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The impact of cement sustainability initiative on the South African cement industry’s performance

A Minor Dissertation Submitted in Partial Fulfilment of the Degree of

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of the

UNIVERSITY OF JOHANNESBURG

by

BELTRAN LABANA

AUGUST 2018

SUPERVISOR:  
Prof. A. TELUKDARIE

CO-SUPERVISOR:  
Ms M MUNSAMY
Abstract

Since the 19th century, Ordinary Portland Cement has contributed significantly to improve human living conditions especially in the urbanisation of society. In this context of urbanisation, millions of tonnes of cement are used yearly for the construction of concrete structures such as bridges, hospitals, residential structures and industrial buildings.

The production of Ordinary Portland Cement does not only contribute positively to improve lives, but also negatively affects them by emitting between 0.9 to 1 tonne of dioxide of carbon (CO₂) per tonne of cement produced. This volume of CO₂ accounts for 5 to 7 percent of the total volume emitted in the world, identifying the cement industry as the second largest polluter in the world.

Much research has been conducted for the past two decades to contribute to the understanding of the sources of CO₂ emission and to propose solutions to the problem. At the same time several organisations and government entities around the world initiated different programmes such as the Cement Sustainability Initiative (CSI) and the Carbon Tax Bill for the protection of the environment and to pave the way for sustainability of the cement industry.

The Cement Sustainability Initiative recommends, amongst other options, the use of best practice such as alternative kinds of fuel to produce cement. In this research study, waste oil and used tyres were used as alternative fuel and an objective function was used to determine the quantity of fuel material for minimising the CO₂ emission. By solving the mathematical model with the Lingo software programme, used tyres were shown to have the highest efficient energy of 20 percent compared to waste oil. This excludes the higher CO₂ emission value of 80.34 percent between the two alternative fuel materials.

Finally, the results indicate that combined usage of coal with alternative fuel material may be categorised as best practice for a positive contribution to the reduction of CO₂ emission in the order of 16.76 percent. This is with considering the local cement industry where the latter has an advanced positive performance in terms of maintaining a long sustainable industry as promoted by the Cement Sustainability Initiative (CSI).
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I would like to praise the mighty God Jesus-Christ for enabling me to persevere and complete this course of Engineering Management besides the difficulties and obstacles encountered all along my studies. I will never stop thanking you, my God, for taking care and blessing me with your grace every day of my life.

My gratitude goes to my supervisor Prof Arnesh TELUKDARIE and co-supervisor Ms M Munsamy for their time, patience, availability and advice throughout this research process. Their guidance and wisdom helped me to see the potential researcher hidden in me and to produce work that I am proud of.

To my wife Gloria Sulubika MUNDA, for being patient and supportive. Find in this dissertation, the strength and the joy of being on my side. This qualification should be your stimulus for being the pillar of our children’s education.

To all of you my children, Brendan, Belda and Sky Beni LABANA, this qualification should be your source of inspiration and success in your studies and lives. For those days that I could not spend enough time with you, see in this document my expression of my love and caring for you.

I would like to thank my father Prof. Jean Lasay’Abar LABANA and my mother Monique Malu THABU for your support and wisdom to enable me to achieve success in my studies. To you my brothers and sister Carlos, Mike, Jean David and Carmel LABANA, may all of you be inspired to pursue your road to success.

Special thanks to Family MUKENDI and to you Prof. Williams KUPOLATI for your assistance and to my friends Joel KANIKI, Teddy MAFUTA, Eric KASIO, Jean-Paul KENA, Dr Stephen NYENDE and many others, thanks to all you guys.

Finally, I thank all of you that I could not mention in this work. I acknowledge that you contributed in many ways to this achievement.
# Table of Contents

DECLARATION ......................................................................................................................... I

ABSTRACT ............................................................................................................................... II

ACKNOWLEDGEMENTS .......................................................................................................... III

LIST OF FIGURES ..................................................................................................................... VI

LIST OF TABLES ...................................................................................................................... VII

LIST OF ACRONYMS ........................................................................................................... VIII

1. Introduction and Background .............................................................................................. 1
   1.1 Research background ........................................................................................................ 1
   1.2 Rationale of the study ..................................................................................................... 2
   1.3 Research objectives ....................................................................................................... 3
   1.4 Research questions ....................................................................................................... 3
   1.5 Research approach ....................................................................................................... 4
   1.6 Layout of this dissertation ............................................................................................. 4

2. Literature Review .................................................................................................................. 5
   2.1 Introduction ................................................................................................................... 5
   2.2 Carbon dioxide emitted from the cement manufacturing process ............................... 5
       2.2.1 The raw material preparation .................................................................................. 6
       2.2.2 The Portland cement clinker production or the pyro-processing .......................... 8
       2.2.3 Clinker grinding and cement production ................................................................. 11
   2.3 Greenhouse gases and their impact on the environment ............................................... 14
   2.4 The South African national policy on climate change .................................................. 15
   2.5 The Cement Sustainability Initiative (CSI) .................................................................. 17
   2.6 Best practice in the cement production ......................................................................... 18
       2.6.1 Energy efficiency in clinker production ................................................................. 18
       2.6.2 Alternative fuels ..................................................................................................... 18
       2.6.3 Alternative raw materials ....................................................................................... 20
   2.7 Conclusion ..................................................................................................................... 20
3. **Research Methodology** ................................................................. 21
   3.1 Introduction .............................................................................. 21
   3.2 Research Methodology ............................................................ 21
   3.3 Data collection method ............................................................. 22
   3.4 Data analysis method ............................................................... 22
   3.5 Life Cycle Assessment (LCA) ..................................................... 22
      3.5.1 Goal and scope ................................................................. 22
      3.5.1.1 Emission types ............................................................. 23
   3.6 Mathematical model ............................................................... 25
      3.6.1 Constraints ...................................................................... 25
   3.7 Conclusion .............................................................................. 27

4. **Findings and Analysis** ........................................................... 28
   4.1 Introduction .............................................................................. 28
   4.2 Findings .................................................................................. 28
      4.2.1 Overview of South African cement industry ......................... 28
      4.2.2 Overview of alternative fuel materials in South Africa .......... 31
   4.3 Mathematical model results ...................................................... 32
   4.4 Analysis .................................................................................. 34
   4.5 Other scenarios ...................................................................... 36
   4.6 Conclusion .............................................................................. 37

5. **Conclusions and Recommendations** ...................................... 38
   5.1 Conclusions ............................................................................ 38
   5.2 Recommendations .................................................................. 39

**List of References** ........................................................................ 40

Appendix A (Common Cément SANS 50197-1) (Concrète Institute, 2016) ................. 47
Appendix C (Southern African cement industry map) (PPC, 2017) ............................... 49
List of Figures

Figure 2-1: Summarised CO$_2$ emissions associated with cement process manufacturing (Habert et al., 2010) .................................................................................................................. 6

Figure 2-2: Raw material preparation process (Lafarge, 2010) ........................................................................... 7

Figure 2-3: Clinker production process (Lafarge, 2010) ..................................................................................... 9

Figure 2-4: Grinding and cement production (Lafarge, 2010) .......................................................................... 11

Figure 2-5: Source of CO$_2$ emissions in the cement manufacturing process ......................................... 14

Figure 2-6: Carbon tax policy process (Hemraj, 2016) ................................................................................. 16

Figure 3-1: Life cycle assessment of cementitious product .............................................................................. 24

Figure 4-1: Cement production capacity in percentage (Dangote Cement, 2017) .................................. 28

Figure 4-2: Annual cementitious supply and demand in Southern Africa (PPC, 2017) ......................... 30

Figure 4-3: Comparison between energy and CO$_2$ emissions from fuel materials ............................... 32

Figure 4-4: Comparison between proportions of energy requirements .................................................. 34

Figure 4-5: Comparison of three different types of fuel material mixes .................................................. 36

Figure 4-6: Life Cycle Assessment of this study ......................................................................................... 37
List of Tables

Table 2-1: Ordinary Portland Cement clinker composition ........................................................................................................ 7

Table 2-2: Physical and chemical reactions occurring in the production process (Benhelal et al., 2013) .................................................................................................................................................................................... 9

Table 2-3: Consumption of thermal energy and FDCO₂ released in the production process of clinker related to the type of kiln technology (Damtoft et al., 2008; Usón et al., 2013) ............................................................... 10

Table 2-4: Properties comparison of PC, FA, GGBS and SF (SFA, 2005) ....................................................................................... 12

Table 2-5: Electrical energy distribution in the cement industry (Usón et al., 2017; Madlool et al., 2011) ........................................................................................................................................................................ 13

Table 2-6: Summary of the source of CO₂ emission in the cement plant ............................................................ 13

Table 2-7: Energy efficiency of cement fuels (Habert et al., 2010) ............................................................................................. 19

Table 3-1: Average value of _e_i_ for different kinds of fuel material (Steyn and Minnitt, 2010; Laboy-Nieves, 2014) ......................................................................................................................................................... 26

Table 3-2: z-Value for proportions of fuel materials .............................................................................................. 26

Table 4-1: Description of South Africa cement kilns (Baldeira, 2016; Ohanyere, 2012) ......................... 29

Table 4-2: Weight of fuel material obtained from different proportions ........................................................................... 33

Table 4-3: Comparison between current and optimised proportions of fuel material ................................ 35

Table 4.4: Results of mathematical models on other scenarios on optimized proportion of fuel material...37
## List of Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>CSI</td>
<td>Cement Sustainability Initiative</td>
</tr>
<tr>
<td>CO$_2$</td>
<td>Carbon Dioxide</td>
</tr>
<tr>
<td>DEA</td>
<td>Department of Environmental Affairs of South Africa</td>
</tr>
<tr>
<td>DNT</td>
<td>Department of National Treasury of South Africa</td>
</tr>
<tr>
<td>FDCO$_2$</td>
<td>Fuel-Derived CO$_2$</td>
</tr>
<tr>
<td>GGBS</td>
<td>Ground Granulated Blast-furnace Slag</td>
</tr>
<tr>
<td>GHG</td>
<td>Greenhouse Gas</td>
</tr>
<tr>
<td>LCA</td>
<td>Life Cycle Assessment</td>
</tr>
<tr>
<td>MSW</td>
<td>Municipal Solid Wastes</td>
</tr>
<tr>
<td>NDC</td>
<td>Nationally Determined Contribution</td>
</tr>
<tr>
<td>OPC</td>
<td>Ordinary Portland Cement</td>
</tr>
<tr>
<td>OPEC</td>
<td>Organization of the Petroleum Exporting Countries</td>
</tr>
<tr>
<td>PPC</td>
<td>Pretoria Portland Cement Company Limited</td>
</tr>
<tr>
<td>RDCO$_2$</td>
<td>Raw Materials CO$_2$</td>
</tr>
<tr>
<td>SCM</td>
<td>Supplementary Cementitious Materials</td>
</tr>
<tr>
<td>TDF</td>
<td>Tyre Derived Fuel</td>
</tr>
<tr>
<td>UNFCCC</td>
<td>United Nations Framework Convention on Climate Change</td>
</tr>
<tr>
<td>WBCSD</td>
<td>World Business Council on sustainable Development</td>
</tr>
</tbody>
</table>
Chapter 1: Introduction and Background

1.1 Research Background

The Cement Sustainability Initiative (CSI) is a project initiated by a group of leading cement companies in 1999 and developed by the World Business Council on Sustainable Development (WBCSD) to promote cement sustainability by reducing the impact of cement production on the environment (WBCSD, 2012a). The initiative is supported by different cement producers around the world accounting for close to forty percent of the world’s cement production. Among those companies, Lafarge South Africa is represented by the mother company Lafarge-Holcim. The purpose of this initiative is summarised in two objectives, namely the reduction of carbon dioxide (CO\textsubscript{2}) emissions and provision of a framework for the sustainability of the cement industry which makes the industry greener and environmentally friendly (WBCSD, 2007 and Mapiravana, 2014).

