919
Raw Material Cost	\$/Tonne	40.93
Overall Cost	\$	36,840,071

### Analysis of the Wet Process Plant

As stated earlier; Adebisi et al. (2015) has identified four technological approaches and eighteen combinations (for two production lines of wet kilns) of these technological approaches to reduce CO<sub>2</sub> emissions at different reduction target (Table 2).

**Table 2:** Combinations (for two production lines of wet kilns) of technological approaches to reduce CO<sub>2</sub> emissions at different reduction target (Adebisi et al., 2015)

Reduction Target (%)	Retrofit Technology
1.0	R <sub>12</sub> , R <sub>13</sub>
2.0	R <sub>12</sub> , R <sub>13</sub>
3.0	R <sub>12</sub> , R <sub>13</sub> , R <sub>23</sub>
4.0	R <sub>12</sub> , R <sub>22</sub>
5.0	R <sub>12</sub> , R <sub>22</sub>
6.0	R <sub>12</sub> , R <sub>22</sub> , R <sub>23</sub>
7.0	R <sub>12</sub> , R <sub>14</sub> , R <sub>22</sub>
8.0	R <sub>12</sub> , R <sub>22</sub> , R <sub>24</sub>
9.0	R <sub>12</sub> , R <sub>14</sub> , R <sub>22</sub> , R <sub>24</sub>
10.0	R <sub>12</sub> , R <sub>14</sub> , R <sub>22</sub> , R <sub>24</sub>
11.0	R <sub>12</sub> , R <sub>13</sub> , R <sub>14</sub> , R <sub>22</sub> , R <sub>23</sub> , R <sub>24</sub>
12.0	R <sub>11</sub> , R <sub>12</sub> , R <sub>14</sub> , R <sub>22</sub> , R <sub>24</sub>
13.0	R <sub>11</sub> , R <sub>12</sub> , R <sub>14</sub> , R <sub>22</sub> , R <sub>24</sub>
14.0	R <sub>11</sub> , R <sub>12</sub> , R <sub>14</sub> , R <sub>22</sub> , R <sub>24</sub>
15.0	R <sub>11</sub> , R <sub>12</sub> , R <sub>14</sub> , R <sub>21</sub> , R <sub>22</sub> , R <sub>24</sub>
16.0	R <sub>11</sub> , R <sub>12</sub> , R <sub>22</sub> , R <sub>14</sub> , R <sub>21</sub> , R <sub>22</sub> , R <sub>23</sub> , R <sub>24</sub>
17.0	R <sub>11</sub> , R <sub>12</sub> , R <sub>22</sub> , R <sub>14</sub> , R <sub>21</sub> , R <sub>22</sub> , R <sub>23</sub> , R <sub>24</sub>
18.0	R <sub>11</sub> , R <sub>12</sub> , R <sub>22</sub> , R <sub>14</sub> , R <sub>21</sub> , R <sub>22</sub> , R <sub>23</sub> , R <sub>24</sub>

Where: R<sub>11</sub>-Adjustable Speed Drive for Unit 1. R<sub>12</sub>-Kiln Drive Efficiency Improvement for Unit 1. R<sub>13</sub>-Reciprocating Grate Coolers for Unit 1. R<sub>14</sub>-Process Control and Management System for Unit 1. R<sub>21</sub>-Adjustable Speed Drive for Unit 2. R<sub>22</sub>-Kiln Drive Efficiency Improvement for Unit 2. R<sub>23</sub>-Reciprocating Grate Coolers for Unit 2. R<sub>24</sub>-Process Control and Management System for Unit 2. R<sub>11</sub> to R<sub>24</sub> are binary variables i.e. variables takes values of 0 or 1.

The wet kilns under consideration have output of 680,087 tons/year of cement for both units at 75% utilization factor and can go well above this value if available resources are well utilized. From Equation 1; substitute for wet kilns output we have the expression for cost estimate of first cost of retrofit technology as follows:

$$\text{Capital Costs (\$2008)} = \text{Scale-up factor} \times (680,087)^{0.6} \quad (2)$$

### Cost Saving Analysis of Retrofit Technology

The cost saving at respective reduction target is expressed below as:

$$\begin{aligned} \text{Cost saving on retrofit (\%reduction target)} = \\ [\text{annualized capital cost of retrofits} + \text{annualized O \& M cost of retrofit}] \\ - \text{Associated cost saving on energy expenditure} \end{aligned} \quad (3)$$

