THE SOUTH AFRICAN CEMENT INDUSTRY:
A REVIEW OF ITS ENERGY EFFICIENCY 
AND 
ENVIROMENTAL PERFORMANCE SINCE 1980.

MPhil: Specializing in Climate Change and Sustainable Development. 
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by

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DECLARATION

Minor dissertation presented for the approval of the Senate in partial fulfillment of the requirements for the MPhil in Climate Change and Sustainable Development in approved courses and a minor dissertation. I hereby declare that I have read and understood the regulations governing the submission on MPhil specializing in Climate Change and Sustainable Development dissertations, including those relating to length and plagiarism, as contained in the rules of this University, and that this minor dissertation conforms to those regulations.

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ABSTRACT
Cement is manufactured to satisfy the demands of the provision of the basic necessities of life. A basic component of concrete, cement has no known substitute and hence will continue to be produced for decades to come. Since approximately 1 tonne of clinker emits nearly 1 tonne of CO\textsubscript{2} during its manufacture, environmental pollution is a major concern for the industry. On estimate, the cement industry, which is energy intensive, contributes between five and eight percent of all CO\textsubscript{2}e (carbon dioxide equivalent), thus making it a vital sector to study. The South African cement industry is one of the major consumers of energy (thermal and electricity) in the country. In 2009 it ranked 9\textsuperscript{th} in the world in terms of CO\textsubscript{2} emissions. With the country relying mainly on fossil fuel (coal) for its energy needs, its cement industry deserves to be reviewed. To this end, this dissertation reviewed the South African cement industry to evaluate its energy use and CO\textsubscript{2} emissions management practices. This is in line with the commitment the South African government made to mitigation and adaptation to climate change and the requirement to develop along a sustainable low carbon path. It is seen that the country’s cement industry could not be effectively ranked with others due to restricted information on energy and emission indicators but it is aware of the negative effects of CO\textsubscript{2} on the environment and as such is evolving timeously to be more energy efficient.

Keywords: Cement, Energy Efficiency, Carbon Dioxide (CO\textsubscript{2}) emissions.
INTRODUCTION

1.1 BACKGROUND

The census data shows South Africa has been increasing in population since 1980 at approximately 2% per annum (Kok and Collinson, 2006). Similarly, the country’s cementitious sales have steadily risen from 7 million tonnes in 1980 to an estimated 11 million tonnes in 2010 (C&CI, 2012). Economists allude to the fact that as population increases, there is bound to be a corresponding rise in demand for the basic necessities of life – with housing as top priority. However, if unchecked, such growth may lead to the unsustainable consumption of scarce natural resources. So to meet structural and infrastructural demands Aïtcin (2008) finds that one of the most important building and construction materials in use is concrete – which has cement as a basic component. This is so because concrete is versatile in use, thus culminating in the justification for production of more cement. The most common cement, Portland cement (PC), is derived from the calcining of clay, sand and limestone (a natural resource), with limestone being its predominant constituent.

The fact that concrete has played, is still playing, and will continue to play major roles in South Africa’s path to meeting its development agenda cannot be over emphasized. Concrete is virtually seen everywhere (Aïtcin, 2008). Though not bearing the same meaning, the terminologies concrete and cement have been used interchangeably by many. As will be further elucidated upon in this dissertation, cement is an essential ingredient in concrete. It possesses many positive features some of which include its ‘bond’ like function and its role in filling the voids between fine and coarse aggregates in concrete, as well as its hydration reaction qualities which enables concrete to gain strength continuously (Owen, 2003). But, by itself, cement is a poor building material mainly due to its high shrinkage properties. Nonetheless, since its use and positive qualities outweigh its negative qualities and since no suitable substitute (with similar or better qualities) has yet been discovered, cement production globally and in South Africa will remain a mainstay of a country’s manufacturing sector for the foreseeable future.
This makes reviewing the South African cement industry’s energy use and environmental performance very important. Additionally, it is warranted to evaluate the South African cement industry’s performance regionally and globally through the lenses of energy efficiency and environmental performance because the industry among others is facing huge pressures in its delivery requirements to the economy and society at large. This is so because cement companies sometimes import cement and/or clinker in order to augment their production rates, still consume large quantities of fossil fuel (coal) to heat up their aging kilns and pre-heaters and, emit a proportionally high amount of CO$_2$ for a single industry.

Hence, this dissertation aims to critically analyze the energy efficiency and environmental performance of the South African cement industry since 1980 with respect to the Portland cement manufacturing process, the energy (thermal and electrical) consumed per tonne of cement produced and the consequent CO$_2$ emissions being a resultant effect of the energy use and limestone de-carbonization in the process. These analyses will fall within the context of the challenges of climate change and sustainable development the industry faces and will be benchmarked against international best practices. Therefore, to do this, the importance of cement will be highlighted in its growing demand and production figures in addition to how critical the material is to meet development objectives. Moreover, the significance of reducing energy use and CO$_2$ emissions during cement manufacture will be discussed.

### 1.2 DISSERTATION OVERVIEW

#### 1.2.1 Rising Cement Demand and Production.

The first Portland cement manufactured in South Africa was in 1892 by De Eerste Zement Fabrieken Beperkt, which became Pretoria Portland Cement, or PPC (PPC, 2010). Since then there has been a steady growth (Akindahunsi, 2011) in the quantity of cement produced in direct relation to the country’s demand (PPC, 2007). Figure 1.1 shows a steady rise in cement production since 1892 while Figure 1.2 depicts a similar rise in demand for cement in South Africa for the same period.
As highlighted in green, a matching link is made for the last three decades (1975 till 2005) showing that in the country, cement is produced to satisfy demand in accordance with the basic economic principle that states; “at market equilibrium, demand equals supply”.

With global rural-urban migration projected to increase by 60% (Pieterse, 2000) such that up to 4.2 billion people are anticipated to be urban dwellers by 2030, South Africa is no different. This trend if applied to the latest census statistics (STATS SA, 2012 cited in Blaine, 2012) shows that by 2030 over 31 million people will be living in the country’s urban centres.

Therefore, with the expected rise in population there is bound to be a corresponding increase in housing and infrastructure demand especially in urban areas which will
culminate in more cement production and importation to meet production deficits if any. For example, as represented in Figure 1.3, the South African Presidential Infrastructure Coordinating Commission (PICC, 2012), illustrated the forecasted growth in the economy based on current infrastructure thus vividly expressing the potential for future investment in infrastructure development. In this Figure, the change in Gross Value Added (GVA\(^1\)) for 2010 and 2020 are shown thus indicating where growth is most likely to occur in the country with increase in forecast growth ranging from white (expected increase ranging from 1 % to 1.5 %) to dark brown (expected increase ranging from 1.5 % -1.8%) as shown in the legend. This depicts the essential role cement plays in development.

Figure 1.3: Projected economic and infrastructure growth in SA (PICC, 2012)

1.2.2 Cement as a Development Imperative.

\(^1\) GVA is a macroeconomic indicator which measures the total value added as a result of a production process – which includes the value of production of the total goods and services made excluding those consumed during production within an area and over a time period (Cadillo, 2012)
Cement is an important ingredient for development because it is a basic component of concrete which is mainly used for construction of structures and infrastructure. South Africa like many other developing countries is grappling with meeting its millennium development goals, most notably in the provision of the basic human needs of its people – shelter. As a leading emerging economy, South Africa’s demand for cement is rising appreciably with a very optimistic forecast cement sales ranging from 18 to 28 million metric tonnes within the next decade (PPC, 2007). Though now, these figures are unrealistic. Figure 1.4 summarises the projection of South Africa’s cement sales as put forward by consulting, financial and cement industry experts. As shown, these cement sale projections were made in 2006, just before the global financial crisis struck, but still it is evident that cement demand continues in an upward trajectory most probably because of its inclination to the housing sector amid rising living standards especially in the developing countries.

![Figure 1.4: Cement sale projections in South Africa (PPC, 2007)](image)

In correlation to the rising standards of living, the housing sector is noted for being the main driver for cement production consuming up to two-thirds of total production.
while the combination of the infrastructure, commercial, institutional and industrial sectors make up the remaining one-third (EARPL, 2012). Consequently, South Africa’s infrastructure backlog has been evaluated at R 3.5 trillion (Abedian, 2012) with low cost housing said to be responsible for the highest demand of cement manufacture (PPC, 2007). This is so because the country has a backlog of about 2.1 million housing units (Sexwale, 2011 cited in Sowetan, 2011).

Table 1.1: Cement demand for major infrastructure projects (PPC, 2007)

<table>
<thead>
<tr>
<th>Investment</th>
<th>Project Value</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
<th>2014</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eskom</td>
<td>€ 10bn</td>
<td>86</td>
<td>115</td>
<td>111</td>
<td>92</td>
<td>83</td>
<td>82</td>
<td>95</td>
<td>86</td>
<td>516</td>
</tr>
<tr>
<td>Transnet</td>
<td>€ 8bn</td>
<td>125</td>
<td>220</td>
<td>195</td>
<td>235</td>
<td>89</td>
<td>84</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gautrain</td>
<td>€ 2.5bn</td>
<td>62</td>
<td>98</td>
<td>94</td>
<td>40</td>
<td>40</td>
<td></td>
<td></td>
<td></td>
<td>300</td>
</tr>
<tr>
<td>2010 FIFA</td>
<td>Est € 2bn</td>
<td>100</td>
<td>113</td>
<td>111</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>325</td>
</tr>
<tr>
<td>SANDRAL</td>
<td>Est € 3bn</td>
<td>78</td>
<td>126</td>
<td>161</td>
<td>147</td>
<td>157</td>
<td>145</td>
<td>152</td>
<td>161</td>
<td>1,126</td>
</tr>
<tr>
<td>Housing</td>
<td>Est € 3bn</td>
<td>726</td>
<td>914</td>
<td>1,081</td>
<td>2,600</td>
<td>2,600</td>
<td>2,600</td>
<td>2,600</td>
<td>2,600</td>
<td>15,974</td>
</tr>
<tr>
<td>ACSA</td>
<td>€ 1.8bn</td>
<td>43</td>
<td>71</td>
<td>64</td>
<td>23</td>
<td>18</td>
<td>18</td>
<td>18</td>
<td></td>
<td>256</td>
</tr>
<tr>
<td>DWAF</td>
<td>Est € 2bn</td>
<td>20</td>
<td>34</td>
<td>42</td>
<td>21</td>
<td>9</td>
<td>2</td>
<td></td>
<td></td>
<td>129</td>
</tr>
</tbody>
</table>

Though Table 1.1 shows only the South African Government’s planned expenditure, the private sector and other investors’ contribution should still be considered i.e. their investments in the country requiring cement. To this end the local industry is spending billions of Rands to meet the projected cement demands. Figure 1.5 reflects the industry’s capacity enhancement plans for this purpose (PPC, 2007). In essence, the sketch given with regard to the rising cement demand and production in addition to the call for sustainable development, clearly expresses why it is now crucial for cement industries to cut energy use from fossil fuels and decrease CO₂ emissions more than ever before.
1.2.3 Reducing Energy Use and CO₂ emissions in cement manufacture.