The cement industry is responsible for 900 kg of CO\textsubscript{2} emitted in the atmosphere due to the production of one tonne of Ordinary Portland Cement (OPC) and this accounts for nearly 5 to 7 percent of global CO\textsubscript{2} emissions (Bhalchandra and Bhosle, 2010; Mathew et al., 2013; Benhelal et al., 2013). Cement production is growing fast due to the demand of China and India (Sarker, 2008) and is also influenced by African demographic trends such as the growing population, urbanisation need, and economic growth. Therefore, the emission of CO\textsubscript{2} should be reduced and managed without compromising the production of cement.

It should be noted that dioxide of carbon is one of the greenhouse gasses (GHG) and contributes to global climate change which is the greatest environmental challenge facing the world in this century (Department of Environmental Affairs, 2012). This paved the way for the adoption of the Kyoto Protocol in 1997 and the government of South African acceded to the protocol in 2002 by the implementation of the national climate change response strategy. The CSI and the national climate change response strategy have the same outcomes such as:

- The reduction of the impact of GHG on climate change;
- Emphasising environmental protection by implementing best practice of production of OPC, and
- The long-term sustainable development of the cement industry.

The South African government introduced a carbon tax bill as an initiative to promote good governance and effective implementation of the climate change response strategy at the national level. This initiative is regarded as a stimulus for investor appetite to shift towards low carbon technologies and alternatives. The carbon tax is presented by the government as a fiscal tool to achieve the commitment to reduction of its GHG emissions by 34 and 42 percent relative to business-as-usual in 2020 and 2025,
respectively as noted in the government submission to the United Nations Framework Convention on Climate Change (UNFCCC) in Paris in 2015 for the Conference of Parties (COP 21) (Partnership for Market Reading, 2016).

Sustainable development may be described as development which meets present needs by using natural products and energy in a way that does not harm the environment without compromising the ability of future generations to meet their needs for a long time (Department of Environmental Affairs [DEA], 2004; Hornby, 2005; Damtoft et al., 2008). There is a direct link between the managerial aspect of CO$_2$ emissions and the financial viability of the cement industry in the middle and long term which emphasises the implementation of best practice in the process of cement production. By considering the direct link mentioned above in the manufacturing process and current production level, the performance of the cement industry may be evaluated by the scale of commitments undertaken and implemented.

This research outlines the state of the art best practice in the process of cement production and it presents a comprehensive managerial approach for better control of emissions by using best practice in the path of sustainability of the cement industry.

1.2 Rationale of the Study

Gao et al. (2016) and Schneidere et al. (2011) find that the cement industry faces three major challenges, namely the rising costs in energy supply, the requirement of reduction of GHG emissions, (carbon dioxide) and the scarcity of high and good quality raw materials. These issues highlight the call for more affordable solutions and “best” OPC manufacturing technologies.

The synergy of addressing global climate change in the cement manufacturing industry by reducing the emission of CO$_2$ during the production process has narrowed the major issues down to two challenges:

- The substitution of OPC by geopolymer cement or ground granulated blast-furnace slag (GGBS) (Duxson and Provis, 2008; Kajaste and Hurme, 2016), and
- The use of more efficient energy in the process of cement production by burning used tyres (Schneider et al., 2011) and municipal solid waste (MSW) (Hasanbeigi et al., 2012; Schörghofer and Mallinson, 2015).

Although the substitution of OPC by geopolymer cement and GGBS have gained momentum, their performance relating to strength development and durability remains a challenge compared to those of OPC (Ludwig and Zhang, 2015); this led to intense research on geopolymer cement or concretes (Sonafrank, 2010; Hardjito et al., 2005; Sarker, 2008).
Feiz et al. (2015) established a life cycle assessment model based on six keys indicators of performance contributing to a better understanding of the CO₂ emissions of different cement products and may be regarded in the cement industry as a best practice for the main purpose of reducing raw material CO₂.

Furthermore, life cycle assessment (LCA) may be used as a tool to assess the contribution of alternative fuels to lessen CO₂ emission (Feiz et al., 2015) in the effort to reduce the effect of global climate change. However, Schneider et al. (2011) argue that the alternative fuels may have an influence on clinker properties and it may be a call for intense research on this issue. Nevertheless, the financial cost due to the carbon tax initiative and the environmental impact of using fossil fuel compared to alternative fuels (used tyres, waste wood, biomass, MSW) underline the use of latter fuels as best practice in the cement industry (Hasanbeigi et al., 2012).

The performance of the cement industry passes by the evaluation of one of the two challenges mentioned above by using the LCA model as a research methodology.

1.3 Research Objectives

This research dissertation aims to reach the following objectives:

1. To present an overview of CO₂ emitted from the production of Ordinary Portland Cement (OPC) and its impact on the environment;
2. To review the existing body of knowledge on the best practice of reduction of CO₂ in the cement industry,
3. To illustrate the optimisation of CO₂ from the manufacturing process of cement by developing a mathematical model, and
4. To describe the impact of the best practice on the reduction of CO₂ in the process of production of Portland cement for the sustainability of the industry.

1.4 Research Questions

To address the research objectives, the following questions needed to be answered:

a. What is the main source of CO₂ emissions in the manufacturing process in the production of OPC and what is the available best practice to mitigate the impact on the environment?

b. What technology and best practice may be adopted for the South African cement industry to meet the target of dioxide of carbon reduction and environmental protection set by the government and the CSI?
1.5 Research Approach

This study investigates the current state of practices in the South African cement industry to reduce the emission of CO$_2$ in the production of Portland cement. The research highlights the comparison between the current managerial strategies to those presented by the scientific and academic community as stated in the literature review.

1.6 Layout of this Dissertation

Chapter one provides some insight into the CSI as a response to global climate change by some major cement producers. The emission of CO$_2$ from the cement industry is briefly discussed. The objectives of this research are stipulated.

Chapter two presents an overview of CO$_2$ emissions from the production process of Ordinary Portland Cement. The literature review aims to provide a sound knowledge of the managerial aspect of CO$_2$ emissions as best practice and discusses the international conventions and local regulations stipulated by the South African government.

Chapter three highlights the research methodology of this research. Life cycle assessment as a methodology measures the emission of CO$_2$; this method assists in the decision making about the appropriate international best practice in the cement industry.

Chapter four deals with the current state of the local South African cement industry and its CO$_2$ emissions; Chapter four also discusses the availability of alternative materials to be used by South African cement producers. In addition, an analysis is presented based on the findings on the current practices in the local industry and a perspective on best practice for CO$_2$ reduction is presented in this chapter.

Chapter five presents recommendations based on this research. The conclusion of this investigation is also presented.
Chapter 2: Literature Review

2.1 Introduction

In this chapter, the emission of carbon dioxide (CO\textsubscript{2}) arising from the process of cement production and manufacturing is summarised and presented. The international conventions such as CSI and the local regulations of the South African government are reviewed. The different practices of environmental management for the reduction of CO\textsubscript{2} are discussed and presented as international best practice.

2.2 Carbon dioxide emitted from the cement manufacturing process

Cement is one of the necessities for economic development and essential for building and infrastructure construction (Benhelal et al., 2013; Uwasu et al., 2013). This necessity causes an increase in the demand and production of cement worldwide as observed in countries such as China and India (Sarker, 2008) and due to the demographic trend in Africa to use the socio-economic and infrastructure developments as instruments to fight poverty.

From the above mentioned, the global production of cement is forecast to grow considerably as corroborated by the volume of cement produced between 2005 and 2013 from 2310 mt to 4000 mt (a growth of 73 percent) (Kajaste and Hurme, 2016). In addition, Hasanbeigi et al. (2012) estimate that the demand and production of cement may be expected to be between 3680 mt to 4380 mt in 2050. This level of production is alarming as cement plants currently emit almost 0.9 tonnes of dioxide of carbon per each tonne of cement produced (Benhelal et al., 2013). Therefore, the reduction of carbon dioxide emission from cement production becomes an environmental issue to be addressed.

To address the emission of CO\textsubscript{2}, a thorough review of cement production is imperative to understand the source of carbon dioxide derived from the manufacturing process. The CO\textsubscript{2} emission from any cement plant may be illustrated by Figure 2-1 (Habert et al., 2010) and it is noted that the carbon dioxide is generated from four different sources (Benhelal et al., 2012) such as:

- The combustion of fossil fuel,
- Transportation of raw material,
- The energy generated for the transportation of raw material, and
- The decomposition of limestone.
The manufacturing process of cement can be summarised as comprising three phases: the raw material preparation, the pyro-processing (clinker production) and the clinker grinding and cement production; these phases may be linked to the four sources of emission of CO\(_2\) with the clinker production process to be the main contributor due to the combustion of fossil fuel and decomposition of limestone occurring during this phase. Furthermore, Benhelal et al. (2012) note that pyro-processing generates 90 percent of the emission from the cement plant and several researchers highlight the need to review the process by either:

- The substitution of Ordinary Portland Cement (OPC) by ground granulated blast-furnace slag (GGBS) or geopolymer cement (Duxson and Provis, 2008; Kajaste and Hurme, 2016), and
- The use of more efficient energy in the process of cement production by burning used tyres (Schneider et al., 2011) and municipal solid waste (MSW) (Hasanbeigi et al., 2012; Schörghofer and Mallinson, 2015).

Gartner (2004) notes that the CO\(_2\) emitted by any production of cement originates from two categories: those contained within the raw materials designated as “raw materials” CO\(_2\) (RMCO\(_2\)) and those which originate from the combustion of fossil fuel referred as “fuel-derived” CO\(_2\) (FDCO\(_2\)) with 50 and 40 percent of the total carbon dioxide emission of the cement plant, respectively (Mahasenan et al., 2002; Benhelal et al., 2012).