The overall cost saving is given as:

$$\begin{aligned} \text{Reduction in overall cost (@ \%reduction cost} = \\ \text{Total operating cost for the plant} \\ + \text{Carbon tax on total emission (without retrofit)} \\ - \text{Cost saving on retrofit (@ \%reduction target)} \end{aligned} \quad (4)$$

$$\begin{aligned} \text{Carbon tax on total emission (without retrofit)} = \\ \text{Carbon tax / ton} \times \text{total emission (ton)} \end{aligned} \quad (5)$$

### Analysis of First Cost and Energy Cost Saving of Retrofit Technology

#### Adjustable Speed Drive for Kiln 1 Fan

From Equation 2 above,

$$\text{Capital Costs (\$2008)} = \text{Scale-up factor} \times (680,087)^{0.6}$$

From Staudt (2008), the scale-up factor for adjustable speed drives is 158. Hence,

$$\text{Capital Costs (\$2008)} = 158 \times (680,087)^{0.6}$$

$$\text{Capital Cost (\$2008)} = \$499,109$$

Leveling the above dollar value to 2019 and assuming an interest rate of 10%

$$\text{Capital Cost (\$2019)} = 499,109(F/P, 10\%, 11)$$

From interest table,  $(F/P, 10\%, 11) = 2.853$

Capital Costs (\\$2019) = \$1,423,958

Annualizing the above capital cost gives:

$$\text{Annual capital cost} = \text{Capital Costs (\$2019)} \times (A/P, 10\%, 10)$$

Adjustable speed drives are classified to have a service life of 10yrs as obtained from the United States department of treasury, internal revenue service, 2010.

$$\text{Annualized capital cost} = 1,423,958 \times 0.1628$$

$$\text{Annualized capital cost} = \$231,820$$

Operating Cost of adjustable speed drives:

Power cost accounts for the chunk of the operating cost of speed drives, other costs however include maintenance cost and cost of rewinding.

Power cost estimation:

Parameters:

A 1000HP, 3000rpm variable speed drives under a 75% load and a 3 shift operation amounting to 8,000hrs.

Power consumption is estimated as below:

$$1\text{HP} = 0.746\text{KW}$$

$$\text{Therefore, } 1000\text{HP} = 746\text{KW}$$

$$\text{Total power consumed} = 746 \times 75\% \times 8000 = 4.48\text{MWH per year}$$

For industrial consumption, cost of electric power per kilowatt hour = ₦38.140/KWh at an exchange rate of ₦306 to \$1 (average exchange rate for 2019),

$$\text{Power (KWh)} = \$0.125$$

$$\text{Annual power cost} = \$558.39$$

Annual maintenance cost is assumed to be 20% of capital cost, therefore, annualized total cost is:

$$\text{Therefore, maintenance cost} = 20\% \times 1,423,958 = \$284,792$$

$$\begin{aligned} \text{Total retrofit cost} &= \text{Annualized capital cost} + \text{Operations and Maintenance cost} \\ &= 231,820 + 558.39 + 284,958 \\ &= \$517,336.39 \end{aligned}$$

The United States Environmental Protection Agency (2008), provided a measure of efficiency associated with cement with cement plant retrofit and for adjustable speed drive for kiln fan, energy saving is stated as 5KWh/ton reduction in energy consumption.

$$\text{Overall operating cost} = \$27,835,961$$

$$\text{Total power consumption: } \$14,042,662$$

Cost saving from energy consumption reduction:

$$1\text{MWH} = \$125$$

$$\text{Hence, } 1\text{KWh} = \$0.125$$

$$\text{Cost saving} = 5 \times 700,000 \times 0.125 = \$437,500$$

Cost saving on energy consumption represents 3.12% of total cost of power consumption and 1.57% of total operating cost.

### Kiln Drive Efficiency Improvement

From Equation 2 above,

$$\text{Capital costs (\$2008)} = \text{scale-up factor} \times (680,087)^{0.6}$$

From Staudt (2008), scale-up factor = 29

$$\text{Capital costs (\$2008)} = 29 \times (680,087)^{0.6} = \$91,609$$

Leveling the above dollar value to 2019 and assuming an interest rate of 10%

$$\text{Capital costs (\$2019)} = 91,609(F/P, 10\%, 11)$$

From interest table,  $(F/P, 10\%, 11) = 2.853$

Capital costs (\\$2019) = \$261,360

Annualizing the above capital cost gives:

$$\text{Annual capital cost} = \text{capital cost (\$2019)} \times (A/P, 10\%, 10)$$

According to the United States Environmental Protection Agency (2008) Kiln drive efficiency improvement equipment is classified to have a service life of 10yrs.