With all the impending projections in population and economic growth, infrastructure development and the manufacture of cement, the development challenge for South Africa and other developing countries becomes how to develop along a low carbon and sustainable path – as defined in South Africa’s National Climate Change Response White Paper (NCCR, 2011). In this document, the country outlined how it intends developing into the future in a low carbon (decreasing CO₂ emissions) manner by postulating among other strategic priorities, an emissions mitigation trajectory of “peak, plateau and decline” within 2020 and 2050, by 2060 and afterwards respectively (NCCR, 2011). Furthermore, the “low carbon path” development can be summed up as that which consumes less energy from carbon intensive sources and promotes renewable energy use. Similarly, the cement industry in South Africa has to follow suit in order to enable the country meet its voluntary commitments to mitigate emissions of greenhouse gases (GHG) when it ratified the Kyoto Protocol² as set out by the United Nations Framework Convention on Climate Change (UNFCCC) in 1997 (Mqadi, Winkler and Kallhauge 2005).

² It should be noted that according to the Kyoto Protocol (2005), South Africa is classified as a developing country therefore it is not obliged to reduce its GHG emissions.
To this end, given that sustainable development and climate change have swiftly become key challenges for most societies – especially in developing countries, the country’s cement industry has risen to the challenge by continuously improving its processes and its member companies are now being lauded for their environmental and social successes. For instance, as far back as 1999 Lafarge, Cimpor and Holcim (three of the major global cement manufacturers with major stakes in the South African cement industry), met with the WBCSD for a 20 year appraisal structuring the concerns around sustainable development that the cement industry faces worldwide (WBCSD, 2002). This meeting which is proving socially and environmentally successful so far, catalysed the global cement industry into carrying out its operations with due diligence, hinged on climate change and sustainable development. But one may argue that the meeting arose because the companies recognized the fact that to sustain their operations for the long term and reap the fruits of the economic opportunities that the challenges may present, they had to mainstream these issues with their business strategies. Whichever way the argument goes, the threat of anthropogenic emissions exacerbating global warming and thus instigating climate change remains one not to be discounted.

According to Winkler and Marquard (2009), South Africa has since antiquity been one of the most energy intensive countries in the world. This coupled with the apartheid legacy has resulted in the country facing numerous development challenges (Scott, 2003). In summary, this dissertation contextualises the challenge of the South African cement industry – in accordance with Winkler and Marquard – as that which aims to achieve the country’s development objectives in alignment with its climate change perspectives.
1.3 RESEARCH OVERVIEW

1.3.1 Problem Statement

This dissertation defines the research problem from two perspectives namely;

- South Africa, among the top 20 global CO₂ emitters,
- South Africa being highly dependent (up to 98 %) on fossil fuel energy.

1.3.1.1 South Africa: A main contributor of CO₂ emissions.

According to Worrell, et al., (2001) and WWF, (2008), the global cement industry contributes between five and eight percent of all anthropogenic CO₂ emissions. For South Africa, Mwakasonda (2012) showed that the country contributed about 1.44 % carbon dioxide equivalent globally (CO₂eq³), while contributing as much as 40 % to 60 % of the entire CO₂eq emissions from Sub Saharan in 2009. With its local economy driven by coal, South Africa’s CO₂ emissions from fossil fuel combustion has multiplied almost seven times since 1950 with up to 93 % of emissions from coal alone (Boden et al., 2011).

In brief, when compared to world economies, South Africa is ranked the 9th largest emitting country accounting for 1.44 % of the world’s annual CO₂eq emissions; China (18.89 %) 1st, USA (12.48 %) 2nd, India (4.44 %) 3rd and Australia (1.33 %) 10th based on 2009 emissions data and the largest emitting country on the continent of Africa as depicted in Table 1.2.

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³ CO₂eq can be defined as the measure of various greenhouse gases in terms of their global warming potentials in comparison to carbon dioxide. It should be noted that the CO₂eq of carbon dioxide is ‘1’ (OECD, 2001).
Table 1.2: Top 20 global greenhouse gas emitting countries (Mwakasonda, 2012)

<table>
<thead>
<tr>
<th>Rank</th>
<th>Country</th>
<th>2009 CO₂e Gt</th>
<th>% Global Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>China</td>
<td>8.50</td>
<td>18.89</td>
</tr>
<tr>
<td>2</td>
<td>United States</td>
<td>5.60</td>
<td>12.48</td>
</tr>
<tr>
<td>3</td>
<td>India</td>
<td>2.00</td>
<td>4.44</td>
</tr>
<tr>
<td>4</td>
<td>Russian Federation</td>
<td>1.50</td>
<td>3.28</td>
</tr>
<tr>
<td>5</td>
<td>Japan</td>
<td>1.10</td>
<td>2.53</td>
</tr>
<tr>
<td>6</td>
<td>Brazil</td>
<td>1.01</td>
<td>2.23</td>
</tr>
<tr>
<td>7</td>
<td>Germany</td>
<td>0.94</td>
<td>2.08</td>
</tr>
<tr>
<td>8</td>
<td>Canada</td>
<td>0.68</td>
<td>1.51</td>
</tr>
<tr>
<td>9</td>
<td>South Africa</td>
<td>0.65</td>
<td>1.44</td>
</tr>
<tr>
<td>10</td>
<td>Australia</td>
<td>0.60</td>
<td>1.33</td>
</tr>
<tr>
<td>11</td>
<td>United Kingdom</td>
<td>0.57</td>
<td>1.26</td>
</tr>
<tr>
<td>12</td>
<td>France</td>
<td>0.46</td>
<td>1.02</td>
</tr>
<tr>
<td>13</td>
<td>Italy</td>
<td>0.40</td>
<td>0.88</td>
</tr>
<tr>
<td>14</td>
<td>Ukraine</td>
<td>0.36</td>
<td>0.79</td>
</tr>
<tr>
<td>15</td>
<td>Poland</td>
<td>0.35</td>
<td>0.77</td>
</tr>
<tr>
<td>16</td>
<td>Spain</td>
<td>0.34</td>
<td>0.76</td>
</tr>
<tr>
<td>17</td>
<td>Turkey</td>
<td>0.29</td>
<td>0.64</td>
</tr>
<tr>
<td>18</td>
<td>Netherlands</td>
<td>0.20</td>
<td>0.45</td>
</tr>
<tr>
<td>19</td>
<td>Czech Republic</td>
<td>0.13</td>
<td>0.28</td>
</tr>
<tr>
<td>20</td>
<td>Belgium</td>
<td>0.12</td>
<td>0.27</td>
</tr>
</tbody>
</table>
1.3.1.2 *South Africa: A major consumer of energy from fossil fuels.*

Due to the physical abundance of the main raw materials, its requirement as a construction material and its relative affordability (Worrell et al., 2001), cement is effectively produced globally. Producing cement involves the emission of CO\textsubscript{2} through fossil fuel combustion (coal burning predominantly), and also through the decarbonation of limestone. According to the World Energy Council (1995), cement production is a highly energy-intensive production type and global cement industries consume an estimate of about 2% of the global primary energy consumption, or approximately 5% of the total global industrial energy consumption. Mainly using coal – a carbon intensive fuel – in the manufacture of clinker, South Africa is heavily dependent on burning of fossil fuels to meet its energy needs (Winkler and Marquard 2009). Therefore, the cement industry in South Africa can be seen as a major consumer of energy from fossil fuels.

In addition to the emission output from fossil fuel combustion which can be environmentally unsafe, Klee (2002) put forward that the other sustainability concerns are noise, dust, other pollutant emissions (NO\textsubscript{x}, SO\textsubscript{x} etc.) and major land disturbance e.g. during blasting and quarrying. However, as the 76\textsuperscript{th} country to ratify the Kyoto protocol, South Africa is steadfast in its efforts to meet its commitment to GHG reduction evident in the country’s ‘peak, plateau, decline’ approach as stipulated in the 2009 government’s climate change response strategy even though it is not mandated to do so (NCCR, 2011).

Therefore, this dissertation expresses the problem statement as: *How does a carbon intensive economy like South Africa develop along a low carbon path?* This illustrates why it is worthwhile to review the energy efficiency and environmental performance of the South African cement industry (Cahn, et al., 1997; Canada Portland Cement Association, 1997 and Cembureau, 1998).
1.3.2 Research Rationale

The justification for this research is founded on the following:

- The projected growth of cement manufacture globally,
- The corresponding anticipated increase in cement related emissions under the “Business As Usual” scenario.

1.3.2.1 Global Projected Cement Growth

The global production of cement in 2050 is projected to grow to 5.5 Gt worldwide (WWF, 2008) i.e. a level roughly six times higher than its level in 1980 (USGS, 2010). With China and India leading the way, Figure 1.6 shows the world’s anticipated production figures till 2050.

As at 2008 – the time of the WWF report, world cement production was estimated at 2.8 Gt (USGS, 2009) but increased to 3.2 Gt in 2011 (USGS, 2012). Projections in cement growth have been linked with projections in population growth. But for the cement industry to balance the expected rises it needs to do so in a manner that facilitates lowering CO₂ emissions from its processes. The next subsection will define this path as the “mitigation path”.

Figure 1.6: Projected cement production in industrialized & developing countries (WWF, 2008)
1.3.2.2 *Global forecast emissions: Cement sector vs Mitigation path*

Figure 1.7, adapted from WWF, (2008) points out the projected global cement emissions set against the estimated and targeted mitigation path. In the figure, the blue curve shows rising CO₂ levels anticipated to continue its steady rise, peaking at around 2025 and declining till about 2050. This path of peak, plateau and decline is to be achieved by implementing stringent measures aimed at curbing CO₂ emissions. Various countries including South Africa have commenced developing such mitigation measures. Similarly, the yellow curve shows the worldwide emissions from the cement sector alone given a situation whereby the industry continues its manufacturing business without further curtailing fossil fuel driven energy consumption or improving on the already existing environmentally safe measures.

This state of affairs has been termed the “Business As Usual (BAU)” scenario (NCCR, 2011; Winkler and Marquard, 2009). Under this scenario and as shown in the figure, the comparative CO₂ emission change from 1990 to 2050 is said to be a fourfold increase in CO₂ emissions from cement production. But it should be noted that the global emission reduction intention has been set at a 50 % reduction. Therefore, cement industries including that in South Africa are expected to produce cement in alignment with the government’s climate change response and sustainable development agenda.

![Figure 1.7: Cement emissions forecast vs Mitigation path (WWF, 2008)](image)
In short, the projection of cement manufacture, CO₂ emissions forecast for the same period and the uncertainties surrounding the impacts of global warming and climate change are some of the factors serving as the rationalization for this research. Also they are the issues which were considered by the cement industry worldwide to consent to the call for the implementation of GHG mitigation efforts. Indeed, to its credit, the global industry has to a great extent evolved in this direction with the industry in South Africa following suit.

1.4 RESEARCH QUESTION

This dissertation seeks to analyse the South African cement industry’s energy efficiency and environmental performance by answering the question:

*How does the South African cement industry compare to others in terms of its energy use and CO₂ emissions in cement manufacturing?*

But in doing so, the following sub questions need to be answered:

1. What is the status quo of the South African cement industry?
   a. What is Portland cement, its components and properties?
   b. How did the industry come to be and who are the major players?
   c. Where does the country’s cement industry generally rank on a global scale?
   d. What is the country and industry’s perception of climate change and sustainable development?