### 2.2.1. The raw material preparation

During this first stage of the cement manufacturing process, raw material rich in calcium is selected. The different steps of material preparation are presented in Figure 2-2. Clay, sand, and limestone are
identified as raw material and used in cement production; it should be noted that limestone contributes 75-90 percent of calcium carbonate (CaCO₃) found in the required raw feed chemical compositions to produce clinker (Gao et al., 2015). Although the minerals silica (SiO₂), iron oxide (FeO₃) and aluminium (Al) are included in the composition of raw material, CaCO₃ and magnesium carbonate (MgCO₃) are the typical raw material for the Portland cement clinker composition as a source of CO₂. In this cement manufacturing process, the limestone and clay (raw materials) are mixed and then crushed to powder form to meet specific proportions required for cement production. The OPC clinker chemical composition is presented in Table 2-1 (Benhelal et al., 2012).

Table 2-1: Ordinary Portland Cement clinker composition

<table>
<thead>
<tr>
<th>Component</th>
<th>Composition (% of total weight)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alumina (Al₂O₃)</td>
<td>3.39</td>
</tr>
<tr>
<td>Calcium oxide (CaO)</td>
<td>41.51</td>
</tr>
<tr>
<td>Iron oxide (Fe₂O₃)</td>
<td>2.54</td>
</tr>
<tr>
<td>Loss of ignition</td>
<td>34.83</td>
</tr>
<tr>
<td>Magnesium oxide (MgO)</td>
<td>2.59</td>
</tr>
<tr>
<td>Potassium oxide (K₂O)</td>
<td>0.57</td>
</tr>
<tr>
<td>Silicate (SiO₂)</td>
<td>14.03</td>
</tr>
<tr>
<td>Sodium oxide (Na₂O)</td>
<td>0.24</td>
</tr>
<tr>
<td>Sulphur dioxide (SO₃)</td>
<td>0.30</td>
</tr>
</tbody>
</table>

At this level, CO₂ is produced from the energy generated for crushing and transportation of raw material which form part of the ten percent of the total emission of the cement plant (Gao et al., 2015; Mikulčič
et al., 2013). The selection and the composition of raw materials from quarry may contribute towards 
best practice in the cement industry. Furthermore, the supply of good quality of raw material (clay and 
limestone) may result in an environmental issue on the long term (Gao et al., 2016) as the use of raw 
materials obtained from waste materials in the clinker and cement process will result in a significant 
saving of natural resources with a replacing 38 percent of limestone or 72 percent of clay (Usón et al., 
2013).

2.2.2 The Portland cement clinker production or the pyro-processing

During this process, the raw minerals are burned at a high temperature to produce alite (impure $\text{Ca}_3\text{SiO}_5$) 
which is the principal active component of OPC clinker. The production of OPC is an energy-intensive 
process during which raw materials are burnt at a high temperature of 1450°C (Habert et al., 2010; Gao 
et al., 2016).

It should be noted that the pyro-processing unit is the core of the manufacturing process of cement and 
the process is summarised as follows: preheater, calciner, kiln, and coolers. During this process, 90 
percent of the total thermal energy required by the cement production process is utilised. The thermal 
energy is produced by the combustion of fossil fuel. Therefore, the CO$_2$ emissions in the pyro-
processing unit are identified at two levels of the process of clinker production.

The first level of CO$_2$ emission in the pyro-processing unit starts with the raw materials being mixed, 
grounded and crushed in the preparation process; then the raw materials are pre-heated with hot exhaust 
gas (from the kiln exhaust and the heated air stream from the coolers) in the preheater tower where the 
temperature reaches 200°C to 900°C at the upper end and the bottom end of the preheater respectively. 
Habert et al. (2010) and Hasanbeigi et al. (2012) note that the decarbonisation of limestone in the pre-
heated tower produces 0.53 tonne of the total 0.92-tonne carbon dioxide produced by the cement 
industry which represents 57.61 percent of the total CO$_2$ emitted to produce one tonne of Portland 
cement. This decarbonisation of limestone and magnesium carbonate from raw materials starts when 
the materials are exposed to a temperature of 550°C in the preheater cyclones. The decarbonisation is 
presented in equations (1) and (2) (Gao et al., 2015).

$$\text{CaCO}_3 \rightarrow \text{CaO} + \text{CO}_2 \uparrow \quad (1)$$

$$\text{MgCO}_3 \rightarrow \text{MgO} + \text{CO}_2 \uparrow \quad (2)$$

Gartner (2004) refers this type of emission as raw materials CO$_2$ (RMCO$_2$) which is the bigger 
contributor of carbon dioxide emission from a cement plant due to the transformation of limestone into 
lime, called decarbonation. At this stage of decarbonation, more than one-third of the raw meal’s weight 
is lost (Gao et al., 2016). These reactions are presented in equations (1) and (2) occurring in the calciner
up to the kiln with a final temperature of 960°C (Mintus et al., 2006). Figure 2-3 shows the stages of the Portland clinker from raw grinding to burning.

![Figure 2-3: Clinker production process (Lafarge, 2010)](image)

In the kiln, the pre-calcined meal slides and tumbles down through increasingly hotter zones from 960°C to 1450°C where several chemical and physical reactions occur, and the list of those reactions are presented in table 2-2 (Benhelal et al., 2013; Gao et al., 2016). Once clinker reaches the bottom of the kiln where the temperature is at 1450°C, the red-hot Portland clinker is cooled to 100°C through different types of coolers and then transferred to a storage tank for the final process of grinding and cement production.

**Table 2-2: Physical and chemical reactions occurring in the production process (Benhelal et al., 2013)**

<table>
<thead>
<tr>
<th>Reaction name</th>
<th>Temperature range (°C)</th>
<th>Reaction</th>
<th>Location in the process</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decalcination</td>
<td>550-960</td>
<td>CaCO$_3$ → CaO + CO$_2$</td>
<td>Preheater, calciner, kiln</td>
</tr>
<tr>
<td>MgCO$_3$ dissociation</td>
<td>550-960</td>
<td>MgCO$_3$ → MgO + CO$_2$</td>
<td>Preheater, calciner, kiln</td>
</tr>
<tr>
<td>Formation of β-C$_2$S</td>
<td>900-1200</td>
<td>2CaO + SiO$_2$ → β-C$_2$S</td>
<td>Kiln</td>
</tr>
<tr>
<td>Formation of C$_3$S</td>
<td>1200-1280</td>
<td>β-C$_2$S + CaO → C$_3$S</td>
<td>Kiln</td>
</tr>
<tr>
<td>Formation of C$_3$A</td>
<td>1200-1280</td>
<td>3CaO + AlO$_3$ → C$_3$A</td>
<td>Kiln</td>
</tr>
<tr>
<td>Formation of C$_4$AF</td>
<td>1200-1280</td>
<td>4CaO + Al$_2$O$_3$ + Fe$_2$O$_3$ → C$_4$AF</td>
<td>Kiln</td>
</tr>
<tr>
<td>Formation of Liquid clinker</td>
<td>&gt;1280</td>
<td>Clinker$<em>{sol}$ → Clinker$</em>{liq}$</td>
<td>Kiln</td>
</tr>
</tbody>
</table>
The second level of CO$_2$ emission in the pyro-processing unit is presented by the combustion of fossil fuel in the calciner and kiln to produce thermal energy. It is documented that 40 percent of the total CO$_2$ emission in the cement plant is identified at this level. However, Benhelal et al. (2013) argue that this “fuel-derived” CO$_2$ (FDCO$_2$) emission may be underestimated and influenced by the poor performance of the kiln due to minor technical and management problems in the plant and lead to additional consumption and significant thermal waste resulting in a remarkable increase of volume of CO$_2$ emitted.

Furthermore, the FDCO$_2$ emission in the cement plant is influenced by the type of thermal energy requirements for the clinkering from the three existing processes such as the dry, semi-wet and the wet. The dry process is the most efficient modern coal-fired preheater plant using an average specific heat consumption of 3.8GJ/tonne clinker and emitting approximately 0.37 kg FDCO$_2$/kg clinker compared to the wet process with 6GJ/tonne clinker and a FDCO$_2$ emission of about 0.6kg/kg clinker by burning traditional carbon fuels, namely coal, oil or petroleum coke (Gartner, 2004; Damtoft et al., 2008). Table 2-3 summarises the FDCO$_2$ released and the thermal energy consumption by kiln technology based on traditional fuels per tonne of Ordinary Portland clinker.

**Table 2-3: Consumption of thermal energy and FDCO$_2$ released in the production process of clinker related to the type of kiln technology.** (Damtoft et al., 2008; Usón et al., 2013)

<table>
<thead>
<tr>
<th>Type technology</th>
<th>GJ/t of clinker</th>
<th>Kg fuel-derived CO$_2$/kg of clinker</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shaft kiln</td>
<td>3.1 – 6.5 and higher</td>
<td>No data found</td>
</tr>
<tr>
<td>Wet rotary kiln</td>
<td>5 – 7.5</td>
<td>About 0.6</td>
</tr>
<tr>
<td>Semi-dry rotary kiln</td>
<td>3.4 – 4</td>
<td></td>
</tr>
<tr>
<td>Dry long rotary kiln</td>
<td>Up to 5</td>
<td>0.4 – 0.6</td>
</tr>
<tr>
<td>Dry rotary kiln with preheater</td>
<td>3.1 – 4.2</td>
<td></td>
</tr>
<tr>
<td>Dry rotary kiln with preheater</td>
<td>3 - 4</td>
<td>0.31 – 0.38</td>
</tr>
</tbody>
</table>

Besides the fact that decarbonisation and the combustion of fuel foil in the kiln are both main contributors to the CO$_2$ emission at this stage of the pyro-processing unit, a small amount of emission is due to the production of electrical energy used by the electrical air fans in the coolers.

Damtoft et al. (2008) note that the principle of substitution of both raw and fuel materials in the production of cement may constitute the greatest scope for significant reduction in CO$_2$ emitted. More clearly this process of substitution depends on:

a) Increasing usage of raw material with high non-carbonate calcium contents compared to limestone, and
b) Alternative low fossil carbon-based fuels to traditional and conventional carbon-based fuels, respectively.

2.2.3 Clinker grinding and cement production

This is the third and final stage of the manufacturing cement process where the Portland clinker produced from the pyro-processing unit is blended with 4 to 5 percent gypsum to control the setting time of clinker. In addition, the clinker is mixed with a specific quantity, type and composition of additives such as slag power plant fly ash to meet the cement standards and market requirements (Benhelal et al., 2013; Gao et al., 2016); then the final mixed product is grinded to a powder and is ready for packing and dispatch as shown in Figure 2-4.

