IOP Conference Series: Earth and Environmental Science

PAPER • **OPEN ACCESS**

Perspectives on environmental CO2 emission and energy factor in Cement Industry

To cite this article: G U Fayomi *et al* 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **331** 012035

View the article online for updates and enhancements.

This content was downloaded from IP address 165.73.192.252 on 24/03/2021 at 12:26

IOP Conf. Series: Earth and Environmental Science **331** (2019) 012035 doi:10.1088/1755-1315/331/1/012035

Perspectives on environmental CO_2 emission and energy factor in Cement Industry

G U Fayomi [1, 2], S E Mini[1], O S I Fayomi[3, 4*], A A Ayoola[5]
[1]Strategic Business Services, Covenant University, Ota, Nigeria
[2]Department of Geography, University of South Africa, Johannesburg, South Africa
[3]Department of Mechanical Engineering, Covenant University, P.M.B 1023, Ota, Ogun State, Nigeria
[4]Department of Chemical, Metallurgical and Materials Engineering, Tshwane University of Technology, Pretoria, South Africa
[5]Department of Chemical Engineering, Covenant University, P.M.B 1023, Ota, Ogun State, Nigeria
*Corresponding author: ojosundayfayomi3@gmail.com, +2348036886783
Ayodeji.ayoola@covenantuniversity.edu.ng

Abstract. The global challenges of pollution emission in cement industry in relation to energy consumption factor are overwhelming. No doubt it has been established that economic development has an impact on the environmental pollution and ecological system. With major constituent of environmental affluence been CO_2, the consideration has to be on the type of manufacturing process, the consumption mix and the additive ratio. This paper focuses on the cement industry and aims to provide a systematic review of the specific operations, its trend and its impact on environmental pollution in terms of energy consumption and emissions evolved.

Keywords: CO_2, Pollutions; energy consumption; environmental pollution

1. Introduction

Cement is widely regarded as one of the most important building materials available to man, and concrete, which is primarily composed of cement, is classified as one of the most universally utilized materials on earth [1, 2]. The buildings sector is classified as the third largest CO_2 emitting institution worldwide [3, 4], with cement production figures stand at between 3.0 - 3.6Gt/year, and it has been estimated that per 1kg of cement produced, 0.5-0.9kg of CO_2 emissions are evolved, and this equates to about 3.24 billion tons of CO_2/year for 3.6 billion tons of cement produced annually [5] Gartner 2004). Over 90% of the energy required for cement manufacture is obtained from fossil fuels, while the remaining 10% of energy is obtained via electricity, the statistical figure of energy consumption for the cement industry stands at 2% of global primary energy consumption or about 5% of total global industrial energy consumption [1]. Ali et al., 2011 affirmed to this, that the cement industry is one of the highest consumers of fossil fuel energy, it approximately consumes 12-15% of total industrial energy use, with an estimated 1.75±0.1 MJ of energy required to produce 1kg of cement, and China being the largest manufacturer of cement in the world with 57.3% of total world production [4, 6]. In terms of mean energy consumption and CO_2 emissions, the cement industry ranks as one of the highest, and this still comes after radical measures were enforced on the industry in the 1970s due to an embargo on oil and gas, that led to innovative solutions and necessitated a need for increased efficiency of production processes, this led to a reduction in consumption of fossil fuel due to the embargo [7].

Having established the fact that industrialization directly influences environmental pollution, the cement industry historically, has affirmed to this trend, and has been observed to generate a high volume of particulate emissions (CO_2), particularly in the production of Portland cement clinker, due to the usage of high carbon fuels and emissions from the cement production process [7, 8]. [9], argued that research trends estimates CO_2 emissions from the cement industry to stand at 5% of the overall global CO_2 emissions due in part to two reasons: the Portland cement make, which is the highest percentage of cement variety in production, having a highly pollution production process, and two, the

Content from this work may be used under the terms of the Creative Commons Attribution 3.0 licence. Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI.
Published under licence by IOP Publishing Ltd

IOP Conf. Series: Earth and Environmental Science **331** (2019) 012035 doi:10.1088/1755-1315/331/1/012035

use of outdated industrial equipment (vertical kilns) in some plants, that consume high amounts of energy as well as evolve a high percentage of particulate matter. While it has been established that economic development has an impact on the environmental pollution and ecological damage. This paper focuses and narrows down on the cement industry and aims to provide a systematic review of the specific operations of the cement industry, and its impact on environmental pollution in terms of energy consumption and emissions evolved.