2. How does the South African cement industry manage energy efficiency and CO₂ emissions during cement production?
   a. What is Energy Efficiency?
   b. How does the industry use and manage Energy (Thermal and Electrical) as well as CO₂ emissions?
   c. What technology is used in the industry and how does it affect energy use and CO₂ emissions?
1.5 RESEARCH AIMS AND OBJECTIVES

1.5.1 Broad Aim
In answering the research question, the broad aim of this dissertation is to form a 30 year review indicating energy use and carbon dioxide (CO₂) emissions management of the South African cement industry.

1.5.2 Objectives
Given the rationale behind the research and the broad aim, the goal of this study is to answer the research question within the following contexts:

- Determine how the South African cement industry compares to others.
- Evaluate the level of energy efficiency practised in the country’s cement industry
- Establish how the industry compares to others in terms of CO₂ emissions per ton of cement produced.

To attain these objectives, the following steps will be followed:

- Extract relevant data/information from the websites and publications of the four major cement manufacturers in South Africa, the Cement and Concrete Institute of South Africa (C&CI) and the Association of Cementitious Material Producers of South Africa (ACMP).
- Extract pertinent data/information from journals, articles, periodicals and so on of some of the other major cement producing countries in the world.
- Analyse and synthesise the extracted data/information to ascertain gaps (if any) before determining the country’s status quo measured against others.

1.6 RESEARCH SCOPE AND LIMITATION
The research will have its boundaries set within the cement manufacture process flow as shown in Figure 1.8 which will exclude packaging and shipping as highlighted. And the limitation of this dissertation is described in the lack of information and data specific to energy use and cement production emissions from the four main companies in the country.

Moreover, this research does not include the following:

- Cement production years before 1980 and after 2010.
- Sources of energy other than coal and electricity.
- Sources of CO\(_2\) emissions other than from coal combustion, purchased electricity and the calcining process. Therefore, sources of emissions like transporting of finished cement and so on will not be considered.
- Other cementitious materials including white and masonry cement because these special cements make up just one percent of the world’s cement production.
- Environmental pollutants other than CO\(_2\). Hence, SO\(_2\), NO\(_x\), and dust will be briefly discussed but not analyzed in-depth.
1.7 DISSERTATION LAYOUT

The research focuses on three main themes namely; the South African cement industry, energy efficiency and environmental performance with respect to CO₂ as a GHG emission. Therefore, the organization of the report will be such that:

- Chapter 1 delivers the *introduction* and *background* to the dissertation.
- Chapter 2 discusses the *literature review* which comprises data and information from various literature, books, journals, articles, electronic sources and so on. This chapter is split into two sections to properly account for the two themes of this dissertation.
- *The method* employed and the research *limitations* are detailed in Chapter 3.
- Chapter 4 contains the *findings* and *analysis*.
- As a denouement, Chapter 5 will present the *conclusion* and *recommendations*.

2.0 LITERATURE REVIEW
This section comprises of a collation of various analysed local and international works applicable to the topic. As mentioned in the layout of the study, the review of literature will be separately discussed under two sections i.e. the country’s cement industry, its energy efficiency and CO₂ emissions. This will be done specifically to allow for a clear definition of each component and to demonstrate their symbiosis in answering the research question. The structure is as illustrated in Figure 2.1:

![Figure 2.1: Structure of Literature Review](image)

### 2.1 THE SOUTH AFRICAN CEMENT INDUSTRY

The historical evolution, main actors, strengths and weaknesses of the country’s cement industry will be probed in an overall local, regional and global context so as to showcase where it currently is in terms of energy efficiency and environmental performance. Then Portland cement will be deciphered by describing its components and properties while summarising its manufacturing process as well as briefly touching on some supplementary cementitious materials (SCMs). Finally, these discussions will terminate in how the industry and the country as a whole perceive climate change and sustainable development.
Cement has been used in construction ever since civilization started to build. Buckley (2001) finds that the Assyrians and Babylonians put up structures with a clayey material. Moreover, as far back as 12,000 BC it was recorded that naturally occurring cement complexes were formed in Israel as a result of unprompted combustion of shale and limestone (Auburn University, 2012). In addition to combining mud and straw to hold dried brick together and utilizing cemnetitious materials to stick bamboo in their boats, it was recorded that in 3,000 BC binding agents such as gypsum and lime were further discovered and mixed with this building materials, and then used in constructions such as the great pyramids built by the Egyptians (Buckley, 2001; Auburn University, 2012). The Greeks furthered the discoveries and applications made by the Egyptians before the Romans eventually developed a binder that was used for constructions of high resilience – such as the great Roman baths (27 BC), the Coliseun and the Constantine Basilica (Buckley, 2001). To achieve these, they made use of slaked lime (a volcanic ash called “Pozzuolana”, derived from the eruptions of Mount Vesuvius near Naples, Italy) as a cementitious material. Similarly, Buckley (2001) found that work done by Pliny and Vitruvius (AD 79) suggested that the cementitious mortar used historically comprised of 20 % lime and 80 % sand or 33 % lime and 66 % pozzolana.

2.3 HISTORY OF PORTLAND CEMENT IN SOUTH AFRICA

From 1892 when the first Portland cement was produced (PPC, 2011; C&CI, 2012) till 2010, almost 419 million tonnes of cementitious materials have been sold with 65 % of this figure recorded for sales between 1980 and 2010 (C&CI, 2012). Using these figures, a calculated average of nearly 14 million tonnes per annum for the last 30 years can be deduced, thus representing a high figure for just one country. Figure 2.2 (C&CI, 2012) shows the regional cementitious sales profile since 1892 with the lowest cementitious materials’ sales figure recorded as 1,360 tonnes for the year 1892 and the highest sales figure recorded as over 15.3 million metric tonnes for the year 2007.

Given the timing, the high figure recorded in 2007 can be linked mainly to the construction of stadiums for the 2010 soccer world cup, the Gautrain Rapid Rail Link project and Eskom’s Kusile and Medupi power station projects. This therefore shows
the importance of the cement sector to South Africa and for return on investments as well.

Still, the history of Portland cement manufacture and sales in South Africa has been impaired by claims of a century old collusion, price fixing and “cartel” like modus operandi which were said to be pervasive from the 20th century until the early part of the 21st century (IOL, 2012). Accordingly, Fourie and Smith, (1994) with Walker, (2006), acknowledged this when they suggested that before 1996, the cement industry in South Africa functioned formally within a recognized cartel.

As a result, the present state of the industry may arguably be attributed to the fine of nearly R 275 million imposed by the South African Competition Commission on two of the four major cement producers in the country – Larfarge SA and AfriSam – for historical collusion relating to market sharing and price fixing. However, for the other two, PPC was exempted given its cooperation and information disclosure while NPC-Cimpor has till date not reached an agreement (IOL, 2012).

Nonetheless, the regulation of cement has since 1999 become the task of the South African National Standard (SANS) – through a mandatory requirement; to do away with cement products without the ‘SANS’ seal of approval (Mining Weekly, 2006).
These in any case highlight the importance of manufacturing cement both for development and as a contribution to GDP.

2.3.1 History of Portland cement in South Africa: The Four Main Actors

This dissertation focuses on the four major companies that produce and sell cement in South Africa namely; Pretoria Portland Cement (PPC), Lafarge, AfriSam and Natal Portland cement – CIMPOR.

2.3.1.1 Pretoria Portland Cement (PPC)

PPC is the first cement company established in South Africa and it has been in existence since 1892. According to PPC (2011), the set up of the company was born out of the need to find a cheaper solution to the costly cement import costs from Europe experienced in the late 19th century. With eight cement production factories and three milling depots in the South African region, PPC has the capability to produce 8 million tonnes of cement annually; thus making it the foremost supplier of cement in the region – comprising of South Africa, Botswana and Zimbabwe (PPC, 2011).

Drawing up a timeline for PPC it is seen that after operations began in 1892, the company started producing Lime in the then Northern Transvaal in 1907. After 18 years of cement and lime manufacture, PPC got listed on the Johannesburg Stock Exchange (JSE) in 1910. The success of this listing and the production operations in addition to the local market demands encouraged PPC to build a new Slurry factory in the North West province of South Africa which started manufacturing cement in 1916. From 1921 till 1998 the company grew and expanded its operations around the country and its environs by opening facilities in De Hoek (1921), Port Elizabeth (1927), Germiston (1937), Orkney (1949), Riebeek (1960), Gaborone, Botswana (1994) and in Dwaalboom (1998).

Furthermore, in 1958, PPC converted from the wet slurry process of cement manufacture to the dry mix process of cement manufacture which increased their production efficiency and cost effectiveness (PPC, 2011). Listed among the top 40
companies on the JSE and included in Financial Times and Stock Exchange (FTSE) index in 2003, PPC gained independence from Barloworld in 2007.

2.3.1.2 Lafarge
Lafarge has its origins traced to an English company called White’s South African Cement Company, established in England in 1913. Trading as Blue Circle in the United Kingdom had since 1914 been offering the South African construction industry services and novel products. That same year, it commenced cement works at Hennenman in the then Orange Free State – historically heralding what is now called the Free State province (Lafarge, 2010). Furthermore, as previously shown, growth in industrialization most often times lead to increase in cement demand. This analogy encouraged Blue Circle South Africa to expand its cement works and according to Lafarge (2010), the Lichtenburg facility (based in the North West province) was born in 1948. Half a century after the inception of the Lichtenburg plant, Lafarge bought over Blue Cicle South Africa, renamed and rebranded it to suit the BEE requirements of the South African government. Hence, Lafarge Industries South Africa (Pty) Limited was created in 1998. Functioning through four business units; Lafarge Concrete, Aggregate, Gypsum and Cement, the company employs 2 740 staff and is capable of manufacturing 3 million tonnes of cement annually (Lafarge, 2010).

2.3.1.3 AfriSam
In 1934, Anglo Alpha cement Limited was formed in South Africa. After operating for over six decades the company changed its name to Alpha (Pty) Limited and shuffled its management hierarchy in 1996 in order to support the Black Economic Empowerments’ (BEE) legislative policy enacted in 1994. Trading for a further 13 years, Holcim, South Africa (the parent company of Alpha (Pty) Limited) formed AfriSam in 2007 (Holcim, 2013). With operations locally, in Lesotho, Swaziland and Botswana, AfriSam has more than 2 000 staff and employs up to 1 000 contractors.

The company has six manufacturing facilities, nine cement depots, 16 yearly quarry and aggregate operations all of which combine to enable the company have almost 4.6
million tonnes of cement production capacity on an annual basis. For half a century, AfriSam has been producing Slagment from its Vanderbijlpark operations thus making it the leading provider of Slag as a cement extender in South Africa. The company reportedly has the capacity to produce 800 000 tonnes of slag cement and 200 000 tonnes of blended cementitious materials per annum (AfriSam, 2010).