![Figure 2-4: Grinding and cement production (Lafarge, 2010)](image)

In South Africa, the local market is supplied with five types of Portland cement (see composition in Appendix A) namely: Portland Cement (CEM I), Portland Composite Cement (CEM II), Blast furnace Cement (CEM III), Pozzolanic Cement (CEM IV) and Composite Cement (CEM). The percentage by mass of additives are calculated to meet the specific purpose of each Portland cement. However, in the effort to reduce CO$_2$ emitted during cement production by reducing the content of clinker, other types of binders are produced and made available on the market. Those binders are known as supplementary cementitious materials (SCM) and these SCMs typically are ground-granulated blast furnace slag (GGBS), fly ash (FA) and silica fume (SF); the content of calcium oxide (CaO) in the SCMs are less than 50 percent of the total weight compared to OPC as shown in Table 2-4 (Ohanyere, 2012; Silica Fume Association, 2005).

Ludwig and Zhang (2015) observe that the main drawback of cement with a high percentage of SCM is the influence of SCMs on concrete properties such as the low early strength and durability. Thus, the
need of new chemical substances such as new concrete admixtures (accelerators, etc.) with a significant impact on concrete with a high volume of SCM to make it suitable for use in engineering is corroborated by the finding of Alexander and Beushausen (2010).

The CO$_2$ emission at this final stage of cement manufacture produces the remaining portion of the 10 percent of the total emission from the cement plant and this CO$_2$ is due to the production of electrical energy needed for final grinding and blending (Gao et al., 2015; Mikulčić et al., 2013).

Table 2-4: Properties comparison 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>$\text{Al}_2\text{O}_3$ content, %</td>
<td>5</td>
<td>23</td>
<td>18</td>
<td>12</td>
<td>&lt; 1</td>
</tr>
<tr>
<td>$\text{CaO}$ content, %</td>
<td>62</td>
<td>5</td>
<td>21</td>
<td>40</td>
<td>&lt; 1</td>
</tr>
<tr>
<td>$\text{Fe}_2\text{O}_3$ content, %</td>
<td>3</td>
<td>11</td>
<td>6</td>
<td>1</td>
<td>&lt; 1</td>
</tr>
<tr>
<td>$\text{SiO}_2$ content, %</td>
<td>21</td>
<td>52</td>
<td>35</td>
<td>35</td>
<td>85 to 97</td>
</tr>
<tr>
<td>Fineness as surface area, m$^2$/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 1. Information from SFA and Kosmatka et al. (2002).

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

It is noteworthy that approximately 100 kWh of electricity is needed to produce one tonne of cement in an efficient cement plant (Benhelal et al., 2013). Usón et al. (2013) and Madlool et al. (2011) summarised the average electrical energy consumption in each section of the manufacturing process. This is presented in Table 2-5. The electricity is employed to run the various electrical components of the cement plant such as cooling fans, kiln motors, conveyors and grinders; the electricity is also used in the production process and for the lighting systems and electrical devices in the plant.

Gartner and Macphee (2011) calculate that 100 kWh of electricity consumption emits close to 100 kg of CO$_2$ per tonne of cement when the electricity is produced with coal as the main fuel. In South Africa,
the equivalent of 1 kWh of electricity supply by Eskom corresponds to 1.03 kg of CO₂ emission (Urban Earth, 2015).

**Table 2-5: Electrical energy distribution in the cement industry (Usón et al., 2013; Madlool et al., 2011)**

<table>
<thead>
<tr>
<th>Section/equipment</th>
<th>Electrical energy consumption (kWh/t)</th>
<th>Share (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mines, crusher, and stacking</td>
<td>1.50</td>
<td>2.00</td>
</tr>
<tr>
<td>Re-claimer, raw material grinding and transport</td>
<td>18.00</td>
<td>24.00</td>
</tr>
<tr>
<td>Kiln feed, kiln and cooler</td>
<td>22.00</td>
<td>29.30</td>
</tr>
<tr>
<td>Coal mill</td>
<td>5.00</td>
<td>6.70</td>
</tr>
<tr>
<td>Cement grinding and transport</td>
<td>23.00</td>
<td>30.70</td>
</tr>
<tr>
<td>Packing</td>
<td>1.50</td>
<td>2.00</td>
</tr>
<tr>
<td>Lighting, pumps, and services</td>
<td>4.00</td>
<td>5.30</td>
</tr>
<tr>
<td>Total</td>
<td>75.00</td>
<td>100.00</td>
</tr>
</tbody>
</table>

In brief, the sources of CO₂ emission in the cement manufacturing processes have been discussed and summarised in Table 2-6 and the data are shown in Figure 2-5. Nevertheless, the electrical energy consumption in table 2-5 seems to be under-evaluated in comparison to the observation by Benhelal et al. (2013). Sathaye (2005) states that the current best practice in the consumption of electrical energy is around 75 to 80 kWh per tonne of clinker. However, Benhelal et al. (2013) also include the electrical energy needed for lighting, office equipment, etc. In South Africa, the typical electrical consumption in a cement plant is calculated to be 110 kWh/tonne of cement produced, which includes the consumption for other devices such as office equipment. (Otterman, 2011; Ohanyere, 2012).

**Table 2-6: Summary of the source of CO₂ emission in the cement plant**

<table>
<thead>
<tr>
<th>Items</th>
<th>Kg of CO₂ emission per tonne of cement produced</th>
<th>Share (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decarbonisation of limestone</td>
<td>530</td>
<td>51.96</td>
</tr>
<tr>
<td>Combustion of fossil fuel</td>
<td>390</td>
<td>38.24</td>
</tr>
<tr>
<td>Electricity consumption</td>
<td>100</td>
<td>9.80</td>
</tr>
<tr>
<td>Total</td>
<td>1020</td>
<td>100</td>
</tr>
</tbody>
</table>
Figure 2-5: Source of CO₂ emission in the cement manufacturing process

The next section of this dissertation will discuss greenhouse gases (GHG) and their impact on the environment.

2.3 Greenhouse gases and their impact on the environment.

Recently climate change has become a global threat due to the increase in the concentration of greenhouse gases (GHG) in the atmosphere. The GHG include carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O), perfluorocarbons (PFCs), tropospheric ozone (O₃), sulphur hexafluoride (SF₆), and chlorofluorocarbons (CFCs) (Damtoft et al., 2008; Herzog, 2009; Department of National Treasury, 2013); The world GHG emissions are presented in Appendix B.

The sun’s radiation heats the surface of the Earth and some of this radiation is trapped in the atmosphere by GHGs. The Earth’s surface has become hotter this century compared to the 1900s due to the heat generated from the warming of the lower atmosphere (troposphere) by the trapped radiation (Damtoft et al., 2008).

Department of National Treasury of South Africa (DNT) (2013) noted that in South Africa, GHGs emitted in the atmosphere amounted to 547 million tonnes in 2009 and the key GHGs are CO₂, CH₄, N₂O, and PFCs; the South African cement industry contributes 1 percent to the emissions. Furthermore, Mwakasonda (2012) highlighted that the CO₂ emitted in 2009 in South Africa amounted to 40 to 60 percent of the entire emissions from Sub-Saharan Africa; Ohanyere (2012) ranks South Africa as the ninth largest CO₂ emitting country in the world and first in Africa based on 2009 emissions data.
Gao et al. (2015) state that the world faces catastrophic consequences due to uncontrolled and unmitigated emission of CO$_2$ by the cement industry, the latter being among the most significant source of GHG (Benhelal et al., 2013). Various authors (Matthew et al., 2005; Damtoft et al., 2008; Climate Change, 2007; Rahman et al., 2009) describe those catastrophic consequences as:

- Increase in the global average temperature: From 1990 to 2100, a projected increase from 1.4-5.8$^\circ$C of the global average temperature would pose a risk to several systems and biodiversity leading to the extinction of 20 to 30 percent of animals and plants,
- Risk of extreme weather events: The intensity of tropical cyclones, intense precipitation events, increase in heat waves, and
- Risk of large-scale discontinuity: Rise of sea level which is associated with loss of coastal area, the shrinkage of the Arctic sea ice by more than 7 percent from 1978 to 2003; projections show a predominantly ice-free Arctic Ocean in summer by 2010.

In the global effort to address the negative impact of greenhouse gas emissions, the United Nations Framework Convention on Climate Change (UNFCCC) initiated the Copenhagen conference and the Kyoto Protocol where an agreement was reached and commitment undertaken by some countries to significantly reduce their emissions of GHGs (Zhang et al., 2012; DNT, 2013). In this perspective of reduction of GHG emissions from the actual business-as-usual growth trajectory of emissions, the South Africa government pledged under the Copenhagen accord to implement appropriate action at national level to mitigate the GHG emissions (DNT, 2013).

2.4 The South African national policy on climate change

As a response to the international efforts to reduce the GHG emissions in the world stated in the Kyoto Protocol and the United Nations Framework Convention on Climate Change (UNFCCC), the South African government via the Department of Environmental Affairs (DEA) published the National Climate Change Response Policy (NCCRP) white paper in 2011 (Manzini, 2016). The 2011 white paper seeks to ensure a coordinated and consistent policy framework to address climate change with the specific target of curbing GHG emissions by 34 and 42 percent respectively below the business-as-usual trajectory by 2020 and 2025 (DNT, 2013).

More recently, during the discussion held during COP 21 in Paris, governments, businesses and several organisations subscribed to the Paris Agreement which required a sizable reduction in energy-related carbon dioxide (CO$_2$) in large emitters, including in developing economies. South Africa ratified the Paris Agreement in April 2016 and endorsed the Nationally Determined Contribution (NDC) with key expectations as follows (Hemraj, 2016):
The NDC requires that emissions peak between 2020 and 2025, plateau for a ten-year period between 2025 and 2035 and decline from 2036 onwards,
- GHG emissions are expected to range between 398 and 614 mt CO$_2$ – eq.

The implementation of a carbon price is driven by the introduction of the 2011 white paper based on a carbon tax which should significantly impact the behaviour of consumer and producer and investment in low carbon technology and alternatives (DNT, 2013). In addition, the carbon tax was noted as an important component in South Africa’s submission of the NDC to the United Nations for COP21 (DNT, 2015a; Hemraj, 2016). Figure 2-6 shows the implementation process of the carbon tax in South Africa.

Figure 2-6: Carbon Tax Policy Process (Hemraj, 2016)

In 2015 the government through the national treasury published the Draft Carbon Tax Bill for public comment and marked the next step for the implementation of the carbon tax following the 2013 Carbon Tax Policy Paper and the 2014 Carbon Offsets Paper (DNT, 2015b).

South Africa is among other countries in the world who see the carbon tax as an important component of the country’s mitigation strategy to lower GHG emissions. The carbon tax has been implemented in several countries around the world with the Scandinavian nations as the pioneers of the policies in the early 1990s and the European countries in 2005. It should be noted that a carbon tax on coal has been implemented by India and China is considering the introduction of a carbon tax (DNT, 2013).
2.5 The Cement Sustainability Initiative (CSI)

The Cement Sustainability Initiative (CSI) was established by the World Business Council for Sustainable Development (WBCSD) to help leaders of the cement industry to manage the environmental impact of their companies’ processes and products (Uwasu et al., 2014) and its main objective is to have the cement plants around the globe collectively improve the environmental performance of the industry (Mapiravana, 2014).