Annualized capital cost =  $261,360 \times 0.1628$

Annualized capital cost = \$42,549.

As assumed earlier, annual operating and maintenance cost is 20% of capital cost

Operating and Maintenance =  $20\% \times 261,369 = \$52,272$

Total Retrofit Cost = Annualized capital cost + operations and Maintenance cost

=  $42,549 + 52,272$

= \$94,821

Efficiency improvement:

Efficiency was calculated from associated energy saving potential of retrofitted equipment. For kiln drive efficiency improvement, energy saving is stated as 0.5KWh/ton reduction in energy consumption (United States Environmental Protection Agency, 2008). Respective efficiency will be calculated for each unit of the plant based on its current electrical energy consumption.

Overall operating cost = \$27,835,961

Total power consumption: \$14,042,662

Cost saving from energy consumption reduction:

1MWH = \$125

Hence, 1KWh = 0.125

Cost saving =  $0.5 \times 700,000 \times 0.125 = \$43,750$

Cost saving on energy consumption represents 0.31% of total cost of power consumption and 0.16% of total operating cost.

### Reciprocating Grate Cooler

From Equation 2 above,

$$\text{Capital costs (\$2008)} = \text{scale-up factor} \times (680087)^{0.6}$$

From Staudt (2008), scale-up factor = 83

$$\text{Capital costs (\$2008)} = 83 \times (680087)^{0.6} = \$262,190$$

Leveling the above dollar value to 2019 and assuming an interest rate of 10%

$$\text{Capital costs } (\$2019) = 262,190(F/P, 10\%, 11)$$

From interest table,

$$(F/P, 10\%, 2) = 2.853$$

Capital Costs (\$2019) = \$748,028

Annualizing the above capital cost gives:

$$\text{Annual capital cost} = \text{capital costs } (\$2019) \times (A/P, 10\%, 20)$$

Cement manufacturing equipment such as coolers are classified to have a service life of 20yrs as obtained from the United States Environmental Protection Agency (2008).

$$\text{Annualized capital cost} = 748,028 \times 0.1175$$

$$\text{Annualized capital cost} = \$87,893.$$

As assumed earlier, annual operating and maintenance cost is 20% of capital cost

$$\text{Operating and Maintenance} = 20\% \times 748,028$$

$$\text{Operating and Maintenance} = \$149,606$$

$$\text{Total Retrofit Cost} = \text{Annualized capital cost} + \text{operations and Maintenance cost}$$

$$= 87,893 + 149,606$$

$$= \$237,499$$

Efficiency improvement:

As obtained for adjustable speed drives, efficiency was calculated from associated energy (heat) saving potential of retrofitted equipment. For reciprocating grate coolers, energy saving is stated as 8% reduction per tonne in heat energy consumption (United States Environmental Protection Agency, 2008).

$$\text{Present heat consumption: } 976,310\text{GJ}$$

$$8\% \times 976,310 = 78,104.8\text{GJ}$$

$$\text{Average heat cost} = 4.1\$/\text{GJ}$$

$$\text{Total cost of heat consumption} = \$14,001,196$$

Cost saving from heat energy consumption reduction:

$$1\text{GJ} = \$4.1$$

$$\text{Hence, } 78,104.8\text{GJ} = \$320,230$$

$$\text{Cost saving} = \$320,230$$

Cost saving on heat energy consumption represents 2.29% of total cost of heat consumption and 1.15% of total operating cost.

### Process Control and Management Systems

From Equation 2 above,

$$\text{Capital costs } (\$2008) = \text{scale-up factor} \times (680,087)^{0.6}$$

From Staudt (2008), the scale-up factor for process control and management systems for kiln = 207.

$$\text{Hence, Capital costs } (\$2008) = 207 \times (680,087)^{0.6} = \$653,897$$

Leveling the above dollar value to 2019 and assuming an interest rate of 10% gives;



$$\text{Capital costs } (\$2019) = 653,897(F/P,10\%,11)$$

From interest table,

$$(F/P,10\%,11) = 2.853$$

Capital Costs (\$2019) = \$1,865,568

Annualizing the above capital cost gives:

$$\text{Annual capital cost} = \text{capital costs } (\$2019) \times (A/P,10\%,10)$$