2.3.1.4 NPC - Cimpor

NPC-Cimpor’s roots can be traced back to 1964 when Durban Cement Limited began operations in Bellair, in the KwaZulu Natal (KZN) province of South Africa. Two decades later, the company transformed into Natal Portland Cement (NPC) in 1984 mainly due to its operations and expansions situated only in the Natal region of Newcastle, Port Shepstone and Durban. Until 2002 when CIMPOR (Cimentos de Portugal) took over NPC completely, it was run by Alpha PPC and Lafarge (NPC, 2010). NPC-Cimpor ran for five years before being formed in full by incorporating a 26 % BEE shareholding partnership to comply with South Africa’s empowerment policy drive. Inclined to plugging the gap in cement shortage, NPC-Cimpor’s appetite for expansion and efficiency saw the installation of South Africa’s latest kiln at its Simuma facility (it is worth mentioning that the last kiln installed in the country prior to this was over two decades old). The foremost cement producing company in KZN, NPC-Cimpor possesses the capacity to manufacture 1.5 million tonnes of cement on an annual basis and it employs over 500 permanent staff, 45 temporary staff and 30 interns (NPC, 2013).

Apart from these companies, the latest news from the industry suggests that another company, Sephaku cement, is due to commence operations in December of 2013 and its capacity has been projected to be 1.2 million tonnes of cement per year. Figure 3.2 shows the locations and total capacity estimates of the four main cement producing companies in the country.

Adapted from (PPC, 2007), the capacity estimates have been updated making use of the latest information and data as currently reported by the companies themselves.
In brief, the four major cement producers have been discussed and put into perspective in terms of their historical development and involvement in the South African cement industry. For the purpose of this dissertation, the next section will explore what the material “cement” consists of, other cementitious materials and how cement is produced.

2.4 PORTLAND CEMENT (PC).

Cement is generally described as “glue”, binder or a binding material (Alexander and Mindess, 2005; Grieve, 2009). Aïtcin and Mindess (2011), extends this definition by referring to cement as “binder” which according to them are fine materials used in to form concrete when hydrated. This so as to shorten, clarify and unlimit the ACI 116 definition of cement because it contains 46 various definitions having “cement” and “Portland cement” as entries.

Portland cement is a result of a chemical mixture including calcium, silicon, aluminium, iron and other compounds. During its manufacture a regulated quantity of gypsum is

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4 Refer to external link: [http://www.prof-ce1.com/books/civil/116r_00.PDF](http://www.prof-ce1.com/books/civil/116r_00.PDF) for the ACI 116 definitions of cement
added to aid in retarding the setting time of concrete (Rinker, 2010). After water, concrete comprising of Portland cement is the material for construction that is mostly used in the world. But on its own, Alexander and Mindess (2005) conclude that it is not appropriate for almost any purpose; with the exception of some unique applications.

Also they alluded to the fact that PC is less frequently manufactured as a single blend product but nowadays combined with other materials to form blended cements. In addition, Aïtcin and Mindess (2011), suggest that in a concrete mix, the PC phase is believed to be the basis on which binding occurs irrespective of the presence of other materials in the mix such as cement extenders or supplementary cementitious materials.

The terminology known as Portland cement was derived by Joseph Aspdin in 1824 who obtained a patent for his cement mixture. He used the term “Portland” because the grey color of his final mix looked like the naturally occurring limestone mined from the Isle of Portland along the English channel (Buckley, 1996-2001; Aitcin, 2011). Various kinds of PC are produced to satisfy different needs and adapt to diverse environments. The South African National Standards (SANS) 50197-1 lists the five different types of cements; product notations and composition (Refer to appendix A)

2.4.1 Portland cement and Supplementary Cementitious Materials: Composition, Types and Properties.

2.4.1.1 Composition of Portland cement.

By composition, PC is known to be made up of Portland clinker, iron, silica, aluminium and most importantly oxides of lime (Alexander, 1998; Grieve, 2009). Table 3.1 shows the percentage by mass composition of PC clinker and its corresponding oxide. According to (Grieve, 2009), since Silica, Alumina and ferric oxide are found in nature, suffice to note that it is easier for cement producers to secure them from shale or clay.

<table>
<thead>
<tr>
<th>Oxide</th>
<th>% by mass in cement</th>
</tr>
</thead>
</table>

Table 2.1: Portland cement clinker: Composition (Grieve, 2009; Alexander and Beushausen, 2010)
2.4.1.2 Types of Portland cement.

According to SANS 50197-1 (Refer to appendix A), there are five basic types of Portland cement commonly known as “Common cements” (C&CI, 2009). These are CEM I, II, III, IV and V.  Alexander (1998) and Rinker (2010) summarized the cement classes as follows;

CEM I:
This type of cement is for general use. Basically, it is used where there is no anticipated attack on the concrete structure e.g. pavements, reinforced concrete buildings.

CEM II:
This kind of cement is used where there is anticipated moderate sulphate attack on the cement or concrete structure. Its selection for use is also hinged on the fact that its rate of hydration is less than the CEM I type and thus can be used for massive structures and in warm weather.

CEM III:
This class of cement represents that which is used when high early strength is required of the concrete structure. It attains high strength more quickly than the CEM I type and hence can be used in cold weather.

CEM IV:
This sort of cement refers to cement types which exhibit low heat of hydration. Their rate of strength development is slower than CEM I. Therefore, they can be used for massive concrete structures e.g. gravity dams.

CEM V:
This range characterizes high sulphate resisting cements used in concrete structures where extreme sulphate attack is anticipated.

![Clinker estimates for cement types](image)

**Figure 2.4: Clinker estimates for cement types (Worrell, et al., 2001)**

### 2.4.1.3 Supplementary Cementitious Materials (SCMs) other than PC

Alexander and Beushausen (2010) stated that these are “latent hydraulic binders”. Meaning that, they get hard when hydrated at a low rate that makes them not suitable for use in engineering. Therefore, due to their low rate of hydration, they require accelerants to expedite their rate of reactions - the most common of which is Calcium Chloride. But because of its steel corrosion and shrinkage effects triethanolamine among others is preferred (Alexander and Beushausen, 2010). It should however be noted that “Slag” is neither a hydraulic binder nor pozzolanic material (Moranville-Regourd, 1998) because just like hydraulic binders slag comprises the same basic oxides but in differing proportions.

As a result, it is devoid of enough calcium to form calcium silicates because their CaO/SiO$_2$ ratios around 2.8. Calcium, Silica, Aluminium and Iron are their basic
components (Alexander and Beushausen, 2010). This dissertation discusses the most common SCMs; Ground Granulated Blast furnace Slag, Fly Ash and Consolidated Silica Fume. Figure 3.3 illustrates the chemical composition of the principal cementitious materials while Table 3.2 provides the properties of each class of the SCMs to be discussed.

![Figure 2.5: Cementitious materials; Chemical composition (Aïtcin, 2008)](image)

Table 2.2: Comparison of chemical and physical properties of PC, FA, GGBS and SF (SFA, 2005)

<table>
<thead>
<tr>
<th>PROPERTY</th>
<th>PORTLAND CEMENT</th>
<th>CLASS F FLY ASH</th>
<th>CLASS C FLY ASH</th>
<th>SLAG CEMENT</th>
<th>SILICA FUME</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂ content, %</td>
<td>21</td>
<td>52</td>
<td>35</td>
<td>35</td>
<td>85 to 97</td>
</tr>
<tr>
<td>Al₂O₃ content, %</td>
<td>5</td>
<td>23</td>
<td>18</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>Fe₂O₃ content, %</td>
<td>3</td>
<td>11</td>
<td>6</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>CaO content, %</td>
<td>62</td>
<td>5</td>
<td>21</td>
<td>40</td>
<td>&lt; 1</td>
</tr>
<tr>
<td>Fineness as surface area, m²/kg (Note 2)</td>
<td>370</td>
<td>420</td>
<td>420</td>
<td>400</td>
<td>15,000 to 30,000</td>
</tr>
<tr>
<td>Specific gravity</td>
<td>3.15</td>
<td>2.38</td>
<td>2.65</td>
<td>2.94</td>
<td>2.22</td>
</tr>
<tr>
<td>General use in concrete</td>
<td>Primary binder</td>
<td>Cement replacement</td>
<td>Cement replacement</td>
<td>Cement replacement</td>
<td>Property enhancer</td>
</tr>
</tbody>
</table>

Note 2. Surface area measurements for silica fume by nitrogen adsorption method. Others by air permeability method (Blake).

### 2.4.1.4 Ground Granulated Blast furnace Slag
GGBS for short, its first use dates back to 1868 as a result of work done by E. Langen in Germany (Papadakis, 1966). According to Mindess et al. (2011), it is a non-metallic product consisting mainly of silicates and aluminosilicates of calcium and other bases, collected at the bottom of the blast furnace as impurities during the production of pig iron. It can either be quenched in water or air.

Aïtcin (2008) states that, Portland cement is a good catalyst for slag activation because it contains lime, calcium sulphate and alkalis. In the Western Cape, South Africa, Corex slag or GGCS as it is popularly known is the most common (Alexander and Beushausen, 2010). Due to the non-detrimental dolomitic limestone used for fluxing, the magnesia (MgO) content in GGBS found in the country is higher than that in other countries (Grieve, 2009). The chemical reaction can be illustrated as:

\[ 3(\text{C}+\text{S}) + 3\text{H} \rightarrow \text{C}_3\text{S}_2\text{H}_3 + \text{S} \]  
\[ (a \times \text{S}) + (b \times \text{CH}) + \text{Other} \rightarrow \text{C}_3\text{S}_2\text{H}_3 + \text{CA products} \]  

In reaction (1), \((\text{C}+\text{S})\) denotes GGBS. In reaction (2), \(a\) and \(b\) are numbers with values required for equilibrium; \(\text{S}\) is derived from reaction (1); \(\text{CH}\) is derived from the hydration of Portland cement (Grieve, 2009).

<table>
<thead>
<tr>
<th>Oxide</th>
<th>% by mass in cement</th>
</tr>
</thead>
</table>

Figure 2.6: General schematic of blast furnace operation and slag production (FHWA, 2012)
2.4.1.5 *Fly Ash (FA)*

FA can be retrieved from the dedusting systems in coal or lignite fired power plants. The composition or chemistry of FA is not consistent because in its parent material, it contains impurities which are not similar in nature. It is termed as such to cover the variety of fine pozzolanic powdered particles similar in size to Portland cement but containing varying proportions of vitreous particles (SFA, 2005). Aïticin (2008) confirmed that the carbon content of FA is very important because of its varying adsorbent capabilities. However, work done by SFA (2005) shows that not all FA has cementitious properties hence its categorization as Class C and F fly ash. Refer to Table 3.4 for the chemical composition of South African FA.

*Class C fly ash* is that with the combined values of SiO$_2$, Al$_2$O$_3$ and Fe$_2$O$_3$ less than 70 % and the CaO content greater than 10 %. This type of FA is normally produced from lignite or sub-bituminous coal. It possesses both pozzolanic and cementitious properties (SFA, 2005)

<table>
<thead>
<tr>
<th>Element</th>
<th>Composition (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO$_2$</td>
<td>34 - 40</td>
</tr>
<tr>
<td>CaO</td>
<td>32 - 37</td>
</tr>
<tr>
<td>Al$_2$O$_3$</td>
<td>11 - 16</td>
</tr>
<tr>
<td>MgO</td>
<td>10 - 13</td>
</tr>
<tr>
<td>FeO</td>
<td>0.3 - 0.6</td>
</tr>
<tr>
<td>MnO</td>
<td>0.7 - 1.2</td>
</tr>
<tr>
<td>K$_2$O</td>
<td>0.8 - 1.3</td>
</tr>
<tr>
<td>S</td>
<td>1.0 - 1.7</td>
</tr>
<tr>
<td>TiO$_2$</td>
<td>0.7 – 1.4</td>
</tr>
</tbody>
</table>
Class F fly ash has a combined value of SiO₂, Al₂O₃ and Fe₂O₃ greater than 70 %. It is normally produced from anthracite or bituminous coal. This type of FA has pozzolanic properties (SFA, 2005). South Africa only has Type F fly ash.