The WBCSD was established in 1996 by the participation of business in the Earth Summit where the reduction of the human impact on the environment was discussed and tangible initiatives were presented (WBCSD, 2016). Among several agreements discussed during the Earth Summit, the United Nations Framework Convention on Climate Change (UNFCCC) was accepted to reconcile worldwide economic development with the protection of the environment (UNFCCC, 2007).

To date, 24 major cement producers – accounting for around 30 percent of global cement production – with operations in more than 100 countries participate in the global efforts of the CSI, in comparison to the 10 cement producers in 1999. They believe there is a strong business case for the pursuit of sustainable development and under the CSI published a set of guidelines for the selection and use of raw and fuel material in the cement manufacturing process (WBCSD, 2014a; WBCSD, 2014b; WBCSD, 2012b).

WBCSD (2007) described the CSI as a large global sustainability programme with steady progress to climate protection, aiming at an average of 12 percent reduction of CO$_2$ emission intensity by the CSI members between 1990 and 2006. Among the major sustainability issues to be addressed by the cement industry were:

- Climate protection,
- Air emissions,
- Use of raw and fuel materials, and
- Local impacts on land and communities.

According to Usón et al. (2013), they are related to the efforts to achieve short-term energy and climate goals of 20 percent by:

- Reducing of GHG emissions,
- Increasing the share of renewable energy, and
- Improving energy efficiency.

In conclusion, Kajaste and Hurme (2016) notice that commitments such as CSI implemented by the cement industry were necessitated by a large amount of CO$_2$ emissions, considerable use of energy and
depletion of resources. In the perspective of achieving these objectives, the best practice available in the literature is also discussed in this chapter.

2.6 Best practice in cement production

Benhelal et al. (2013) and Schneider et al. (2011) identify three approaches to contribute significantly to carbon mitigation: energy efficiency in clinker production as the first approach, alternative fuels as second and alternative raw materials as third.

2.6.1 Energy efficiency in clinker production

Recent research indicates that the dry rotary kiln with preheater and precalciner is the most energy efficient cement production process compared to others as presented in Table 2-3 as the exhaust gases from the kiln and the cooler systems are used for the calcination of raw material (Habert et al., 2010; Schneider et al., 2011; Benhelal et al., 2013). Additionally, Benhelal et al. (2013) mention that changing from a wet to a dry process saves up to 50 percent of required energy and reduces 20 percent of CO₂ emissions.

Schneider et al. (2011) and Benhelal et al. (2013) discuss further improvements in the current level of energy efficiency by generating electricity from the flue gas (preheater) and hot air (cooler systems) and by using the actual waste heat in a recovery system they further suggest that the example of China and Japan where the production of electricity from boilers which are widely integrated in cement kilns may be followed in other parts of the world.

Interestingly, the generated renewable electricity produced from the waste heat recovery system will reduce the dependency on the national grid resulting in a green environment with less CO₂ emitted (Benhelal et al., 2013). Another example of energy efficiency is set in Spain by a cement plant using exhaust gases from the clinker cooler to dry sewage sludge and using the dried sewage sludge as an alternative fuel for the kiln (Cembureau, 2017).

2.6.2 Alternative fuels

Gartner (2004) noted that energy efficiency in the cement industry had improved due to the reduction of the industry’s dependency on oil in mid-1970 due to the OPEC oil embargo, which led Western countries to intensify research into and development of new technology to improve the Ordinary Portland Cement manufacturing process. The new technology is based on the substitution of oil by coals, coke and a wide variety of waste fuel as the primary combustible. Habert et al. (2010) found the new process technologies had an energy efficiency of 10 percent from 1973 to 1983 and a decrease in the improvement rate from 1983 to 2003; the reduced improvement rate coupled with the necessity for
the reduction of cost production and lower CO$_2$ emission paved the way for a new research area of carbon-neutral fuels (Table 2-7) as new combustible.

**Table 2-7: Energy efficiency of cement fuels (Habert et al., 2010)**

<table>
<thead>
<tr>
<th>Material</th>
<th>Emission of CO$_2$ factor (gCO$_2$/MJ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Animal meal</td>
<td>0</td>
</tr>
<tr>
<td>Coal</td>
<td>96</td>
</tr>
<tr>
<td>Natural gas</td>
<td>54.2</td>
</tr>
<tr>
<td>Petroleum coke (Pet coke)</td>
<td>101</td>
</tr>
<tr>
<td>Plastic</td>
<td>75</td>
</tr>
<tr>
<td>Refused derived fuels</td>
<td>8.7</td>
</tr>
<tr>
<td>Used tyres</td>
<td>85</td>
</tr>
<tr>
<td>Waste oil</td>
<td>74</td>
</tr>
<tr>
<td>Waste wood</td>
<td>0</td>
</tr>
</tbody>
</table>

From Table 2-7, only animal meal and waste wood may be regarded as carbon-neutral fuels due to the zero net CO$_2$ emission. Besides the net emissions of CO$_2$ observed during the combustion of materials listed in Table 2-7 in incineration plants, those materials burned in the cement kiln may contribute significantly to net reduction in emissions of CO$_2$ and better environmental management as no residue is generated and ashes are completely incorporated in the clinker (Damtoft et al., 2008; Habert et al., 2010). Additionally, Damtoft et al. (2008) argue that the burning of the animal meal and waste wood can be regarded as a reservoir for GHG and decay to form methane which is more powerful than CO$_2$.

Usón et al. (2013) classify the alternative fuel into three categories: gas (e.g. natural gas, biogas), liquid (e.g. used oils and solvents) and solid (e.g. used tyres, waste wood, plastic, animal meal, municipal waste, sludge).

The more widely used materials as alternative fuels- are an animal meal, municipality solid waste, sewage sludge, waste oil, lumpy materials, and used tyres, due to the waste management consideration. One of the most powerful alternative fuels is used tyres due to their high level of energy content (Usón et al., 2013; Schneider et al., 2011; Damtoft et al., 2008); however, Pipilikaki et al. (2005) in another study recommend limiting used tyres to 30 percent by weight of the fuel mix due to the presence of zinc which may affect the properties of the clinker.

Schneider et al. (2011) argue that the substitution of fossil fuel by alternative fuels may alter the clinker properties; however, they notice the possibility of manufacturing high-performance Portland cement.
clinker by the implementation of adequate comprehensive production and quality control for the significant substitution rates of alternative fuels.

Cembureau (2017) estimates that by 2050, the thermal energy consumed in the kiln will be potentially from the combustion of 40 percent of traditional fuels (30 and 10 percent for coal and Petcoke respectively) and 60 percent of alternative fuels (about 40 percent could be biomass) which could lead to a reduction of 27 percent of FDCO$_2$ emissions.

2.6.3 Alternative raw materials

Driven by the two factors of CO$_2$ constraint and cost reduction at the global level, cement producers are considering other suitable material in their cement production (Damtoft et al., 2008; Schneider et al., 2011).

From this perspective, clinker may be partly replaced by selected materials that react with calcium hydroxide and are commonly named supplementary cementitious materials (SCM): fly ash (FA), granulated blast furnace slag (GBFS), silica fume (SF) and natural pozzolans (Habert et al., 2010). It should be noted that FA, GBFS, and SF are industrial by-products from other industries such as coal fire plants and steel plants.

In 1967, in the effort to develop an alternative cement to Ordinary Portland Cements, Glukhovsky made a significant contribution to the understanding and development of alkaline cement which led Davidovits to develop geopolymer cement (Shi et al., 2011) which shows good mechanical performance and attractive environmental benefits. It is regarded as one of the best long-term options for sustainability and projected to replace OPC from 2030 (Tempest et al., 2015; Kajaste et al., 2016).

In conclusion, Kajaste et al. (2016) recognises the substitution of clinker with alternative raw materials as an efficient way to improve GHG management in the production process; the cement industry may reduce up to 312 mt in the level of CO$_2$ emitted during 2013 in annual cement production by increasing the global use of alternative raw materials to 34.2 percent in cement.

2.7 Conclusion

In this chapter the manufacturing process of OPC was presented and the sources of emission of carbon dioxide CO$_2$ related to the production process described. In addition, best practice for CO$_2$ reduction from the process of production of cement was discussed. The current initiatives of the South African government and international bodies such as the World Business Council for Sustainable Development (WBCSD) were highlighted.
Chapter 3: Research Methodology

3.1 Introduction

In this chapter the research methodology of this investigation to answer the research question, which was “What technology and best practice may be adopted by the South African cement industry to meet the target of dioxide of carbon reduction and environmental protection set by the government and the CSI” is outlined by coupling the content analysis methodology and life cycle assessment (LCA) methodology (Chen et al., 2010). It should be stated that the first research question was addressed in Chapter 2.

The choice of this approach and the research method applied in this study are argued in this chapter; the acquisition and the analysis of data are explained in the current research methodology.

The limitations of this research study are presented under the scope of the LCA method. The limitations are guided by the constraint of time and availability of resources allocated for this investigation.

3.2 Research Methodology

Elo and Kyngäs (2007) note that content analysis aims to describe a phenomenon in a conceptual form; content analysis is also defined by Krippendorff (1980) as a research technique for making replicable and valid interferences from data in the contexts of their use for gaining knowledge and new insights. According to the latter perspective, to attain a condensed and broad description of the phenomenon, two methods are distinguished in the content analysis methodology, namely the qualitative method and the quantitative method (Ankrah, 2007; Krippendorff, 1980).

The description of the phenomena in any research study is constructed by seeking to answer the ‘Why’ and ‘How’ questions when applying the qualitative method and the ‘How much’ or ‘How many’ questions in the quantitative method (Ankrah, 2007). In addition, Lam and Van Der Voordt (2002) and Matodzi (2015) mention that the quantitative method is focused on the quantitative measurement of some characteristics while the qualitative method is specifically important in behavioural sciences, where the focus is to discover the underlying motives of human behaviour.

In this research study, the quantitative method was chosen as research methodology as strong evidence for explaining the phenomenon is gathered by collecting numerical data from secondary sources and analysed using a mathematically based method (Matodzi, 2015). Furthermore, the answer to the second research question of this study is related to the economic and environmental assessment of the use of alternative practices in the manufacturing process of cement by local cement producers which is not directly related to explaining a phenomenon of human behaviour; however, the research objectives and strategy are more related to the quantitative approach.
3.3 **Data collection method**

Johnson and Turner (2003) define the data collection method as a technique used to collect empirical research data and identify six major methods of data collection applicable to quantitative methodologies such as focus groups, texts, questionnaires, observation, interviews, and secondary data.

In order to collect empirical research data, the secondary data method, also known as existing or available data (Johnson and Turner, 2003), the method was considered to gather necessary data from published reports, articles, official documents, journals papers, etc.