Process control and management systems are classified to have a service life of 10yrs as obtained from the United States Environmental Protection Agency (2008).

$$\text{Annualized capital cost} = \$1,865,568 \times 0.1628$$

$$\text{Annualized capital cost} = \$303,714.$$

Annual operating and maintenance costs of process control and management system is assumed to be 20% of capital cost, hence O & M is given as

$$O \& M = 20\% \times \text{capital cost}$$

$$= 20\% \times 1,865,568 = \$373,113$$

$$\text{Total Retrofit Cost} = \text{Annualized capital cost} + \text{Annual Operations and Maintenance cost}$$

$$= \$303,714 + 373,113$$

$$= \$676,827$$

Efficiency improvement:

The United States Environmental Protection Agency, (2008) provided a measure of efficiency associated with cement plant retrofit process control and management system is estimated to provide an energy reduction of 2.5 – 5% per MJ/ton of cement.

A 3.75% per MJ/ton energy reduction representing the average of the value quoted by United States Environmental Protection Agency (2008), was selected.

$$\text{Present heat consumption: } 976,310\text{GJ}$$

$$3.75\% \times 976,310 = 36,612\text{GJ}$$

$$\text{Average heat cost} = 4.1\$/\text{GJ}$$

$$\text{Total cost of heat consumption: } \$14,001,196$$

Cost saving from heat energy consumption reduction:

$$1\text{GJ} = \$4.1$$

$$\text{Hence, } 36,612\text{GJ} = \$150,108$$

$$\text{Cost saving} = \$150,108$$

Cost saving on heat energy consumption represents 1.07% of total cost of heat consumption and 0.54% of total operating cost.

## RESULTS

This section presents the total cost of each retrofit technology (in terms of annualized capital cost and operating and maintenance cost) and its corresponding energy savings. Afterwards; the retrofit cost savings of combinations of retrofit technology as presented by Adebiji et al., (2015) follow suit. The retrofit cost savings was evaluated in terms of total retrofit cost, energy savings of retrofit and cost of avoided emission (depending on the CO<sub>2</sub> reduction target) for each combination of retrofit technology.

### Costs of Retrofit Technology for Kiln 1 and Kiln 2

Table 3 shows the cost of retrofit technology and energy savings for kiln 1 and kiln 2. These costs were determined using the cost estimation methods and engineering economic techniques.

**Table 3:** Summary of Cost on for Retrofit Technology for Kiln 1 and Kiln 2

Retrofit Technology	Annualized Capital Cost (\$)	Operating and Maintenance Cost (\$)	Total Retrofit Cost (\$)	Energy Saving (\$)
Adjustable speed drive R <sub>11</sub> / R <sub>21</sub>	231,820	285,516	517,336	437,500
Kiln drive efficiency improvement R <sub>12</sub> / R <sub>22</sub>	42,549	52,272	94,821	43,750
Reciprocating grate cooler R <sub>13</sub> / R <sub>23</sub>	87,893	149,606	237,499	320,230
Process control and management system R <sub>14</sub> / R <sub>24</sub>	303,714	373,113	676,827	150,108

Table 4 shows the direct annual gross carbon dioxide (CO<sub>2</sub>) emission from cement production using the cement-based methodology tool developed by WRI and WBCSD, 2002. Using this tool, the annual CO<sub>2</sub> emission was calculated from the plant data provided in Table 1 using the given annual cement production and other necessary factors required by the tool.

**Table 4:** Direct Annual Gross Carbon Dioxide Emissions from Cement Production

A	B	C	D	E	F	G
Annual Cement Production (tonnes/yr)	Clinker to Cement Ratio (%)	Tonne of Raw Material per Tonne of Clinker	CaCO <sub>3</sub> Equivalent Raw Material Ratio (%)	CO <sub>2</sub> to CaCO <sub>3</sub> Stoichiometric Ratio Constant	Carbon Dioxide Emissions Factor (tonnes CO <sub>2</sub> /tonnes clinker produced) B x C x D x E	Annual Carbon Dioxide Emissions (tonnes/yr) A x F
680,087	84%	1.54	78%	0.44	0.44	300,137

### Cost Savings on Retrofit/Economic analysis of CO<sub>2</sub> reduction target

Table 5 shows the reduction target of CO<sub>2</sub> emission and the corresponding cost savings on retrofit. The retrofit cost saving is a function of total retrofit cost, energy saving of retrofit and cost of avoided emission for each combination of retrofit technology depending on the reduction target. For instance; consider cost saving on retrofit at 1% reduction, R<sub>12</sub> and R<sub>13</sub> were the retrofit technology chosen thereby reducing emission by 3,001 ton.