Figure 2.7: Production of fly ash in a dry-bottom utility boiler with electrostatic precipitator (FHWA, 2012)

A simplified reaction for FA can be illustrated as:

2S + 3CH → C₃S₂H₃ ................................. (3)

Note: CH is derived from the hydration of Portland cement (Grieve, 2009).

Table 2.4: Chemical composition of South African FA (Grieve, 2009)

<table>
<thead>
<tr>
<th>Oxide</th>
<th>% by mass (FA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>48 - 55</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>28 - 34</td>
</tr>
<tr>
<td>CaO</td>
<td>4 - 7</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>2 - 4</td>
</tr>
<tr>
<td>MgO</td>
<td>1 – 2</td>
</tr>
<tr>
<td>Na₂O + 0,658 K₂O</td>
<td>1 – 2</td>
</tr>
</tbody>
</table>

2.4.1.5 Consolidated Silica Fume (CSF)
According to Aïtcin (2008), SF is the by-product of the fabrication of silicon metal, ferrosilicon alloys or occasionally zirconium. He reports that, according to Fidjestøl and Lewis (1998), silica fume is a hundred times finer than Portland cement particles. They are very reactive fine pozzolans, possessing also filler effects (Bentur, 2002; Kosmatka and Wlsion, 2011). Bentur further stated that adding SF into concrete reduces the bleeding effect and alters the microstructure of the hydrated cement paste which looks amorphous. This according to Regourd (1983), makes the transition zone (ITZ) around the coarse aggregates more compact in comparison Portland cement.

![Figure 2.8: Schematic of Silica Fume production (SFA, 2005)](image)

<table>
<thead>
<tr>
<th>Oxide</th>
<th>% by mass (CSF)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>92 - 96</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>1,0 - 1,5</td>
</tr>
<tr>
<td>CaO</td>
<td>0,3 - 0,6</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>1,0 - 1,6</td>
</tr>
<tr>
<td>MgO</td>
<td>0,6 - 0,8</td>
</tr>
<tr>
<td>K₂O</td>
<td>1,2 - 2,0</td>
</tr>
<tr>
<td>H₂O</td>
<td>0,4 - 0,8</td>
</tr>
</tbody>
</table>

2.4.1.6 Natural Pozzolans
Natural pozzolans have been used for centuries. As previously mentioned, the term “pozzolan” comes from a volcanic ash mined at Pozzuoli, a village near Naples, Italy, following the 79 AD eruption of Mount Vesuvius. However, the use of volcanic ash and calcined clay dates back to 2000 BC and earlier in other cultures (Buckley, 1996-2001). In addition to controlling heat rise, natural pozzolans were used to improve resistance to sulphate attack and were among the first materials to be found to mitigate alkali-silica reaction. The most common natural pozzolans used today are processed materials, which are heat treated in a kiln and then ground to a fine powder they include calcined clay/shale, and metakaolin (Kosmatka and Wilson, 2011).

2.4.1.7 Calcined clays/shales

Their use dates back to the Phoenician times (Buckley, 1996-2001; Auburn University, 2012). Calcination of up to 750°C sees clays or shales dehydrate and loose its crystalline structure. It should be noted that the addition of these materials to concrete increases its water demand. A typical example is Metakaolin (2 SiO₂ • Al₂O₃) which is produced as a result of the calcination of kaolin 2 SiO₂ • Al₂O₃ • 2H₂O (Aïtcin, 2008)

Table 2.6: Chemical composition of some natural pozzolans and calcined clays (Papadakis and Venuat, 1968)

<table>
<thead>
<tr>
<th>Oxides</th>
<th>Pozzolans</th>
<th>Trass</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Italy Latium</td>
<td>Greece Santorini</td>
</tr>
<tr>
<td>SiO₂</td>
<td>48 65</td>
<td>47 55 62 84</td>
</tr>
<tr>
<td>Al₂O₃ + TiO₂</td>
<td>22 13</td>
<td>20 16 12 8 18 22</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>9 6</td>
<td>3 4 2 3 9 3</td>
</tr>
<tr>
<td>CaO</td>
<td>7 3</td>
<td>4 3 6 2 3 2</td>
</tr>
<tr>
<td>MgO</td>
<td>3 2</td>
<td>0.5 1 1 4 0.5</td>
</tr>
<tr>
<td>Na₂O + K₂O</td>
<td>5 6.5</td>
<td>9 9 3 – 4 11</td>
</tr>
<tr>
<td>SO₃</td>
<td>0.5 0.5</td>
<td>– – 0.7 1 –</td>
</tr>
<tr>
<td>LOI</td>
<td>5 4</td>
<td>16 10 14 0.8 2 6</td>
</tr>
</tbody>
</table>

2.4.1.8 Rise Husk ash
The protective pod of rice which is silicious in composition when calcined up to a temperature of 750°C brings out its vitreous silica nature in the ashes. This ash form possesses very good pozzolanic properties but again when mixed with fresh concrete, it tends to increase the water demand of the mix (Malhotra and Mehta, 1996).

As a result of the rate of energy consumption (from coal: a fossil fuel) and CO$_2$ emissions experienced per ton of cement produced, the industry has been working very hard to reduce its dependence on fossil fuels and emissions which may be harmful to the environment. Thus, for about three decades, the global cement industry and the South African cement industry have researched SCMs and their applicability in this regard. To this end, the most commonly used SCMs and a few others have been discussed and their roles as cement extenders which ultimately reduces the quantity of cement required in selected mixes and applications have been shown.

So, the next section will briefly touch on how PC is manufactured in South Africa, with a view to consolidating on work already done by others and highlighting where energy is utilized, CO$_2$ emissions occur (within the scope of the dissertation) and how they can be reduced and mitigated respectively.

2.4.2 **Portland cement manufacturing process.**

Portland cement is generally made by further grinding and blending cooled cement clinker with measured quantities of gypsum. Gypsum is added more often than not to act as a retarding agent for the setting time of concrete. But to produce the cement clinker, naturally occurring materials like calcium carbonate (limestone), clay/shale and sand are quarried, ground, mixed and milled to fine granules at very high temperatures (up to 1450°C) in a 3° to 4° inclined rotating kiln for chemical reactions to occur thus producing cement (MARSH, 2005; Grieve, 2009; Aitcin and Mindess, 2011). In a nutshell, according to Worrell et al., (2001) this process can simply be described in three steps i.e. preparation of the raw materials, clinker production in the kiln and manufacture of cement.
2.4.2.1 Preparation of Raw Materials.

The raw materials used in the production of cement clinker can be distinguished as primary and secondary. The primary raw materials are basically the limestone, sand, clay and haematite (mineralized Fe₂O₃). These materials are necessary because they contain the basic constituents of cement (oxides of calcium, silica, alumina, iron and so on) as shown in Table 3.1. After quarrying washing and stockpiling all these materials, raw limestone is fed through several calibrated crushers so as to attain a material size of less than 19 mm particle size.

Then blending the crushed limestone with the prepared shale, sand and haematite, the mixture is sent to the raw mill where further grinding and blending occurs bringing the mixture to a fine powder. This powder is conveyed to the blending silo for homogenization to produce what is known as the “kiln feed”. At this stage the kiln feed is stored in silos ready for use. According to (MARSH, 2005), 1 ton of clinker can be derived from about 1.5 tonnes of kiln feed.

In addition, should the requirement of the final product (cement) be of a special need such as to resist sulphate attack, for mass concrete structures where a low heat of hydration is required, secondary raw materials such as supplementary cementitious materials SCMs can be included as additional components. This however, depends on the location of the cement plant, and the availability of the secondary material.

2.4.2.2 Clinker production in the kiln.

The kiln is a cylindrical shaped vessel-like steel structure, inclined up to 4 degrees to the horizontal to allow for gravity flow of the homogenized materials through it. MARSH (2005), suggests that for proper blending of the feed, the kiln rotates between 0.5 to 4.5 revs/min to cater for sufficient residence time of the kiln feed which is needed for a complete thermal conversion process to occur (Worrell et al., 2001; MARSH, 2005).

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5 The residence time of the kiln feed refers to the standard time it spends within the kiln system for complete thermal conversion of its particles to occur.
To produce clinker, the homogenized kiln feed passes into the kiln system via a multistage preheating process – which can cut energy requirement in the entire process by up to half (Worrell, 2001; MARSH, 2005; Aitcin and Mindess 2011) – where ample heating required for the thermal process is applied on the feed before it reaches the calcining, upper transition, sintering and lower transition zones; otherwise called the four thermal zones (MARSH, 2005):

**The Calcining Zone:**
This is the zone where the heat peaks at a temperature of 900° C. Here, through thermal action, limestone is chemically disintegrated to lime by releasing carbon dioxide. The process is called calcinations.

**The Upper-Transition Zone:**
In this zone, the kiln feed is exposed to more heat that rises to a temperature as high as 1 200° C where more thermal conversion is imminent.

**The Sintering Zone:**
Sintering refers to the action that produces materials from finely ground materials (in powder form). Thus, this zone also known as the burning zone, is that which sees lumps of clinker (greater than 3 mm but less than 20 mm in diameter) forming at a temperature of 1 450° C.

**The Lower Transition Zone:**
Also called the cooling zone, it is the phase where the formed clinker starts to cool though he zone is still at a temperature of 1 250° C. As the clinker forms, it continues its path to the firing end of the kiln system where it is sent to cool to about 100° C before it is fed through to its storage location.

It should be noted that because of its relatively cheap price and its abundant availability, cement companies in South Africa derive almost all the energy used to fire their kilns from coal (a highly energy intensive fuel).
To summarize, PC is a man-made material that is chemically produced by the combination of naturally occurring materials like limestone, sand and clay in a controlled environment. When mixed at specified proportions with aggregates, sand and sometimes other additives (cement extenders), it forms concrete after hydration. Concrete which is vital for construction is the most used material after water on earth (Aitcin, 2008; Alexander and Beushausen, 2010; Aitcin and Mindess, 2011). Recent construction breakthroughs have shown the advancement in the versatile applications of Portland cement globally and in South Africa.

Therefore, this chapter has shed light on the South African cement industry. In doing so, the origins of the industry have been discussed from the historical point of view of the four main players. One recurrent theme in the evolution of the industry is that cement production was and is still is a viable business venture in the country owing to the desire and appetite South Africa has to develop and build world class infrastructure.
PC as a basic constituent of concrete has been unpacked from a global to local perspective. The basic types of PC in South Africa were briefly mentioned along with its components and properties. In recognition of the fact that the manufacture of plain Portland cement is fast being replaced by blended cements, some supplementary cementitious materials were also mentioned. In conclusion, the chapter wrapped up with a description of how cement is manufactured using the dry process.