3.4 **Data analysis method**

For the analysis of data gathered, Microsoft Excel spreadsheet software was used to establish the statistical outputs. The empirical data were presented in the form of charts, graphs, and tables.

3.5 **Life Cycle Assessment (LCA)**

The potential environmental impact of the life cycle of a product based on the relevant inputs and outputs at the environmental level is calculated and evaluated using LCA (DEAT, 2004). Fava (1997) views LCA as a method to build a quantitative and qualitative inventory of environmental burdens or releases and to identify alternatives to improve the environmental performance of any product.

Noticed as one of the tools for a wide range of environmental management tasks since the 1992 UN Earth Summit (DEAT, 2004), the LCA was used in this research study for an evaluation of the environmental assessment and the economic implications of best practice in the manufacturing process of South African cement production.

3.5.1 **Goal and scope**

The goal of this research is to compare the environmental and economic impact of carbon dioxide emission of the current production process to a new modified production process of Ordinary Portland Cement by considering the carbon tax bill initiated by the South African government. The modified production process will cover the use of alternative fuel materials.

In addition, the goal of this research is to showcase the contribution of using alternative fuel material such as used tyres in the local cement manufacturing process to achieve two of the main objectives of cement sustainability initiative (CSI): the climate protection and reasonable usage of raw materials for the sustainability of the industry.

The scope of this investigation is to calculate the carbon dioxide (CO₂) level emitted from the production of OPC by using either only coal as fuel material or coal and used tyres simultaneously as fuel materials.
by South African producers based on their combined 2016 domestic cementitious production whilst all six South African cement producers such as PPC, AfriSam, Lafarge Holcim, NPC-Cimpor, Dangote Cement (Sephaku) and Mamba Cement are operational. It should be noted that the industry of cement in South Africa is very sensitive (Ohanyere, 2012) and data were incomplete for an intensive evaluation for each producer in this study.

The functional unit in this research is the production of 1 kg of clinker as the main component of cementitious products: Ordinary Portland Cement and blended cements as described and in accordance with SANS 50197-1 as shown in appendix A. Mungai et al. (2013) mention that the term “cementitious products” refers to cement complying with SANS 5019-1. Clinker production has the highest level of environmental impact in the manufacturing process of cement. The LCA system for this study is presented in Figure 3-1. The figure shows the inputs, the product system and the output of the cement Portland production.

For this study, the LCA method has a system sub-divided in three compartments, namely: raw material production, clinker production, and cement final production as shown in Figure 3-1.

Although most cement plants are located close to limestone quarries, the transportation system and the distance to transport fuel material for the kilns to the cement plants were designed in such a way to reduce the related cost and CO$_2$ emissions. Therefore, the CO$_2$ emissions from the transport for primary fuel material were not considered in this LCA study as little data were available.

Estimation of CO$_2$ emission for the transport of secondary fuel material, namely used tyres and waste oil should be evaluated based on the mode of transport, the capacity of the storage (either for used tyres or waste oil) and the distances between the stores and the cement plants. The total CO$_2$ emitted should be added to the total CO$_2$ obtained from the combustion of alternatives fuel material. Due to the lack of accurate and sufficient local data on the transport of alternative fuel materials, the carbon dioxide related to transport was omitted in this study.

### 3.5.1.1 Emission Types

For this evaluation of CO$_2$ from the use of alternative fuel in the manufacturing process of cement, the type of emissions should be differentiated. The InEnergy Report (2010) classified the emissions of greenhouse gas in three types and defined as mentioned below:

- **Scope 1 (direct) emissions of GHG**: GHG emitted directly from sources controlled or owned by the entity conducting the report.
• \textbf{Scope 2 (indirect) GHG emissions:} those emissions related to activities of the entity conducting the report. However, the sources are controlled by another entity. Those emissions of GHG could be due to the usage of stream, heat, and electricity bought from another supplier.

• \textbf{Scope 3 (other indirect) GHG emissions:} Based on internal requirements, pre-set standards, and CDP requirements, those GHG emissions may vary from one entity to another. Emissions could be generated by outsourced activities, organisational activities and final production transportation by a third party and staff commuting.

In light of the InEnergy report (2010), the scope of emissions of this study are as follows:

**Scope 1 (direct):** emissions emitted from the burning of used tyres in the cement kiln; **Scope 2 (indirect):** these emissions refer to the transport of the used tyres from the storage facilities of tyres to the cement plants; and finally **Scope 3: (other indirect):** emissions due to the use of purchased electricity for any mechanism of transport of used tyres to the cement kiln. It should be noted that this
latter scope 3 will not be considered in the evaluation due to the lack of details on the type of transport mechanism from the truck to the kiln.

3.6 Mathematical Model

In this research study, the mathematical model for the optimisation of CO\textsubscript{2} from the manufacturing process of cement is developed. It should be noted that this mathematical model only deals with the combustion of fuel material in the kilns to produce clinker. In addition, the volume of clinker in this research has been taken as the same volume of cement produced by the manufacturing company.

The mathematical model consists of an objective function to find the best proportion of the three fuel materials (coal, used tyres and waste oil) studied in this research for the reduction of CO\textsubscript{2} emission resulting from the combustion of fuel materials in the kiln; the objective function was resolved by using the linear programming Lingo software and the final solution to the mathematical model represents the weight of the constituents, namely: coal, used tyres and waste oil.

The first objective function can be written as:

\[
Z\left(\text{Rand/year}\right) = \sum_{i=1}^{n} \sum_{j=1}^{m} a_i X_{ij} + \sum_{i=1}^{n} \sum_{j=1}^{m} c_i X_{ij} \tag{3}
\]

Where:

- \(Z\) : the annualised cost of fuel materials used in the production of cement (R/year)
- \(a_i\) : cost of purchasing fuel material \(i\) (with \(i = 1, 2, 3, n\)). For this study the value of \(n\) is limited to 3 kinds of fuel material: coal, used tyres and waste oil.
- \(c_i\) : cost of CO\textsubscript{2} emitted from the combustion of fuel material \(i\) (with \(i = 1, 2, 3, n\)).
- \(X_{ij}\) : the quantity of fuel materials \(i\) to be burnt in unit \(j\) (where \(j = 1, 2, 3, \ldots, m\)).

The first term in the objective function is related to the cost of purchasing the fuel material while the second term represents the cost of CO\textsubscript{2} emitted from combustion of fuel materials in the kiln unit.

3.6.1 Constraints

Constraints were selected in such a way to achieve cost efficiency and reduction of emissions. In addition, the \(a_i\) and the \(c_i\) were parameters in the equations which may vary from one country to another and from one company to another based on their goals and target in the reduction of emissions derived from their production of cement. Therefore, the cost of CO\textsubscript{2} was not defined as a model constraint, meaning not defined as a decision variable. The constraints of cement production applicable to the objective function are presented below:
a) Demand constraint

The production ($P$) of cement should be greater than or equal to the demand for cement. Therefore, the demand ($D$) used in this study is equal to:

$$\sum_{j=1}^{m} P = D \quad (4)$$

b) Energy satisfaction

This constraint is related to the type of process of cement production. As established, all the South African cement plants use the dry kiln process and energy satisfaction is:

For minimum energy:

$$\sum_{i=1}^{n} \sum_{j=1}^{m} e_i X_{ij} \geq 3000xD \quad (5)$$

For maximum energy:

$$\sum_{i=1}^{n} \sum_{j=1}^{m} e_i X_{ij} \leq 4000xD \quad (6)$$

$e_i$: Is the energy obtained from the combustion of fuel material $i$ and presented in Table 3-1.

**Table 3-1: Average value of $e_i$ for different kinds of fuel material (Steyn and Minnitt, 2010; Laboy-Nieves, 2014).**

<table>
<thead>
<tr>
<th>Energy $e_i$ in GJ/t</th>
<th>Coal</th>
<th>Used tyres</th>
<th>Waste oil</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>26</td>
<td>31.4</td>
<td>20</td>
</tr>
</tbody>
</table>

c) Fuel proportion:

To avoid the changes of clinker properties, six limits in the proportions of fuel materials were considered:

For fuel proportion:

$$\frac{\sum_{i=1}^{n} X_{i1}}{\sum_{i=1}^{n} \sum_{j=1}^{m} X_{ij}} = z \quad (7)$$

With $z$ representing the value of proportion and presented in Table 3-2.

**Table 3-2: z-Value for proportions of fuel materials**

<table>
<thead>
<tr>
<th>Item</th>
<th>Lower Quantity</th>
<th>Higher Quantity</th>
<th>Optimum value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>0.75</td>
<td>1</td>
<td>$\geq 0.75$</td>
</tr>
<tr>
<td>Used tyres</td>
<td>0</td>
<td>0.20</td>
<td>$\leq 0.20$</td>
</tr>
<tr>
<td>Waste oil</td>
<td>0</td>
<td>0.05</td>
<td>$\leq 0.05$</td>
</tr>
</tbody>
</table>
d) Capacity constraint

Each unit of production has its own limit to the volume of cement to be manufactured. From the perspective of good management in the production of cement and protection of the unit of production, an assumption of only 80 percent of full capacity in energy equivalent of maximum energy (4000 mt/t of clinker) may be utilised. Therefore, the total capacity of the unit is:

$$\sum_{i=1}^{n} \sum_{j=1}^{m} e_i X_{ij} = 0.8 \times 4000 \times CAP_j$$

(8)

With $CAP_j$ is the maximum capacity of production of unit $j$.

By solving the objective function with the Lingo program for the lower and the higher limits of proportions of each fuel material, $X_{ij}$ will provide the minimum and the maximum weights of fuel material needed in the optimisation of the CO$_2$ emissions.

3.7 Conclusion

In conclusion, the quantitative content method was considered for this investigation and the data collection and data analysis were presented. In addition, the mathematical model for the optimisation of CO$_2$ emission from the combustion of fuel material was explained. The limitation of this study was presented, the goal and scope of this study were presented in the life cycle assessment for environmental impact evaluation.
Chapter 4: Findings and Analysis

4.1 Introduction

This chapter contains findings on the status of the South African cement industry, the CO₂ emissions related to the level of production is presented and the approach to managing the emissions and the environmental impact is presented and analysed. The proposed approach considers the use of three fuel materials, namely coal, used tyres and waste oil simultaneously as combustible in the cement kiln which leads to computation using the mathematical model for the programming goal of optimization of resources.

4.2 Findings

4.2.1 Overview of South Africa cement industry

With an urbanisation rate of 64.8 percent, the domestic consumption of cement is estimated at 243 kg of cement per capita (PPC, 2017) which makes a long-term investment in the South African cement industry attractive. Six manufacturers, namely: PPC, AfriSam, Lafarge Holcim, NPC/Cimpor, Sephaku Cement and Mamba Cement together have a current national cement production capacity of 17.4 million tonnes per annum (mtpa) with allocated capacity in percentage as shown in Figure 4-1.