2. Raw Materials Utilized In Cement Industry

Pollution in the cement industry in part stems from the raw materials used in the making of Portland cement, ordinary Portland cement (OPC), is the major cement product, and is produced from a mixture of limestone and clay, pyrolysed in a kiln at temperatures around 1,450°C, and then blended with some additives [2, 8]. According to [12], the average worldwide production figure for clinker stood at 3.6 billion, with worldwide production figures projected to reach over 5 billion by 2030. Typical reactions for the production of clinker include:

$$3CaCO_3 + SiO_2 \rightarrow Ca_3SiO_5 + 3CO_2\text{: with clay } (SiO_2)$$
$$CaCO_3 + \text{heat} \rightarrow CaO + CO_2$$

As can be seen from the process reaction all clinker production processes evolve CO_2, the major constituent of Portland Cement is CaO, and the amount of CaO found is clinker is estimated at 65%, the CO_2 emissions produced are estimated at about 0.5-0.9kg per 1kg of clinker produced [10-12] .Therefore a subsequent increase in the amount of clinker produced indirectly leads to an increase in worldwide CO_2 pollution as seen in Table 1.

Table 1. Constituents of modern Portland cement clinker [12]

Constituents of a finished modern Portland cement clinker		
Tricalcium silicate	50%	Ca_3SiO_5 or $3Ca.SiO_2$
Dicalcium silicate	25%	Ca_2SiO_4 or $2Ca.SiO_2$
Tricalcium aluminate	10%	$Ca_3Al_2O_6$ or $3CaO.Al_2O_3$
Tetracalcium aluminoferrite	10%	$Ca_4Al_2Fe_2O_{10}$ or $4CaO.Al_2O_3.Fe_2O_3$
Gypsium	5%	$CaSO_4.H_20$

The hydration (mixture) of these clinker compounds with water is what produces cement, in which the constituents undergo a chemical reaction and produce an amorphous solid hydrate.

$$2CaSiO_4 + 5H_20 \rightarrow 3CaO_2SiO_2 + 4H_20 + Ca(OH)_2$$
(Phase 2 cement)

2.1. Pollution in Cement Industry

The major industrial pollutant emanating from the manufacture of cement is the evolution of CO_2, an estimated 40% of the total CO_2 generated from the industry, emanates from fossil fuel burning which is used in the production process, and another 50%, from the raw materials utilized and the manufacturing process, and 10% from indirect emissions by transportation of finished goods [3, 12, 13]. According to [1], for every 1kg of cement produced, 0.9kg of CO_2 is evolved, and this equates to the evolution of about 3.24 billion tons of CO_2/year for the current projected 3.6 billion produced annually, and these figures don't take into account the emissions from the quarrying and transportation of raw materials and the transport and delivery of produced cement.

The emission sources at different stages of the product life cycle process are:

- The combustion of fossil fuel in the clinkering process to heat the raw material of limestone ($CaCO_3$), produces CO_2 at temperatures exceeding 1450°C.
- The calcination process (raw material conversion) in cement production process, also generates a significant amount of CO_2.
- Indirect emission from transportation and delivery of raw materials and finished goods.
- CO_2 generated from fossil fuel based electricity generation means, for running plant and equipment [14].

It should however be observed that the amount of CO_2 evolved in the manufacturing process also depends on:

- The type of manufacturing process adopted i.e. type of kiln used
- The type of fuel used (petroleum, natural gas, coal etc.)
- The clinker/cement ratio i.e. percentage of additives [14, 15].