Having gone through the dry cement making process, it is evident that it is an energy intensive process as stated by (Worrell et al., 2001). Being that the country relies heavily on coal for its energy source (Mqadi et al., 2005), the cement industry is no different but it is making efforts to curb its coal consumption. Also the fact that during the calcining process, vast amounts of CO$_2$ is emitted into the environment is a source of concern for the industry. Hence, this shows the relevance of analyzing the energy efficiency and environmental performance of the cement industry in South Africa as will be seen in the next section.

![Figure 2.10: Energy utilization in a modern kiln (Otterman, 2011)](image-url)
Figure 2.10 shows a modern cement kiln. Here, its input components and energy requirements are highlighted for each phase of cement production. AFR refers to alternative fuels and raw materials which for sometime are being used to substitute coal for energy in cement kilns. Aiding in reducing the amount of coal consumed, recycling of waste materials and reduction of CO$_2$ emissions, its use represents a shift of paradigm which is very important for the industry as it deals with energy efficiency, climate change and sustainable development issues. Some examples of AFRs are rubber tyres, sludge and depleted solvents (CEMBUREAU, 1997).

2.5 ENERGY EFFICIENCY IN THE SOUTH AFRICAN CEMENT INDUSTRY.

2.5.1 INTRODUCTION

Energy is a major resource utilized and consumed in the production of cement. Sourced mainly from fossil fuels, electricity or a combination of both, energy is an integral part of the needs of a cement plant. Thus, it should be in constant supply to avoid interruptions e.g. in a manufacturing process which can mar output and productivity. Therefore, it is imperative that each company tackles this issue from a corporate perspective. In this dissertation, the source of energy that will be discussed will refer to that from coal (thermal energy) and electricity (electric energy) only.

This section will define energy efficiency and explore its benefits. Then, it will look into how the South African cement industry has managed the challenges and prospects of energy utilization and consumption in the production of cement. To do this, the South African energy policy will be unpacked and juxtaposed with that of its cement industry with a view to identifying gaps (if any).

2.5.2 DEFINITION OF ENERGY EFFICIENCY.
Energy has generally been defined as the ability to do work. But in accordance with Lehrman (1973), energy should not be defined without heat. Rather, he said it should be defined as a quantity with a measurement of work and expressed algebraically such that the sum of its algebraic parts remains constant either in an aggregated or segregated system. Thus, energy may be termed as heat, work and so on depending on its transfer mechanism (Lehrman, 1973). Given the definition of energy, it is evident that for work to take place e.g. manufacturing cement, energy is indeed an important resource to achieving it. This leads to the question of energy efficiency and its role in the cement manufacturing business and the environment.

### 2.5.3 What is Energy Efficiency?

In broad terms, efficiency represents an action or set of actions devised to produce a desired effect with minimal to zero wastage of input resources. So, energy efficiency can be defined as a designed plan or set of plans meant to utilize energy in production with as little waste as possible. Similarly, EPA (2008) defines an efficient system as that which derives similar or more output while using a smaller amount of energy. Additionally, DME (2004) stated that in meeting the requirements of sustainable development – defined by the Brundtland commission as satisfying present needs without jeopardising the ability to satisfy future needs (Brundtland, 1987) – energy efficiency is one of the cheapest options available. Furthermore, it alluded to the fact that practising energy efficiency can be advantageous to the environment because it can deal with all issues surrounding pollution; issues such as CO2 emissions from cement production – as is the focus of this dissertation.

Hence, as Ottermann (2011) suggested, competitiveness within the cement industry will be hinged on how effectively cement companies can manage energy. Therefore, the next section will explore the ways in which the country’s cement industry has handled energy use.

### 2.6 ENERGY USE AND MANAGEMENT IN THE SA CEMENT INDUSTRY.
For a cement manufacturing facility to remain economically viable, it needs to plan and budget for energy because according to (Otterman, 2011), it represents more than a third of the production costs in most cement factories. While Taylor, Tam and Gielen (2006) inferred that energy represents between a fifth and nearly 40% of the energy costs. However, Otterman pointed out that the challenges of energy supply in South Africa viewed from a short, medium and long term basis, shows that very high electricity costs, rapid depletion of coal sources will make it difficult for cement producers to operate if the system they are accustomed to remains unchanged (Otterman, 2011).

In addition, the issue of mitigating greenhouse gas emissions which has fast become the subject of global discourse, constitutes another challenge to the industry and is one that should not be overlooked.

To shed more light on energy utilization and its management in cement production, this dissertation will delve into the cement manufacturing process and probe where energy is consumed and how it is being managed.

2.6.1 Technology and Thermal Energy consumption in the manufacture of cement

In work done by Taylor, Tam and Gielen (2006), they found that combining the energy used in manufacturing non-metallic minerals, cement production alone accounts for about 66% of all the energy use. The cement kiln is the component that accounts for the most coal use. With other process functions like drying of raw materials before use utilizes coal as well in cases where the kiln does not dry the raw materials completely. Additionally, the clinkering phase which has fans that work on electricity supply, consumes up to 6 000 MJ/tonne of clinker manufactured. However, it should be noted that its major source of thermal energy is coal (Taylor, Tam and Gielen, 2006; Otterman, 2011).

Figure 2.11 illustrates the vast proportion of coal consumption in comparison to other energy sources in a typical cement plant in South Africa. The light blue portion representing about 70% of the entire cost of energy utilized in cement production in a

---

6 Thermal energy can be defined as the component of total energy (potential and kinetic) which determines the temperature (measure of heat) of a medium or system.
typical plant in South Africa, shows the coal consumed during the raw and finish milling processes. The darker blue portion (15% of the total cost) shows the part of the clinkering phase using coal. In this plant, the remaining energy costs (10% electrical energy, 5% a combination of Petrol, Diesel and Explosives) completes its energy cost breakdown structure.

![Pie chart showing energy utilization at a cement plant in RSA for the year 2010](image)

**Figure 2.11**: A typical cost split of energy utilization at a cement plant in RSA for the year 2010 (Otterman, 2011)

### 2.6.1.1 Technology applicable to cement production

This dissertation will focus on five kinds of kilns that have been used or still in operation in the South African cement industry. These are the three kinds of dry kilns i.e. the one with preheater and precalciner (PH-PC); with preheater and without a precalciner (PH); and the long dry kiln with preheater(s). In addition, the other two kinds of kilns are the semi-wet/semi-dry and the wet types. These various kiln types have different thermal energy consumption rate per tonne of cement clinker produced. Figure 4.2 shows the kiln types whose functionality is expressed for the years 1990, 2000, 2005 and 2006. Also, it should be noted that their functionality varies according to the kind of kiln technology (WBCSD, 2009).
Figure 2.12: Average thermal energy consumed per tonne of cement clinker produced for various kiln types for all WBCSD member countries involved in the GNR project. (WBCSD, 2009)

From the Figure, it shows that as at 2006 most of the countries whose data was utilised in producing the graphs made use of the wet kiln process to produce cement. It is also evident that the PH-PC dry kiln consumes about half of the energy required for the wet kiln process. The cement kiln technology employed in developing countries like South Africa have mostly been small scale types which are now regarded as less modern and less efficient types. But of late, the country’s cement producing companies are gearing up by retrofitting, building new kilns and cement plants all together. The efficiency drive initiated by the WBCSD’s CSI – of which South African cement industry is a signatory to – has encouraged the push for cement plants to be more efficient. To this end, large scale kilns which are known to be more efficient (Taylor, Tam and Gielen, 2006; WBCSD-CSI, 2009; IEA, 2009) are fast replacing the older kiln types in existence since the first cement was produced in South Africa. In other words, the wet cement making process is being substituted with the more efficient dry cement making process which constitutes preheater(s) and pre-calciners (Worrell et al., 2001; Taylor, Tam and Gielen, 2006; Otterman, 2011).

7 GNR (“Getting the Numbers Right”) is a report put together by the WBCSD’s Cement and Sustainability Initiative for its participating members. The report presents analyzed cement production data as submitted by member countries. Refer to http://www.wbcsdcement.org/pdf/CSI%20GNR%20Report%20final_updated%20Nov11_LR.pdf for the project report.
Table 2.7 presents the International Energy Agency, IEA’s 2002 data gathered from the regions indicated, the estimated breakdown (expressed in percentage) of various kiln types used in the regions and the corresponding fuel mix used to generate thermal energy. With regards to the WBCSD data, in 2002 the share of dry process kiln types in relation to others in Africa indicated a good sign of progress regarding the issue of energy efficiency. On the contrary, for the same year, Australia and New Zealand showed signs of a less efficient cement industry because of the proportion of wet process (less efficient) kiln types superceeding other types.

Table 2.7: IEA estimates of Cement Manufacturing Process Types and Energy Mix by Region (WBCSD, 2002)

<table>
<thead>
<tr>
<th>Process Type</th>
<th>Energy Mix</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry (%)</td>
<td>Coal (%)</td>
</tr>
<tr>
<td>Semi-dry (%)</td>
<td>Oil (%)</td>
</tr>
<tr>
<td>Wet (%)</td>
<td>Gas (%)</td>
</tr>
<tr>
<td>Vertical (%)</td>
<td>Other (%)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Region</th>
<th>Dry (%)</th>
<th>Semi-dry (%)</th>
<th>Wet (%)</th>
<th>Vertical (%)</th>
<th>Coal (%)</th>
<th>Oil (%)</th>
<th>Gas (%)</th>
<th>Other (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>United States</td>
<td>65</td>
<td>2</td>
<td>33</td>
<td>0</td>
<td>58</td>
<td>2</td>
<td>13</td>
<td>26</td>
</tr>
<tr>
<td>Canada</td>
<td>71</td>
<td>6</td>
<td>23</td>
<td>0</td>
<td>52</td>
<td>6</td>
<td>22</td>
<td>15</td>
</tr>
<tr>
<td>Western Europe</td>
<td>58</td>
<td>23</td>
<td>13</td>
<td>6</td>
<td>48</td>
<td>4</td>
<td>2</td>
<td>42</td>
</tr>
<tr>
<td>Japan</td>
<td>100</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>94</td>
<td>1</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>Australia and NZ</td>
<td>24</td>
<td>3</td>
<td>72</td>
<td>0</td>
<td>58</td>
<td>&lt;1</td>
<td>38</td>
<td>4</td>
</tr>
<tr>
<td>Southeast Asia</td>
<td>80</td>
<td>9</td>
<td>10</td>
<td>1</td>
<td>82</td>
<td>9</td>
<td>8</td>
<td>1</td>
</tr>
<tr>
<td>Thailand</td>
<td>82</td>
<td>9</td>
<td>8</td>
<td>1</td>
<td>82</td>
<td>9</td>
<td>8</td>
<td>1</td>
</tr>
<tr>
<td>South Korea</td>
<td>93</td>
<td>0</td>
<td>7</td>
<td>0</td>
<td>87</td>
<td>11</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Eastern Europe</td>
<td>54</td>
<td>7</td>
<td>39</td>
<td>0</td>
<td>52</td>
<td>34</td>
<td>14</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Latin America</td>
<td>67</td>
<td>9</td>
<td>23</td>
<td>1</td>
<td>20</td>
<td>36</td>
<td>24</td>
<td>12</td>
</tr>
<tr>
<td>Middle East</td>
<td>82</td>
<td>3</td>
<td>16</td>
<td>0</td>
<td>0</td>
<td>52</td>
<td>30</td>
<td>4</td>
</tr>
<tr>
<td>Africa</td>
<td>66</td>
<td>9</td>
<td>24</td>
<td>0</td>
<td>29</td>
<td>36</td>
<td>29</td>
<td>5</td>
</tr>
<tr>
<td>BRICS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td>66</td>
<td>1</td>
<td>32</td>
</tr>
<tr>
<td>Brazil</td>
<td>98</td>
<td>n.a.</td>
<td>n.a.</td>
<td>n.a.</td>
<td>1</td>
<td>66</td>
<td>1</td>
<td>32</td>
</tr>
<tr>
<td>Former Soviet</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td>66</td>
<td>1</td>
<td>32</td>
</tr>
<tr>
<td>Union</td>
<td>12</td>
<td>3</td>
<td>78</td>
<td>7</td>
<td>7</td>
<td>1</td>
<td>68</td>
<td>&lt;1</td>
</tr>
<tr>
<td>India</td>
<td>50</td>
<td>9</td>
<td>25</td>
<td>16</td>
<td>96</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>China</td>
<td>43</td>
<td>0</td>
<td>2</td>
<td>55</td>
<td>94</td>
<td>6</td>
<td>&lt;1</td>
<td>0</td>
</tr>
</tbody>
</table>