![Figure 4-1: Cement production capacity in percentage (Dangote Cement, 2017)](image)

All cement kilns in South Africa use the dry process (Muigai et al., 2013) and there are twenty-one kilns in total for all six producers with different average ages as presented in Table 4-1. It should be noted that Dangote Cement (Sephaku) and Mamba Cement are the new producers in the local market with
respectively four and two years of production in 2018. The location of all cement plants in South Africa is presented in Appendix C.

Table 4-1: Description of South African cement kilns (Baldeira, 2016; Ohanyere, 2012)

<table>
<thead>
<tr>
<th>Producer</th>
<th>Kilns</th>
<th>Minimum Age (Years)</th>
<th>Maximum Age (Years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PPC</td>
<td>13</td>
<td>21</td>
<td>47</td>
</tr>
<tr>
<td>AfriSam</td>
<td>3</td>
<td>21</td>
<td>34</td>
</tr>
<tr>
<td>Lafarge</td>
<td>2</td>
<td>24</td>
<td>34</td>
</tr>
<tr>
<td>NPC Cimpor</td>
<td>1</td>
<td>24</td>
<td>24</td>
</tr>
<tr>
<td>Dangote Cement</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Sephaku)</td>
<td>1</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Mamba Cement</td>
<td>1</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

N.B: The minimum and maximum ages are calculated from 2018.

In 2015, the domestic production of cement was 13.8 million tonnes per annum (mtpa) before the input of Mamba Cement’s production. However, the cement production decreased to a forecasted value of 13.4 mtpa in 2016 including Mamba Cement’s production (Emeran, 2016) due to the decrease in domestic cement sales growth. The evolution in the demand and capacity of the cement industry in Southern African are presented in Figure 4-2; where the following observations are made by PPC (PPC, 2017):

- A new cement unit SK9 of PPC with the latest production technology will be operational by the end of 2018 and will increase the capacity close to 20 million tonnes per annum (mtpa) of cement,
- In 2020, an estimated 3.0 mtpa of industry capacity will not meet emissions regulations, and
- After 2020, it is estimated that additional capacity will be required as the cement industry will be running at high capacity.

It is highlighted that the cement industry supply and demand presented in Figure 4-2 was obtained from the Southern African cement plants, except that some of the capacity comes from the PPC cement plant in Botswana.
Figure 4-2: Annual cementitious supply and demand in Southern Africa, Botswana, Lesotho & Swaziland (PPC, 2017)
4.2.2 Overview of alternative fuel materials in South Africa

The current environmental management of waste materials in South Africa shows that cement producers are more likely to use liquid and sludge waste, used oil and waste tyres as alternative fuel material for their production of cement as illustrated in the following cases:

The National Oil Recycling Association South Africa (NORA-SA) is mandated by the South African government to recycle waste oil and it had collected 29 402 442 litres in 2016. PPC Lime, part of the PPC Group, utilises some of this untreated waste oil to start up their very large lime kilns in the Northern Cape.

Recycling and Economic Development Initiative of South Africa (REDISA) was mandated by the South African government to recycle used tyres. In South Africa, the stockpile of used tyres is estimated to consist of 60 to 100 million pieces across the country with 11 million used tyres added every year. However, REDISA has been liquidated for bad management and the South African government must appoint a new company (DEA, 2017).

During the time REDISA was operational, PPC had planned to receive a load of 8 000 tonnes of tyres per year from REDISA facilities for co-processing at De Hoek Kiln 6 resulting in a heat replacement of 15 percent from coal materials and PPC had installed a manual feed system of used tyres at the De Hoek plant at the cost of r less than R 10 million (PPC, 2016).

NPC Cimpor entered into an agreement with Oricol Environmental Services early in 2017 to co-process liquid and sludge waste in its cement kiln near Port Shepstone.

Figure 4-2 shows that used tyres produced more energy than coal and waste oil in the order of 17.20 percent and 36.31 percent, respectively. However, the used tyres emit more carbon dioxide (CO$_2$) than the two other fuels, coal and waste oil, with a difference of 6.48 percent and 44.55 percent, respectively.

It may be observed from the results presented in Figure 4-2 that used tyres are less environmentally friendly regarding carbon dioxide compared to the same volume of coal and waste oil. However, the 6.48 percent difference in CO$_2$ identified between used tyres and coal may be regarded as negligible for the following reasons:

- The cost of energy produced and obtained from coal to a smaller volume of used tyres,
- The environmental impact of used tyres: harmful smoke emitted from incinerator during the burning process, the spoiling of the landscape and creating health hazards.

In addition, used tyres and waste oil cannot replace coal fuel material 100 percent as the properties of clinker cement will be dramatically modified.
Therefore, three kinds of fuel material should be burnt together in such a way that the following provisions should be met:

- The composition of clinker properties should not be modified,
- A reduction in the CO$_2$ emission from the combustion of fuel materials should be observed,
- The level of energy should remain the same or be higher, and
- Cost efficiency should be regarded as a priority by considering the cost of material and the limits of CO$_2$ emissions set by the South African government.

To achieve a balance between the fuel material (coal, used tyres and waste oil), the mathematical model developed in chapter three and its solution is presented in the next section of this chapter.

4.3 Mathematical model results

It should be noted that the mathematical model is applicable to any cement producing company and is not related to a specific local producer as companies did not grant authorisation to use their data. However, the data used in this case study, such as the demand (D) of cement and the capacity (CAP) of the unit of production for the local cement company, were compiled from data available in the public domain.

For this investigation, the availability of data accessible by the public and the volume of cement produced per year were reasons which motivated the selection of the PPC Company as the ideal local cement producer in South Africa. Therefore, the results from Lingo software are presented below:
Table 4-2: Weight of fuel material obtained from different proportions

<table>
<thead>
<tr>
<th>Proportion of materials</th>
<th>Weight (in tonnes) of fuel material</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Coal</td>
</tr>
<tr>
<td>Lower proportion</td>
<td>51 444.2</td>
</tr>
<tr>
<td>Higher proportion</td>
<td>72 153.9</td>
</tr>
<tr>
<td>Optimised proportion</td>
<td>55 219.2</td>
</tr>
</tbody>
</table>

From Table 4-2 it may be observed that there is no contribution of used tyres and waste oil at the lower proportion. The energy obtained for lower proportion is under-produced and the cement kiln is not used efficiently. At the higher proportion, all three fuel materials contribute to the higher percentage of each fuel material; the total energy obtained is 125 percent which is higher than the capacity of the cement kiln.

It should be noted that this first scenario used in the solution of the mathematical model, the cost of fuel materials were estimated as follows:

- The cost of coal: R 1030/t (index Mundi, 2018),
- The cost of used tyres: R 840/t (Alibaba, 2018; muzenda and popa, 2015),
- The cost of waste oil: R 1008/t (Alibaba, 2018), and
- The cost of CO₂ generated per tonne of fuel material may vary significantly from one fuel material to another fuel material depending on the several factors as stated in the carbon tax published by the South African government (DNT, 2015b).

It may be also observed that the cement kiln is not used efficiently for the production of cement at the lower proportion and higher proportion, as at the lower proportion, a small amount of cement will be produced and bad quality cement will be produced due to excessive energy at the higher proportion. The optimised proportion is recommended to achieve efficiency in the usage of the cement kiln and production of cement.

The optimised proportion is balanced between the coal and used tyres, the weight of waste oil is nil and is not taken into consideration. The total weight of the mixed fuel material (coal and used tyres combined) is 4.3 percent less heavy compared to the higher proportion of coal alone. Furthermore, the total weight of used tyres for the optimised proportion is 0.1 tonnes heavier than those of higher proportion.

Values in Table 4-2 are plotted in Figure 4-4 and interpreted as follows:
It is observed that waste oil should not be used in combination with the other fuel materials, namely coal and used tyres, as the energy contribution is nil. Therefore, the contribution of energy is distributed between coal and used tyres for 55419.3 and 13855.3 tonnes, respectively.

The difference between the higher limit of proportion of used tyres to the optimum proportion for used tyres is in order of $8.01 \times 10^{-4}$ percent higher which it is negligible and it may be considered that used tyres are burned together with coal in the proportion of 20 to 80 percent.

Another observation from Figure 4-4 was that used tyres provide the most efficient energy of 20 percent compared to waste oil besides the higher CO$_2$ emission value of 80.34 percent between the two alternative fuel materials.

### 4.4 Analysis

This study evaluates the opportunity of using coal as main fuel material simultaneously with alternative fuel material such as used tyres. This investigation compares the level of emissions of CO$_2$ from the combustion of fuel materials in the cement kiln. Two types of fuel material were considered such as:

- 100 percent of coal fuel material (current proportion of fuel material), and
- 80 percent of coal and 20 percent of used tyres fuel materials (optimised proportion of fuel material).

From the mathematical model, the difference in cost and weight between the combinations of fuel material mentioned above are presented in Table 4-3.
Table 4-3: Comparison between current and optimised proportions of fuel material

<table>
<thead>
<tr>
<th>Item</th>
<th>Objective function (R/Year)</th>
<th>Quantity (in tonnes) of fuel material</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Waste Oil</td>
</tr>
<tr>
<td>Current proportion of fuel material</td>
<td>0.58 x 10⁹</td>
<td>N/A</td>
</tr>
<tr>
<td>Optimised proportion of fuel material</td>
<td>0.75 x 10⁶</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Three observations may be drawn from Table 4-3:

- Burning waste oil in the cement kiln may not contribute significantly to obtain the required energy while reducing the level of CO₂ emissions,
- It is more cost effective to use coal and used tyres simultaneously as fuel material than to use coal only,
- The total quantity of optimised fuel material is less than the current proportion of fuel material, therefore a reduction in the cost of transportation may be capitalised.

Besides the cost efficiency of the optimised proportion of fuel material, the combination of 80 percent of coal with 20 percent of used tyres presents a reduction in the emission of CO₂ and others greenhouse gases in the atmosphere.

Asamany et al. (2015) conducted an investigation into the gasses emitted by the combustion of coal and used tyres as fuel material and the study noted the emission of three GHGs such as CO₂, SO₂, and NOₓ. Following on the investigation conducted by Asamany et al. (2015), the current research study shows in Figure 4-5 the comparison of GHG emissions between 100 percent coal fuel and 20 percent of used tyres in the fuel mix with coal in the cement kiln.
Figure 4-5: Comparison of three different types of fuel material mixes

From Figure 4-5 it is clear that coal fuel (100) emitted more GHGs than the fuel mix of coal and used tyres; the difference is about 16.30 percent, 0.68 percent, and 74.2 percent for SO$_2$, CO$_2$, and NO$_x$, respectively. However, those GHG emissions are 22.83 percent for SO$_2$, 20.14 percent for CO$_2$ and 83.87 percent for NO$_x$ when the coal and used tyres are burnt separately.