Where; R<sub>12</sub> – Kiln Drive Efficiency Improvement for Kiln 1, R<sub>13</sub> – Reciprocating Grate Coolers for Kiln 1

Cost of avoided emission = \$30 × 3,001.37 = \$90,041.1

Total retrofit cost (O&M inclusive) for R<sub>12</sub> & R<sub>13</sub> = \$332,320

Total Energy Cost Saving of Retrofit = \$363,980

Applying Equation 2, we have:

$$\text{Cost saving (1\% reduction target)} = \$332320 - \$363980 - \$90041 = -\$121701$$

The negative sign is as a result of an accrued saving in term of cost reduction

**Table 5:** Economic analysis of CO<sub>2</sub> reduction target

Reduction Target	Retrofit Technology	Amount of CO <sub>2</sub> emission reduced (Tons)	Total Retrofit Cost (\$) A	Total Energy Cost Saving of Retrofit B	Cost of avoided emission (\$) C	Cost Saving on Retrofit (@ % reduction Target) A - (B+C)
1%	R <sub>12</sub> , R <sub>13</sub>	3,001	332,320	363,980	90,041	-121,701
2%	R <sub>12</sub> , R <sub>13</sub>	6,003	332,320	363,980	180,082	-211,742
3%	R <sub>12</sub> , R <sub>13</sub> , R <sub>23</sub>	9,004	569,819	684,210	270,123	-384,514
4%	R <sub>12</sub> , R <sub>22</sub>	12,005	189,642	87,500	360,164	-258,022
5%	R <sub>12</sub> , R <sub>22</sub>	15,007	189,642	87,500	450,206	-348,064
6%	R <sub>12</sub> , R <sub>22</sub> , R <sub>23</sub>	18,008	427,141	407,730	540,247	-520,836
7%	R <sub>12</sub> , R <sub>14</sub> , R <sub>22</sub>	21,010	866,469	237,608	630,288	-1,427
8%	R <sub>12</sub> , R <sub>22</sub> , R <sub>24</sub>	24,011	866,469	237,608	720,329	-91,468
9%	R <sub>12</sub> , R <sub>14</sub> , R <sub>22</sub> , R <sub>24</sub>	27,012	1,543,296	387,716	810,370	345,210
10%	R <sub>12</sub> , R <sub>14</sub> , R <sub>22</sub> , R <sub>24</sub>	30,014	1,543,296	387,716	900,411	255,169
11%	R <sub>12</sub> , R <sub>13</sub> , R <sub>14</sub> , R <sub>22</sub> , R <sub>23</sub> , R <sub>24</sub>	33,015	2,018,294	1,028,176	990,452	-334
12%	R <sub>11</sub> , R <sub>12</sub> , R <sub>14</sub> , R <sub>22</sub> , R <sub>24</sub>	36,016	2,060,632	825,216	1,080,493	154,923
13%	R <sub>11</sub> , R <sub>12</sub> , R <sub>14</sub> , R <sub>22</sub> , R <sub>24</sub>	39,018	2,060,632	825,216	1,170,534	64,882
14%	R <sub>11</sub> , R <sub>12</sub> , R <sub>14</sub> , R <sub>22</sub> , R <sub>24</sub>	42,019	2,060,632	825,216	1,260,575	-25,159
15%	R <sub>11</sub> , R <sub>12</sub> , R <sub>14</sub> , R <sub>21</sub> , R <sub>22</sub> , R <sub>24</sub>	45,021	2,577,968	1,262,716	1,350,617	-35,365
16%	R <sub>11</sub> , R <sub>12</sub> , R <sub>22</sub> , R <sub>14</sub> , R <sub>21</sub> , R <sub>22</sub> , R <sub>23</sub> , R <sub>24</sub>	48,022	2,910,288	1,626,696	1,440,658	-157,066
17%	R <sub>11</sub> , R <sub>12</sub> , R <sub>22</sub> , R <sub>14</sub> , R <sub>21</sub> , R <sub>22</sub> , R <sub>23</sub> , R <sub>24</sub>	51,023	2,910,288	1,626,696	1,530,699	-247,107
18%	R <sub>11</sub> , R <sub>12</sub> , R <sub>22</sub> , R <sub>14</sub> , R <sub>21</sub> , R <sub>22</sub> , R <sub>23</sub> , R <sub>24</sub>	54,025	2,910,288	1,626,696	1,620,740	-337,148