Thus these three areas provides a wide scope for improvement and innovation in the production process for the both the management of energy consumption and reduction of CO_2 emissions. Figure 1 provides an estimate of CO_2 emissions produced at 0.38MJe/kg of electricity/clinker, emission factor of electricity production 0.22kg/MJe, fuel use: 3.35MJ/kg of clinker for dry process and 5.4MJ/kg for wet process.

Table 2. CO_2 emissions in kg per 1kg cement produced for dry and wet cement production process for various fuels and clinker/cement ratios [1]

	Process emissions	Process and fuel-related emissions (CO_2)							
		Dry process				Wet process			
Clinker/cement ratio	Clinker	Coal	Fuel oil	Natural gas	Waste	Coal	Fuel oil	Natural gas	Waste
55%	0.28	0.55	0.5	0.47	0.36	0.67	0.59	0.53	0.36
75%	0.38	0.72	0.66	0.61	0.47	0.88	0.77	0.69	0.47
(Portland) 95%	0.49	0.89	0.81	0.75	0.57	1.09	0.95	0.9	0.57

Cement production is largely an energy-dependent process, which begins with: raw materials preparation, fuel preparation and finish grinding. The world cement production has been observed to be increasing from the 1990s and is projected to keep increasing till 2050 as can be seen in the figure below. Cement is observed to be the second most consumed resource after water, as demand increases annually due to infrastructural development in developing and developed nations [15].

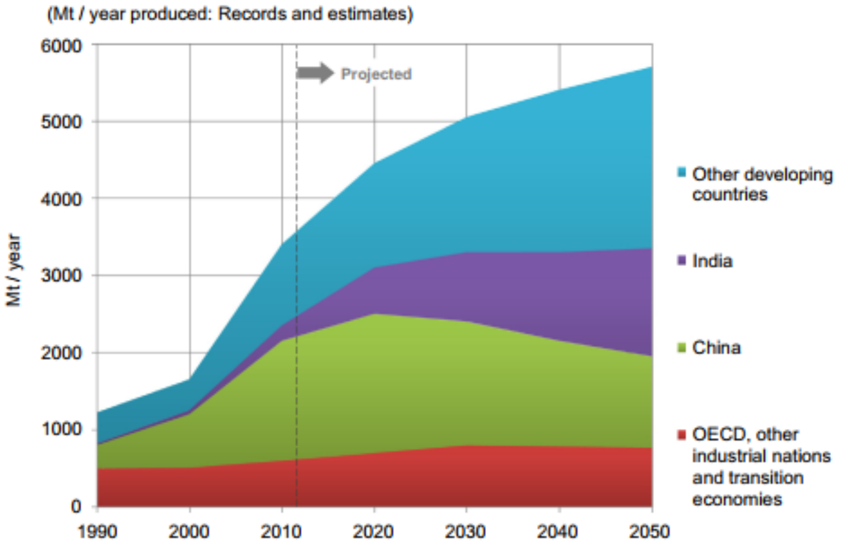

Figure 1. Current and estimated global cement production figures [12].

2.2. Historical Review of Cement Industry

Statistical estimates show that global trend for cement production, emission rates and energy consumption have been consistently increasing [16] in 1994, an estimated 1.381Gt of cement was produced, accompanied by an estimated 1.126Gt of CO_2 emissions. Average primary energy consumption for production was estimated at 4.8MJ/kg of cement, while consuming 6.6EJ of primary energy overall, and evolution of CO_2 was estimated at 1126Tg (=1.126Gt) of CO_2, these estimates account for ≥5% of the world carbon emission [1]. It should be noted that the amount of energy consumed and quantity of CO_2 emitted during these periods came after OPEC enforced an embargo on oil and gas in the 1970s, which forced the cement industry to innovate, become less fuel dependent and more fuel efficient, turning to cokes, coal and other forms of fuels, hinting that prior to this period, the emissions generated and energy consumed were even much higher. The table 3 and 4 presents the primary cement production data and growth rates, production figures have grown from 594Mt in the 1970 to 1453Mt in 1995, at an estimated rate of 3.6%