From an environmental point of view, burning used tyres in the cement kiln presents many advantages such as:

- Reduction of black smoke which is harmful to health,
- Reduction of residual ashes which may pollute the landscape,
- Increase of energy efficiency which leads to sustainable development of the cement industry.

This CO$_2$ reduction of 16.76 percent in emission may not be enough to help the local cement producers to meet their targeted quota for 2020 required by the South African government. However, this will encourage the producers to assess more options in the reduction.

4.5 Other scenarios

In the previous analysis, the scenario considered was that the cost of used tyres was cheaper than waste oil. In these paragraphs, two other scenarios were considered such as:

a) Used tyres (R 1020/t of fuel material) more expensive than waste oil (R 950/t of fuel material),

b) Used tyres have the same cost as waste oil (R 975/t of fuel material).
The results of mathematical models on these scenarios are presented in Table 4.4 below:

**Table 4.4: Results of mathematical models on other scenarios on optimised proportion of fuel material**

<table>
<thead>
<tr>
<th>Item</th>
<th>Objective function (R/Year)</th>
<th>Quantity (in tonnes) of fuel material</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Waste Oil</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Used Tyres</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Coal</td>
</tr>
<tr>
<td>Scenario 1 (Primary case)</td>
<td>0.75 x 10⁶</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td></td>
<td>13855.3 (20%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>55219.2 (80%)</td>
</tr>
<tr>
<td>Scenario 2</td>
<td>0.69 x 10⁷</td>
<td>2582.5 (4.3%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>13699.9 (18%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>52539.2 (77.7%)</td>
</tr>
<tr>
<td>Scenario 3</td>
<td>0.62 x 10⁷</td>
<td>2582.5 (4.3%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>13699.9 (18%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>52539.2 (77.7%)</td>
</tr>
</tbody>
</table>

From Table 4.4, it may be concluded that waste oil will contribute in the combustion energy in the Kiln and reduction of CO₂ emission from the cement production unit as shown in the Life Cycle Assessment of this study shown in Figure 4.6 when the cost of waste Oil is same of less than the cost of used tyres.

**Figure 4.6: Life Cycle Assessment of this study**

### 4.6 Conclusion

In conclusion, there is a benefit for cement producers to substitute coal fuel material by used tyres to a certain percentage, while more effort should be made by the cement producers to reduce their CO₂ emissions to meet the South African government’s goal of 42 percent CO₂ reduction by 2025 as the government’s goal for 2020 will be missed.
Chapter 5: Conclusions and Recommendations

5.1 Conclusions

This research was conducted on the production and manufacturing process of cement and its impact on the environment. In addition, this research highlighted the source of CO$_2$ emission from cement plants to originate from the decarbonisation of raw material, limestone transformed to clinker: the combustion of fuel material (51.96 percent of total kg of CO$_2$ per tonne of cement), coal for energy purposes in the cement kiln (38.24 percent) and the use of electricity for equipment (fans, motors, etc.), (9.80 percent) of total kg of CO$_2$ per tonne of cement.

Best practice is developed worldwide to address the emissions from those three sources, namely: decarbonisation of raw material, combustion of fuel material and use of electricity for equipment. Best practice was discussed and reviewed in this study as a solution to mitigate the impact on the environment.

Acknowledged that the cement industry is one of the major contributors of CO$_2$ emission in the world with approximately seven percent of the global contribution; the South African government with other governments worldwide and the World Business Council on Sustainable Development (WBCSD) developed initiatives such as the Cement Sustainability Initiative (CSI) and the Carbon Tax Bill to resolve the problem.

From an objective point of view, the cement sustainability initiative and the carbon tax bill aim to protect the environment from the destructive impact of the production of cement and encourage the cement companies to adopt a more sustainable business approach. Among all six South African cement producers, only Lafarge South Africa through its mother company Lafarge-Holcim is the signatory of the Cement Sustainability Initiative (CSI); however, all of them are putting best practice such as a dry kiln cement process and use of alternative fuel material in place to reach the same outcomes described by the CSI.

This study focused on the use of alternative fuel, namely used tyres and waste oil in combination with coal in the cement kiln for reduction of CO$_2$ emission as new technology and best practice for the global cement industry in general and the South African industry in particular. For this purpose, a mathematical model was developed to solve an objective function for the weight of fuel materials to be used simultaneously. Results obtained from the Lingo software program for the objective function show that waste oil, used tyres and coal should be used to 0 percent, 20 percent, and 80 percent, respectively.

In addition, the use of alternative fuel material may reduce the emission of CO$_2$ from the combustion of fuel material in kiln cement by 16.76 percent. However, this may not be enough towards the
government’s target of 42 percent CO\textsubscript{2} reduction by 2025. This is reinforced by the conclusion made by PPC in their 2017 report that local cement producers will not meet the government’s goal of CO\textsubscript{2} reduction set for 2020.

\section*{5.2 Recommendations}

Three recommendations based on the results of this study are as follows:

- More research is required to develop new processes and investigate the use of new raw material in substitution of limestone as more than 50 percent of CO\textsubscript{2} is emitted from the decarbonisation of limestone,

- Two parameters were considered in the development of the mathematical model, namely the cost of fuel material and the target of CO\textsubscript{2} emissions set by the South African government. However, a new mathematical model should consider other parameters such as the cost of CO\textsubscript{2} from the decarbonisation, and

- An integrated managerial model of cement production using alternative fuel materials should be studied and developed for the South African local cement industry which takes into consideration the difficulties faced by South Africa regarding the bad waste management of used tyres.
List of References


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Kosmatka, Kerkkoff and Panarese (2002)


### APPENDIX A

Common Cements SANS 50197-1 (Concrete Institute, 2016)

<table>
<thead>
<tr>
<th>Main types</th>
<th>Notation of the 27 products (types of common cement)</th>
<th>Composition (percentage by mass *)</th>
<th>Main constituents</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Clinker</td>
<td>Blast-furnace slag</td>
</tr>
<tr>
<td></td>
<td></td>
<td>K</td>
<td>S</td>
</tr>
<tr>
<td>CEM I</td>
<td>Portland cement</td>
<td>CEM I</td>
<td>95 - 100</td>
</tr>
<tr>
<td></td>
<td>Portland-slag cement</td>
<td>CEM I/A-S</td>
<td>80 - 94</td>
</tr>
<tr>
<td></td>
<td>Portland-silica fume cement</td>
<td>CEM I/B-S</td>
<td>65 - 79</td>
</tr>
<tr>
<td></td>
<td>Portland-pozzolana cement</td>
<td>CEM I/A-D</td>
<td>90 - 94</td>
</tr>
<tr>
<td></td>
<td>Portland-fly ash cement</td>
<td>CEM I/A-P</td>
<td>80 - 94</td>
</tr>
<tr>
<td></td>
<td>Portland-burnt shale cement</td>
<td>CEM I/A-Q</td>
<td>80 - 94</td>
</tr>
<tr>
<td></td>
<td>Portland-limestone cement</td>
<td>CEM I/B-Q</td>
<td>65 - 79</td>
</tr>
<tr>
<td></td>
<td>Portland-composite cement h)</td>
<td>CEM I/A-V</td>
<td>80 - 94</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CEM I/B-V</td>
<td>65 - 79</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CEM I/A-W</td>
<td>80 - 94</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CEM I/B-W</td>
<td>65 - 79</td>
</tr>
<tr>
<td>CEM II</td>
<td>Portland-slag cement</td>
<td>CEM I/A-T</td>
<td>80 - 94</td>
</tr>
<tr>
<td></td>
<td>Portland-burnt shale cement</td>
<td>CEM I/B-T</td>
<td>65 - 79</td>
</tr>
<tr>
<td></td>
<td>Portland-limestone cement</td>
<td>CEM I/A-L</td>
<td>80 - 94</td>
</tr>
<tr>
<td></td>
<td>Portland-composite cement h)</td>
<td>CEM I/A-M</td>
<td>80 - 88</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CEM I/B-M</td>
<td>65 - 79</td>
</tr>
<tr>
<td>CEM III</td>
<td>Blast furnace cement</td>
<td>CEM II/A</td>
<td>35 - 64</td>
</tr>
<tr>
<td></td>
<td>CEM II/B</td>
<td>20 - 54</td>
<td>60 - 80</td>
</tr>
<tr>
<td></td>
<td>CEM II/C</td>
<td>5 - 19</td>
<td>81 - 95</td>
</tr>
<tr>
<td>CEM IV</td>
<td>Pozzolana cement</td>
<td>CEM IV/A</td>
<td>65 - 89</td>
</tr>
<tr>
<td></td>
<td>CEM IV/B</td>
<td>45 - 64</td>
<td>-</td>
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<tr>
<td>CEM V</td>
<td>Composite cement</td>
<td>CEM V/A</td>
<td>40 - 64</td>
</tr>
<tr>
<td></td>
<td>CEM V/B</td>
<td>20 - 38</td>
<td>31 - 49</td>
</tr>
</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.
APPENDIX B

World Greenhouse Gas Emissions in 2005
Total: 44,153 MTCO₂ eq.

End Use/Activity

Transportation 14.3%

Road 10.6%

Rail, Ship, & Other Transport 2.9%

Residential Buildings 10.2%

Commercial Buildings 6.3%

Unallocated Fuel Combustion 3.8%

Iron & Steel 4.0%

Refrigerant, Insulation, & other
Chemicals 4.1%

Cement 5.0%

Other Industry 7.0%

T&D Losses 2.2%

Other Fuel Combustion 8.6%

Coal Gas Extraction, Refining & Processing 6.4%

Industry 14.7%

Fugitive Emissions 4.0%

LULUCF (tropics only)

Deforestation 11.3%

Afforestation -0.4%

Harvest/Management 1.3%

Agriculture Energy Use 1.3%

Agriculture Soils 5.2%

Livestock & Manure 5.4%

Biofuels 1.5%

Other Agriculture 1.7%

Landfills 1.7%

Energy 34.9%

Electricity & Heat 34.9%

Carbon Dioxide (CO₂) 77%

Methane (CH₄) 15%

Nitrous Oxide (N₂O) 7%

HFCs, PFCs, SF₆ 1%

Sources & Notes: All data are for 2005. All calculations are based on CO₂ equivalents, using 100-year global warming potentials from the IPCC (2006), based on a total global estimate of 44,153 MTCO₂ equivalent. See Appendix 2 of Navigating the Numbers: Greenhouse Gas Data & International Climate Policy (WRI, 2005) for a detailed description of sector and end-use/activity definitions, as well as data sources. Dotted lines represent flows of less than 0.1% of total GHG emissions.

* Land Use Change includes both emissions and absorptions, and is based on analysis that uses revised methodologies compared to previous versions of this chart. These data are subject to significant uncertainties.
N.B: Please take note that Continental Cement represents Mamba Cement plant.