Table 6 shows the total cost on retrofit at various reduction targets by evaluating the overall operating and maintenance cost without retrofit with CO<sub>2</sub> tax and cost savings on each retrofit to determine the percentage reduction in cost for each percentage reduction target. The carbon tax on total emission (without retrofit) was calculated using Equation 6 while the total cost in a carbon era was calculated using Equation 7 as stated below:

$$\text{Carbon tax on total emission (without retrofit)} = \text{Carbon tax/ton} \times \text{total emission (ton)} \quad 6$$

$$\text{Carbon tax on total emission (without retrofit)} = \$30/\text{ton} \times 300,137 = \$9,004,110$$

$$\begin{aligned} &\text{Total cost with retrofit in a carbon tax era} = \\ &\text{Total operating cost for the plant} \\ &+ \text{Carbon tax on total emission (without retrofit)} \\ &- \text{Cost saving on retrofit (@ \% reduction target)} \end{aligned}$$

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Note that the total operating cost (without retrofit) is \$27,835,961.  
 Therefore at reduction target of 1%, the total cost on retrofit is calculated thus:

$$\text{Total cost of the cement plant on Retrofit} = \\ \$27,835,961 + \$9004110 - \$121701 = \$36,718,370$$

**Table 6:** Total Cost Spent on Retrofit Technology and Percentage Reduction in overall Operating Cost

Reduction Target (%)	Total O&M (No Retrofit) (\$) A	CO <sub>2</sub> Tax (\$) B	Cost Saving on Retrofit (@ % reduction Target) C	Total Cost with Retrofit (\$) A+B+C	Reduction in Cost (%)
1	27,835,961	9,004,110	-121,701	36,718,370	0.33
2	27,835,961	9,004,110	-211,742	36,628,329	0.57
3	27,835,961	9,004,110	-384,514	36,455,557	1.04
4	27,835,961	9,004,110	-258,022	36,582,049	0.70
5	27,835,961	9,004,110	-348,064	36,492,007	0.94
6	27,835,961	9,004,110	-520,836	36,319,235	1.41
7	27,835,961	9,004,110	-1,427	36,838,644	0.004
8	27,835,961	9,004,110	-91,468	36,748,603	0.25
9	27,835,961	9,004,110	345,210	37,185,281	-0.94
10	27,835,961	9,004,110	255,169	37,095,240	-0.69
11	27,835,961	9,004,110	-334	36,839,737	0.0009
12	27,835,961	9,004,110	154,923	36,994,994	-0.42
13	27,835,961	9,004,110	64,882	36,904,953	-0.18
14	27,835,961	9,004,110	-25,159	36,814,912	0.07
15	27,835,961	9,004,110	-35,365	36,804,706	0.10
16	27,835,961	9,004,110	-157,066	36,683,005	0.43
17	27,835,961	9,004,110	-247,107	36,592,964	0.67
18	27,835,961	9,004,110	-337,148	36,502,923	0.92

**DISCUSSION**

The plant under consideration has an annual carbon dioxide emission of 300,137 tonnes and overall plant operating cost is \$27,835,961. Also, the plant uses two Kilns for its clinker production. Emission cost is benchmarked at \$30/ton of emission. This is based on the average dollar value as proposed by most countries. Meaning, in a regime of carbon tax, an astounding sum of \$9,004,110 would be paid on total emission bringing overall operating cost to (\$27,835,961 + \$9,004,110). An optimization model whose objective was to identify the best retrofit technology strategy to reduce CO<sub>2</sub> emanations with the least cost has been developed by Adebiyi et al. (2015) using the industry data. This research therefore evaluated the economic worthwhile of retrofit technology strategy selected for CO<sub>2</sub> reduction by Adebiyi et al. (2015).