Table 3. Cement production data between 1970-1995 for major world regions [1]

	Cement Production						**Average Annual Growth**	
	1970	**1975**	**1980**	**1985**	**1990**	**1995**	**1970-1995**	**1990-1995**
Region/Country	**Tg**	**Tg**	**Tg**	**Tg**	**Tg**	**Tg**	**%**	**%**
China (incl. Hong Kong)	27	47	81	148	211	477	12.2%	17.7%
Europe	185	194	223	178	196	181	-0.1%	-1.7%
OECD-Pacific	69	83	113	100	126	154	3.3%	4.1%
Rest of Asia	20	31	49	57	89	130	7.8%	8.0%
Middle East	19	29	44	75	93	116	7.4%	4.6%
Latin America	36	52	76	71	82	97	4.1%	3.4%
Eastern Europe/ former Soviet Union	134	177	190	190	190	96	-1.3%	-12.7%
North America	76	73	79	81	81	88	0.5%	1.5%
India	14	16	18	31	49	70	6.6%	7.3%
Africa	15	20	28	35	38	44	4.5%	2.7%
World	594	722	901	965	1156	1453	3.6%	4.7%

Global estimates have predicted the mean carbon emission intensity of CO_2 emissions from cement production for this period as 0.81kg of CO_2 per kg of cement, with China being the largest emitter of CO_2. Table 4 provides the key statistics for carbon emission for cement production as at 1994.

Table 4. Global emission of CO_2 from cement production [1]

	Cement Production	Clinker/Cement Ratio	Primary Intensity	Primary Energy	Process Carbon Emissions	Carbon Emissions. Energy Use	Total Carbon Emissions	Share of World Total
Region/Country	**Tg**	**%**	**MJ/\kg**	**PJ**	**Tg CO_2**	**Tg CO_2**	**Tg CO_2**	**%**
China	423	83%	5.0	2117	175	197	372	33.0%
Europe	182		4.1	749	73	56	129	11.5%
OECD Pacific	151		3.5	533	65	41	105	9.3%
Other ASIA	124		4.9	613	56	179	105	9.3%
Middle East	111		5.1	563	51	44	95	8.4%
North America	88		5.4	480	39	40	78	7.0%
EE/FSU	101		5.5	558	42	38	80	7.1%
Latin America	97		4.7	462	41	30	71	6.3%
India	62	89%	5.0	309	28	30	60	5.1%
Africa	41		4.9	201	18	15	33	2.9%
World Total	1381		4.8	6585	587	830	1126	100.0%

3. Conclusion

- As observed from the statistical data, cement production and energy consumption has increased steadily between 1994 and 2010, and this has also characterized an increase in the emission of CO_2.
- It was observed that the cement industry has been one of the highest energy consuming and CO_2 emitting institutions worldwide (rated third worldwide), and while improved techniques and modern technologies have brought about an increase in efficiency of production, reduced energy consumption and reduced CO_2 emissions through a variety of techniques.
- However, despite the efforts of the industry and government to increase efficiency of production and regulate the emission of CO_2 associated with cement production, a rise in CO_2 continues particularly as a consequence of increased demand for infrastructural development.

Acknowledgement
The author will like to acknowledge the financial support from Covenant University CUCRID toward the publication of this manuscript.