8 Data collated for only Siam Cement Company
2.6.1.2 Thermal Energy consumed in cement production

According to WBCSD-CSI and IEA (2009), a cement kiln consuming below 3 500 MJ / tonne of clinker is regarded to be an energy efficient type. Though, in 2002 the WBCSD theoretically found that the least thermal energy consumed in the production of a tonne of clinker is 1 760 MJ / tonne of cement clinker produced. Also, wet kilns (which are said to be the least efficient) utilize between 5 300 and 7 100 MJ / tonne while kilns having preheater(s) and pre-calciners are said to consume about 3 060 MJ to manufacture a tonne of cement (WBCSD, 2002).

Figure 2.13 presents collated data showing typical energy utilisation per tonne of cement clinker produced in different regions for the years 1990, 2000, 2005 and 2006. With the preceding paragraph as reference, Figure 2.13 shows that the wet kiln type is the least efficient because the WBCSD-CSI member countries making use of this kiln type in their cement plants, recorded a thermal (fuel) energy consumption average of over 6 000 MJ / tonne of clinker produced. While those using the dry preheater and precalciner kiln types operated more efficiently because they recorded an average thermal energy consumption of under 3 500 MJ / tonne of produced clinker.

Figure 2.13: Thermal energy consumed per tonne of cement clinker produced (WBCSD, 2009).
For China and North America (US and Canada), the three countries responsible for almost 50% of the global cement production figures, make use of nearly 5 000 MJ / tonne of cement clinker. As for the EU, their consumption figure sits at about 3 700 MJ / tonne while the rest range from 3 150 to 3 650 MJ / tonne (Taylor, Tam and Gielen, 2006). Similarly, the Association of Cementitious Material Producers of South Africa (ACMP) released figures presented in Table 2.8 showing the average energy consumed in cement production from 2007 till 2010. The figures show an increase between 2007 and 2008 and then a steady decline onwards largely due to more efficient plants and the use of both cement extenders and alternative fuels (ACMP, 2009). Next, the electrical energy consumption rate will be looked at to complete the assessment of the total energy use of the South African cement industry.

Table 2.8: Thermal energy consumed per tonne of cement clinker produced in South Africa (ACMP, 2009).

<table>
<thead>
<tr>
<th>Year</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy Consumption (GJ)</td>
<td>2 238 278</td>
<td>2 620 412</td>
<td>1 741 542</td>
<td>1 511 703</td>
</tr>
</tbody>
</table>

Includes Afrisam, Lafarge, NPC and PPC

2.6.2 Electrical Energy utilization in the manufacture of cement

When making cement, finish milling (grinding and blending clinker to cement with gypsum and other additives) is the stage that consumes the most electrical energy while the raw milling phase (grinding limestone along with other additives to a fine kiln feed) requires the second highest electrical energy (Otterman, 2011). Figure 4.4 shows how a 110 kWh of electricity is split in the production of 1 tonne of cement in a typical plant in South Africa. For this plant, it is seen that the combination of quarrying and other supporting activities utilizes the least electrical energy while as previously mentioned finish milling requires the most electrical energy. Although the clinkering process highlights the second highest consumption value, it should be noted that it is a phase made up of multi-stages and whose energy source is mainly dependent on thermal energy from coal.
But Sathaye, J., et al. (2005), stated that according to the current best practice for electricity consumption in the cement industry, a plant utilizing electrical energy at a rate between 75 to 80 kWh is classified as efficient and modern. Even at this, the energy efficiency of the combination finish and raw milling (grinding) stages are still as much as 90 % to 95 % inefficient because this amount of the process is converted to heat (Taylor, Tam and Gielen, 2006). The consumption rate of the South African plant (110 kWh / tonne of clinker) represented in Figure 2.14 corresponds to those in Brazil which Soares and Tolmasquim (2005) found to range between 90 and 200 kWh / tonne of clinker.

Table 2.9: Total Electricity purchased for cement clinker produced in South Africa (ACMP, 2009).

<table>
<thead>
<tr>
<th>Year</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity Purchased (MWh)</td>
<td>611 150.5</td>
<td>606 153.5</td>
<td>946 498</td>
<td>852 230</td>
</tr>
</tbody>
</table>

Includes Afrisam, IDM, NPC and PPC
Comparing Table 2.9 to 2.8 it is seen that electricity purchased dropped from 2007 to 2008 by 1% while simultaneously 17% more energy was consumed within the same period. Between 2008 and 2009, 56% more electricity was purchased and 34% less coal energy was utilized.

And from 2009 to 2010 both thermal and electrical energy consumption dropped. These fluctuations of energy use in the South African cement industry shows an absolute increase in electricity purchased of about 50% and a concurrent absolute decrease of about 50% in thermal energy consumed from 2007 to 2009. Given the 2008 global financial crisis, these indications may be attributed to international coal demand that may have benefitted South Africa and hence encouraged the country to export more thereby making less available for consumption.

In a nutshell, making use of modern efficient kiln technologies is a way of achieving reduction of energy costs (Worrell, 2001; WBCSD-CSI, 2002 and 2009; Taylor, Tam and Gielen, 2006; Otterman, 2011). Therefore as alluded to by the authors, in order to increase efficiency with time it is pertinent to advance in technology as well. Though, looking at the bigger picture of mitigating emissions, it can be deduced that installing modern kilns (e.g. dry rotary kilns) alone cannot guarantee reduced emissions except when combined with operating the technologically advanced plant efficiently. Thus, raising the vital question of how energy is managed in the South African cement industry.

2.6.3 Energy management in cement production

Managing energy in a cement plant is a key ingredient to its success and sustenance and requires buy in, informed policy and strategy from the corporate level. For South Africa, energy management is very important because as previously mentioned the country is one of the highest emitters of CO₂ and consumers of fossil fuel for energy in the world. To manage cement production effectively, it is important to know the efficiency requirements of the components of the production process. See Appendix B for the steps and energy consumed for each step in cement production.
Therefore, in accordance with WBCSD (2009) and Otterman (2011), the production capacity of cement plants with modern PH-PC kiln types is usually higher than those with other kinds of kilns.

As such, these kiln types record higher values of energy efficiency i.e. at a thermal energy consumption rate of up to 600 MJ / tonne of cement clinker produced. Additionally, their reports showed that long dry kilns with no preheater consumes about 800 MJ / tonne of cement clinker while the old wet kilns consumes nearly 1 120 MJ / tonne of cement clinker. With this in mind, the challenge for the management of a cement plant can be summarised as their ability to overcome hurdles such as: the cost of energy; constantly securing energy and the government’s regulations on climate change.

2.6.3.1 The medium to long term Cost of Energy in SA

In recent years Eskom (South Africa’s main electricity company) has announced potential increases in the cost of electricity supply which are gradually being implemented and are estimated to be in the region of about 30 %. This cost increase including the inconsistent coal prices may not augor well for energy prices in the medium to long term. Accordingly, Otterman (2011) indicated that the projected increase could raise the cost of input into the cement production process by as much as 45%.

2.6.3.2 Constantly Securing Energy.

The constraints in energy supply in South Africa is a growing concern for the cement industry. From the variations in the supply of electricity to meet demand adequately, to the issues surrounding export and local coal consumption. Figure 4.5 shows the risk level faced by the local coal market should local exports rise to its maximum capacity.
2.6.3.3 Government’s regulation of Climate Change

Part of the reasons for the persistent stalemate in the UNFCCC’s COP/CMP meetings is the issue of the carbon tax\(^9\). The implementation of this ‘tax’ will most likely raise the prices of cement in the country because of the increment in operating costs (Otterman, 2011; RFF, 2012).

To summarise, the conundrum for cement plant managers would be how to innovatively create solutions that will ensure their products are affordable whilst remaining competitive in terms of commodity prices. Also, it is seen that using less fossil fuels for energy is better enhanced by utilizing more modern and efficient plants which can be beneficial to the company’s profit margins and the environment at large. In this dissertation, the indication for the benefit to the environment will refer to the measure of CO\(_2\) emissions as discussed next.

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\(^9\) A price to be set by the UNFCCC’s COP/CMP per tonne of CO\(_2\) emitted by a country. Presently the cost is estimated at about 25 USD/tonne of CO\(_2\) (RFF, 2012)
3.0 METHODOLOGY AND LIMITATIONS OF THE RESEARCH

3.1 RESEARCH METHOD
The process used for this dissertation, as adapted from (DST, 2007), is categorized under three main activities namely; research initiation, criteria recognition for assessment and prioritization of energy efficiency and GHG emissions from cement manufacture and collation of a synthesized dissertation.

3.1.1 1st Activity: Research Initiation
In addition to the aims spelt out in item 1.3.2, this research endeavors to provide a concise picture of how the country’s cement industry has performed in relation to others so that it can do better going forward.

3.1.2 2nd Activity: Criteria Recognition
The purpose of this activity is to critically create an analytical framework to be used in carrying out the research. Here, the parameters for reviewing the energy consumption and emissions performance of the country’s cement industry were identified, prioritized and systemically analyzed using the benchmarking and energy saving tool for the cement industry (BEST, 2008) and cement based (ICF, 1999) methodologies respectively.

3.1.3 3rd Activity: Synthesized Report
This section sees the collation of the data and information originating from the framework for the final document from the previous activity and in a prioritized format.
3.2 CRITICAL ANALYTICAL FRAMEWORK

In achieving the one broad objective and the four aims of this dissertation, a desktop review methodology is adopted within a critical analytical framework context. This framework is in line with the theoretical framework supporting the idea that cement has no known substitute and hence will have to be continuously produced. The research descriptively analyses data and information from numerous sources such as journals, articles, reports, electronic sources, personal and expert views and books. This dissertation is highly dependent on data from the Association of Cementitious Material Producers of South Africa (ACMP), the Cement and Concrete Institute of South Africa (C&CI), electronic databases and annual reports of the country’s top four cement manufacturers namely; PPC, Afrisam, Lafarge and NPC-Cimpor. Furthermore, the study is done within the context of the cement life cycle analysis (LCA) i.e. from “Cradle to Gate” (Huntzinger, et al., 2009) as previously mentioned.