At a reduction target of 1% to 2%; 3,001 to 6,003 tonnes of carbon dioxide were reduced. Tables 5 and 6 shows the retrofit technology selected namely; kiln drive efficiency improvement for kiln 1 and reciprocating grate coolers for kiln 1. The result shows a \$121,701 in cost savings on retrofit and a 0.57% reduction in total cost on retrofit. It was observed that at reduction target of 9%, 10%, 12% and 13%, the cost saving on retrofit was not economically

worthwhile selected for the combination of retrofit technology strategy at each reduction target respectively. Instead of reduction in cost with the strategies, there was increase in cost making such combination of technology not economically worthwhile at those reduction target listed in Table 6. The negative sign in the percentage reduction in cost in Table 6 shows an increase in total cost on retrofit. Although at reduction targets of 9%, 10%, 12% and 13%, Table 5 shows there is reduction in CO<sub>2</sub> emission making the retrofit technology efficient in reducing carbon dioxide emission but not economical in terms of cost reduction.

Further economic analysis at other reduction targets shows the cost savings and percentage reduction in total cost on retrofit. At reduction targets of 2%, 4%, 5%, 6%, 17% and 18%; there is economic worthwhile of these retrofit technologies in terms cost savings and percentage reduction in total cost on retrofit with reduction target of 6% giving the best economic viability amongst the aforesaid.

Carbon Emissions Trading on the Floor of the Exchange is policy under consideration by the Federal Government of Nigeria. This carbon trading is fashioned after the Emission Trading Scheme (ETS) that is fully underway in Europe as a method of fighting emissions with the aid of established emission standards or caps, which restrict how much an entity/organization/country is permitted to emit, and to buy/promote the excess/savings. As a machine of governance through markets, carbon trading relies on the allocated performance of marketplace agents to provide the proper indicators for innovative and effective ways of pursuing economic activities, more so for ensuring socioeconomic optimality within the use of public goods, the climate being a regular example. The availability of two external agents, a regulator (government organisation) and a broking firm (trading platform) represent the vital and sufficient circumstances for the workability of carbon buying and selling. These vital and sufficient circumstances are fulfilled in Nigeria through the Ministry of Environment acting as the regulator whiles the Nigerian Stock Exchange acting as the broking firm (Onyeka, 2020). With this in the pipeline, it is evident that the Nigeria government is fully committed to the reducing CO<sub>2</sub> emanations in all sectors of Nigeria economy and that all sectors of the economy should brace up for carbon tax regime which is imminent.

In this research, the economic viability of combination of four retrofit technologies to reduce CO<sub>2</sub> emanation and minimize operating cost were considered which revealed reduction targets in terms of cost savings and percentage reduction in total cost on retrofit. The research also showed some cases where the combinations of this technology were not economical in term of cost savings and percentage reduction in total cost on retrofit.

## CONCLUSION

The cement industry is responsible for the contribution of global carbon dioxide emanation emitted from the calcination process of limestone. CO<sub>2</sub> emanations have contributed to a large scale climate change which has global repercussions. There are technologies that mitigate the release or capture CO<sub>2</sub> emanation. The combinations of these retrofit technologies are quoted to reduce emission, reduce heat and electrical energy consumption and by extension reduce the operating and maintenance cost as well as increase in productivity of the production line. So, it is the main goal of this research to evaluate the economic viability of implementing these retrofit technologies.

Engineering economics and cost estimation techniques were used to evaluate the economic viability of implementing these retrofit technologies in terms of cost savings on retrofit and percentage reduction in total cost on retrofit. The best strategy to reduce CO<sub>2</sub> emanation economically is the combination of R<sub>12</sub>, R<sub>22</sub> and R<sub>23</sub> retrofit technologies at 6% reduction target, giving a cost saving of \$520,836 on retrofit and 1.41% reduction in total cost.

It should be noted that this research only implemented the use of technology as a way of reducing CO<sub>2</sub> emanations in the cement industry. Due to the rate at which carbon dioxide is been emitted in the cement industry, the government should implement carbon tax on the cement industry so as to hold the cement companies responsible for the CO<sub>2</sub> emanations. If set high enough, it turns into a powerful financial motivator that motivates changes to clean

energy across the economy, essentially by making it more economically rewarding to move to less carbon concentrated manufacturing techniques. Cement plant operators should be compelled to adhere to strict environmental, safety regulations, litigations and sanctions can be employed to implements this regulation.

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**Author contributions:** Olasunkanmi Oriola Akinyemi (Introduction, methodology and results/discussion). Hezekiah Oluwale Adeyemi: (Literature review and revisions). Adeshinaayomi Lawal Akintan: (Methodology and Results). Musediq Adedoyin Sulaiman: (Revisions). Ademola Oluwafemi Sadiq: (Data Collection). Olaolu Folorunsho: (Revisions).