References

[1] Hendriks, C. A., Worrell, E., Jager, D. De, Blok, K., & Riemer, P. (2004) (n.d.). Emission Reduction of Greenhouse Gases from the Cement Industry, 1–11.
[2] Cai, B., Wang, J., He, J., & Geng, Y. (2016). Evaluating CO 2 emission performance in China's cement industry : An enterprise perspective. *Applied Energy*, *166*, 191–200. https://doi.org/10.1016/j.apenergy.2015.11.006
[3] Habert, G., Billard, C., Rossi, P., Chen, C., & Roussel, N. (2010). Cement and Concrete Research Cement production technology improvement compared to factor 4 objectives. *Cement and Concrete Research*, *40*(5), 820–826. https://doi.org/10.1016/j.cemconres.2009.09.031
[4] Lei, Y., Zhang, Q., Nielsen, C., & He, K. (2011). An inventory of primary air pollutants and CO_2 emissions from cement production in China, 1990-2020. *Atmospheric Environment*, *45*(1), 147–154. https://doi.org/10.1016/j.atmosenv.2010.09.034
[5] Ali, M. B., Saidur, R., & Hossain, M. S. (2011). A review on emission analysis in cement industries. *Renewable and Sustainable Energy Reviews*, *15*(5), 2252–2261. https://doi.org/10.1016/j.rser.2011.02.014
[6] Madlool, N. A., Saidur, R., Hossain, M. S., & Rahim, N. A. (2011). A critical review on energy use and savings in the cement industries. *Renewable and Sustainable Energy Reviews*, *15*(4), 2042–2060. https://doi.org/10.1016/j.rser.2011.01.005
[7] Gartner, E. (2004). Industrially interesting approaches to "'low-CO_2"' cements $, *34*(January 2004), 1489–1498. https://doi.org/10.1016/j.cemconres.2004.01.021

[8] Zhang, C., Han, R., Yu, B., & Wei, Y. (2018). Accounting process-related CO_2 emissions from global cement production under Shared Socioeconomic Pathways. *Journal of Cleaner Production*, *184*, 451–465. https://doi.org/10.1016/j.jclepro.2018.02.284

[9] Benhelal, E., Zahedi, G., Shamsaei, E., & Bahadori, A. (2013). Global strategies and potentials to curb CO 2 emissions in cement industry. *Journal of Cleaner Production*, *51*, 142–161. https://doi.org/10.1016/j.jclepro.2012.10.049

[10] Du, G., Sun, C., Ouyang, X., & Zhang, C. (2018). A decomposition analysis of energy-related CO 2 emissions in Chinese six high-energy intensive industries. *Journal of Cleaner Production*, *184*, 1102–1112. https://doi.org/10.1016/j.jclepro.2018.02.304

[11] Ke, J., Zheng, N., Fridley, D., Price, L., & Zhou, N. (2012). Potential energy savings and CO_2 emissions reduction of China's cement industry. *Energy Policy*, *45*(2012), 739–751. https://doi.org/10.1016/j.enpol.2012.03.036

[12] Imbabi, M. S., Carrigan, C., & Mckenna, S. (2013). Trends and developments in green cement and concrete technology. *International Journal of Sustainable Built Environment*, *1*(2), 194–216. https://doi.org/10.1016/j.ijsbe.2013.05.001

[13] Chen, C., Habert, G., Bouzidi, Y., & Jullien, A. (2010). Environmental impact of cement production : detail of the different processes and cement plant variability evaluation. *Journal of Cleaner Production*, *18*(5), 478–485. https://doi.org/10.1016/j.jclepro.2009.12.014

[14] Hasanbeigi, A., Price, L., & Lin, E. (2012). Emerging energy-efficiency and CO 2 emission-reduction technologies for cement and concrete production : A technical review. *Renewable and Sustainable Energy Reviews*, *16*(8), 6220–6238. https://doi.org/10.1016/j.rser.2012.07.019

[15] Schneider, M. (2015). Cement and Concrete Research Process technology for efficient and sustainable cement production. *Cement and Concrete Research*, *78*, 14–23. https://doi.org/10.1016/j.cemconres.2015.05.014

[16] Hasanbeigi, A., Price, L., Lu, H., & Lan, W. (2010). Analysis of energy-efficiency opportunities for the cement industry in Shandong Province, China : A case study of 16 cement plants. *Energy*, *35*(8), 3461–3473. https://doi.org/10.1016/j.energy.2010.04.046