3.3 RESEARCH LIMITATIONS

To achieve the set objective and aims of this research within the prescribed scope, it should be mentioned that the limitations of this research are considered as;

3.3.1 Access to pertinent data and Information

The limitations to this research are summed up in the acquisition of relevant data and information specifically from the four main companies because the cement industry in South Africa is very sensitive.

3.3.2 Data and Information verity

Due to the fragile state the local cement industry is in and its well documented antecedents, there is no way to cross check and verify the precision and accuracy of the industry’s overall energy and emissions data published by the ACMP, C&CI and the individual companies. Therefore this research is confined to desktop reviews and thus wholly reliant on these sources and those previously mentioned.
3.3.3 Hegemony and Autonomy within the South African cement industry

Given that the major players in the country’s cement industry have been operating for decades and were borne out of multi-billion dollar parent companies, there is a strong sense of deliberate collusion and dominance present in the economic sector although no endorsed proof or official report of this exists. Moreover, South Africa’s nascent democracy has had its fair share of bad media and publicity regarding similar collusion claims in some major industries e.g. bread, airline, construction and milk industries among others.

3.3.4 Lack of previous literature on the topic

The shortage of local literature relating to this research can be attributed to the restricted access to relevant data and information which may largely be due to the susceptibility of the industry as a whole.

To summarise this chapter, the research methodology employed is that which seeks to rate the companies collectively. Then, the approach establishes and untangles the factors that characterises the industry’s energy use and emissions performance. To end with, it collates a study that contributes to local literature. To accomplish these, a critical analytical framework defined by the cradle to gate boundary concept is used. But, securing the correct, reliable and verifiable data and information about the in-depth operations, the cement market “monopolistic power” held by the major players as well as shortage of literature regarding this topic in the South African cement industry are identified restrictions of this research.
4.0 FINDINGS AND ANALYSIS

This chapter contains findings from the desktop study and review of literature. It endeavors to show how the cement industry in South Africa manages its energy consumption and CO₂ emissions in relation to others. The findings made during the research and review of literature is subsequently discussed.

4.1 FINDINGS

4.1.1 South Africa and its cement industry.

- Since 1980 the population of the country has been increasing by approximately 2% per annum. In addition there has been similar growth in rural urban migration.

- The demand for cement has equally been on the rise with a corresponding rise in cement production. This has seen an increase in cementitious sales of about 57% between 1980 and 2010.

- First cement was produced in 1892.

- From 1892 till 2010, 419 Mt of cement has been produced. 65% of these sales were recorded between 1980 and 2010. Thus, an average production of 14 Mt pa since 1980.

- Lowest cementitious sale of 1 360 t was recorded in 1892 while the highest sale of 15.3 Mt was noted in 2007.

- There are 4 major cement producers namely; PPC, Afrisam, Lafarge and NPC-Cimpor. Their kiln descriptions are shown in Figure 4.1.
All the cement producers in SA utilize one or more SCMs to extend the cement produce.

Though some are being retrofitted and upgraded to improve efficiency, most of the cement plants are more than half a century old.

Built in 2009, Lafarge’s Lichtenburg plant has the latest kiln in SA. However, Sephaku cement company, the latest addition to the 4 major players, will have the newest kiln line by the end of 2013.

The estimate of current market share of the 4 major producers are as follows;

- PPC 50%
- Lafarge 25 %
- Afrisam 15 %
- NPC-Cimpor and others 10 %
4.1.2 Energy Efficiency and CO₂ emissions in the SA cement industry

- Energy costs represent between 20% to 40% of the total production costs of cement factories.

- Cement production (especially the calcining process) is highly energy intensive. The major source of thermal energy in SA is coal and the main source of electricity is Eskom.

- SA is among the highest CO₂ emitters in the world.

- Energy efficient kiln consumes between 3000 to 3500 MJ/t of clinker produced. And less energy efficient kilns consume between 5300 to 7100 MJ/t of clinker produced.

- Electrical efficient kiln consumes 75 to 85 kWh/t of clinker produced.

- Cement consumption per capita in the country is about 0.25 t/capita or 1 m³/capita. A typical plant in SA consumes electricity at about 110 kW/h

- CO₂e emissions per capita in the country is about 13 tCO₂e/capita (OECD, UNEP, 2011).
4.2 ANALYSIS

- The SA cement industry is one of the oldest in Sub-Saharan Africa and for about 120 years it has been producing cement to meet local and regional (SADC\textsuperscript{10} region) demands.

- SA cement industry leads most of the African continent in terms of cement production and sales figures. Consequently, regarding cement production, it is the highest ranked in terms of energy use and CO\textsubscript{2} emissions in SSA\textsuperscript{11}. However, the country is at the forefront of scientific research into the chemistry of cement and the use of cement extenders in SSA.

- The four main producers control more than 95\% of the local market. Therefore this leaves little or no room for other players and if unchecked, can create an atmosphere of monopoly, price collusion and so on. For this reason and the sensitivity of the entire industry, retrieving data and information valuable to this research proved very difficult.

- The analysis of the findings regarding the energy efficiency and CO\textsubscript{2} emissions of the SA cement industry shows that though the cement utilization per person is roughly the same as that of the global average, the industry’s energy (thermal and electrical) use and CO\textsubscript{2} emissions are still relatively high.

\textsuperscript{10} SADC: South African Development Community

\textsuperscript{11} SSA: Sub Saharan Africa.
5.0 CONCLUSION AND RECOMMENDATIONS

In conclusion, this dissertation finds no existing critical review of the South African cement industry as a whole with respect to energy efficiency and CO\textsubscript{2} emissions. Neither is there an in-depth review of the four main producers in comparison to a benchmark. Therefore, it differs from existing literature on the subject matter because the dissertation aims to explore the topic within the South African context. But, it is seen that each company has websites - which are regularly updated and regular publications which highlight their specific achievements and so on. The cement industry representatives like the ACMP and C&CI also have regular publications which endeavor to present collated data. However, information regarding exact cement production and emission figures as well as efficiency levels of plants are difficult to retrieve from each of the companies. This may be attributed to the fine they recently paid for alleged price collusion and fixing. This research contributes to previous work in that it includes South Africa in most of the comparisons made though it raises new questions as to where exactly the country is in terms of how exactly it compares with others in energy use and management of CO\textsubscript{2} emissions.

Finally, this study is built around the theoretical framework that till date there is no known substitute for cement. Backed up by research through various literature, it is founded on the economic theory that demand equals supply. On this basis, cement production will continue for some time to come. Hence, since cement manufacture relies heavily on energy (mainly sourced from coal in South Africa) and emits CO\textsubscript{2} at a rate almost equal to a tonne of clinker produced, cement companies in the country will have to embark on continuous improvement and bring their plants and processes up to date with the latest technology and know-how. In answering the research question, the dissertation finds no conclusive evidence as to where the industry belongs in comparison to others because of the difficulty in acquiring information. But it should be mentioned that a lot of progress has been made regarding installing new kilns and retrofitting existing ones to improve energy use and reduce CO\textsubscript{2} emissions.
Thus, the aim of the work is to review a very important industry in South Africa which is highly energy intensive and emits a significant quantity of CO$_2$ for a single industry with a view to reviewing its energy use and environmental performance for the past 30 years. The importance of the review is borne out of the need for such industries to practice energy conservation, use little or no energy from fossil fuel sources and reduce emissions that may be harmful to the environment.

As such the recommendations of this dissertation are listed next.

SA cement industry should;

- Invest more in research into the chemistry of cement and its production process because the calcining stage (decarbonising limestone to lime) is responsible for most of the CO$_2$ emissions. In addition, the hydration process may reveal the best way to reduce the quantity of CaO in the C$_3$S (Tricalcium silicate) which has the highest percentage by mass in CEM I common cements.

- Utilize more Alternative Fuels and Raw materials like the SCMs as previously discussed.

- Invest in more new (energy efficient) technologies.

- Encourage more joint implementations and transfer of technology.

- Increase reduction of clinker to cement ratios.

- Further explore and consider opportunities that will be beneficial in case the carbon tax is signed into law. An example of this is the opportunity present in the clean development mechanism (CDM) which monetarily rewards CO$_2$ emission reduction schemes.

- Consider a portfolio of these recommendations as the best emissions reduction and energy efficiency practice.

BIBLIOGRAPHY


OECD, 2001. Environmental Indicators for Agriculture; Methods and Results. 


## Common cements SANS 50197-1 (C&CIC, 2009)

<table>
<thead>
<tr>
<th>Main types</th>
<th>Notation of products (types of common cement)</th>
<th>Composition, percentage by mass(a)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Clinker</td>
</tr>
<tr>
<td></td>
<td></td>
<td>K</td>
</tr>
<tr>
<td><strong>CEM I</strong></td>
<td>Portland cement</td>
<td>95-100</td>
</tr>
<tr>
<td></td>
<td>Portland-slag cement</td>
<td>80-94</td>
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<tr>
<td></td>
<td>Portland-slag cement</td>
<td>65-79</td>
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<tr>
<td></td>
<td>Portland-silica fume cement</td>
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<tr>
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<tr>
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<td>Portland-fly ash cement</td>
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<td>Portland-fly ash cement</td>
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<td><strong>CEM II</strong></td>
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<td><strong>CEM III</strong></td>
<td>Blastfurnace cement</td>
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<td><strong>CEM IV</strong></td>
<td>Pozzolanic cement(1)</td>
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<tr>
<td></td>
<td>Composite cement(1)</td>
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</tbody>
</table>

**Notes**

(a) The values in the table refer to the sum of the main and minor additional constituents.
(b) The proportion of silica fume is limited to 10%.
(c) In portland-composite cements CEM II A-M and CEM II B-M, in pozzolanic cements CEM IV A and CEM IV B, and in composite cements CEM V A and CEM V B, the main constituents other than clinker shall be declared by designation of the cement.
Process steps* and Energy (Thermal and Electrical) use in cement production (Worrell, et al., 2001)

<table>
<thead>
<tr>
<th>Process step</th>
<th>Fuel use (GJ/t of product)</th>
<th>Electricity use (kWh/t of product)</th>
<th>Primary energy (GJ/t of cement)</th>
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<tr>
<td>Crushing</td>
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<td>Jaw crusher</td>
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<td>Gyratory crusher</td>
<td>0.3–0.7</td>
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<td>Roller crusher</td>
<td>0.4–0.5</td>
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<td>Hammer crusher</td>
<td>1.5–1.6</td>
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<td>0.03</td>
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<tr>
<td>Impact crusher</td>
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<td>4.2</td>
<td>25</td>
<td>4.5</td>
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<td>Short dry—suspension</td>
<td>3.3–3.4</td>
<td>22</td>
<td>3.6–3.7</td>
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<td>preheating</td>
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<td>&amp; precalciner</td>
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<td>Roller press/separator</td>
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*Specific energy use is given per unit of throughput in each process. Primary energy is calculated per tonne of cement, assuming portland cement (containing 95% clinker), including auxiliary power consumption. NA. Not applicable.

³Primary energy is calculated assuming a net power generation efficiency of 33% (LHV).

Assuming grinding of Portland cement (95% clinker, 5% gypsum) at a fineness of 4000 Blaine.