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# Carbon dioxide equivalent emissions from the manufacture of concrete in South Africa

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# CARBON DIOXIDE EQUIVALENT EMISSIONS FROM THE MANUFACTURE OF CONCRETE IN SOUTH AFRICA

**Marc Alan Wright**

A dissertation submitted to the faculty of Science, University of the Witwatersrand, Johannesburg, in fulfilment of the requirements for the degree of Master of Science.

15 March 2011

# Declaration

I declare that this dissertation is my own, unaided work, except where otherwise acknowledged. It is being submitted for the degree of Master of Science in the University of Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in any other university.

Signed this ___ day of _____ 20___

_____

Marc Alan Wright.

# Abstract

Data was obtained by means of an electronic questionnaire distributed throughout South Africa during 2008 and 2009. Specific activity data was gathered from 130 of the processes and activities contributing to the concrete industry which include admixture, aggregates, cement, fly ash, precast, in-situ concrete, slagment, steel reinforcing and water. The Cement and Concrete Institute initiated this project to develop a model for the quantification of $CO_2$ emissions specific to the concrete industry. The institute's intention is to determine the emissions resulting from the production of a cubic meter of concrete in South Africa. Depending on the outcome, this will allow the institute to promote the application of concrete over other construction alternatives.

The new $CO_2e$ model was developed following accepted GHG (Greenhouse Gas) protocol rules. These include relevance, completeness, consistency, transparency and accuracy, when examining direct (scope one), indirect (scope two) and other indirect (scope three) emissions. The emissions associated with each activity are determined by individual process specific questionnaires. The gathered activity data was then consolidated electronically and manipulated to determine the $CO_2e$ emissions per ton of product for each process or activity. Emission factors for each activity were determined and inputted into the $CO_2e$ model to determine the overall emissions per cubic meter of concrete, province and sector.

The final model allows the user to input specific concrete mixes to determine the $CO_2e$ emissions resulting from a cubic meter of the specific mix going into roof tiles, bricks, precast concrete slabs or in-situ concrete. It was found that an average cubic meter of in-situ concrete containing a CEM (cement) I 42.5 with extension and admixture with a strength of 30 MPa resulted in a range of between 215 and 240 kg $CO_2e$ per cubic meter. In order to compare these emissions to international studies it is only necessary to consider direct emissions. Considering direct emissions, the production of an average South African concrete mix resulted in a range of 142 to 170 kg $CO_2/m^3$ compared to Australia with a range of 251 to 273 kg $CO_2/m^3$ and the United Kingdom with 266 kg $CO_2/m^3$. This equates to between 57 and 62 percent less $CO_2$ emitted from the production of an average South African concrete. The $CO_2$ resulted from direct emissions (67 percent), indirect emissions (23 percent) and the remaining other indirect sources with ten percent.

# ACKNOWLEDGEMENTS

**THIS RESEARCH IS DEDICATED TO MY FAMILY**

My Wife, for her devoted patience, motivation and continuous encouragement throughout the duration of this research, I could not have done it without her, as well as our new born, Keagan.

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This MSc was done in conjunction with a project for the Cement and Concrete Institute. I would like to thank them for allowing me to extend the research into this MSc dissertation.

# List of Abbreviations

| | |
|---|---|
| CaO | - Calcium Oxide |
| C | - Carbon |
| $Ca(OH)_2$ | - Calcium Hydroxide |
| $CaCO_3$ | - Calcium Carbonate |
| $CH_4$ | - Methane |
| $CO_2$ | - Carbon dioxide |
| $CO_2e$ | - Carbon dioxide equivalent |
| CV | - Emission Factor |
| GHG | - Greenhouse Gas |
| Gt | - Giga tonne |
| $H_2O$ | - Water |
| ha | - Hectare |
| HFC | - Hydrofluorocarbon |
| kg | - Kilogram |
| ksi | - kilo pounds per square inch |
| l | - Litre |
| MJ | - Mega joule ($10^{12}$ joules) |
| MPa | - Mega pascal |
| MWh | - Mega watt hour |
| $N_2O$ | - Nitrous Oxide |
| $O_2$ | - Oxygen |
| PFC | - Perfluorocarbons |
| ppm | - Parts per million |
| psi | - Pounds per square inch |
| $SF_6$ | - Sulphur hexaflouride |
| $SiO_2$ | - Silicon dioxide |
| t | - ton |
| µm | - micrometer ($10^{-6}$ meters) |

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# Chapter 1

# Overview

In this chapter, the current status of concrete and cement production worldwide is detailed followed by a discussion on the knowledge of $CO_2e$ (Carbon dioxide equivalent) emissions from the concrete industry in South Africa. The literature review then examines the current status of GHG (Greenhouse Gas) emissions as well as projecting the growth of these emissions. The importance of carbon emissions quantification is discussed. The primary emission factors and emission sources are detailed. The material flow of the processes and activities of the concrete industry is explored. Lastly, the research goals and design of this dissertation are outlined.

# Introduction

Since the beginning of the industrial revolution in 1760 there has been an increase in the use of fossil fuel energy resulting in amplified emissions of GHGs (Greenhouse Gases) (Slanina, 2004). This increased global dependency on oil, coal and natural gas has resulted in the release in excess of 1100 Gt (Giga tonne) of $CO_2e$ emissions to the atmosphere (IPCC, 2001). The release of GHGs contributes to anthropogenic induced global warming with the most significant of these gases being $CO_2$ (Carbon dioxide) (IPCC, 2001). This is due to the sheer quantities that are being emitted, even though it does not have the highest radioactive forcing potential. The cement industry is energy intensive and accounts for a significant portion of these anthropogenic GHG emissions.

Globally the cement industry contributes between five and eight percent of all $CO_2e$ (Carbon dioxide equivalent) emissions (CIF, 2003; Flower and Sanjayan, 2007; Ulm, 2007). The cement industry in South Africa produced 14.1 million tonnes in 2007. This equates to approximately half a percent of global production. World production totalled 2.77 billion tonnes in 2007 with the three major global contributors being China accounting for 1.35 billion tonnes (49 percent), India accounting for 170 million tonnes (six percent) and USA accounting for 97 million tonnes (three percent) (USDoI, 2009).

Cement is only a constituent of concrete and global emissions estimates have not been made for the concrete industry but the author would estimate this to be in the range of ten to 14 percent. The growth of the concrete industry is being fuelled by key world economies resulting in an increased demand for construction materials, in particular concrete. An average concrete mix requires approximately 350 kg (kilograms) of cement per cubic meter (concrete density of 2.4 t (ton) per cubic meter). In 2007 South Africa produced approximately 100 million tonnes of concrete in structure. This construction resulted in the release of a large quantity of $CO_2e$ in South Africa, which until not has not been accurately quantified. This report will examine the various

activities within the concrete industry and calculate their individual as well as cumulative contribution to the emissions of $CO_2e$ resulting from the concrete industry in South Africa.

It is widely accepted that concrete is the most extensively used construction material. Currently, the world production of concrete is about one tonne per year for every living person (Lippiatt and Ahmad, 2004; Flower and Sanjayan, 2007). Concrete is the second most consumed material apart from water (Flower and Sanjayan, 2007). Despite the current global financial crisis resulting in reduced demand for construction materials, a long term projection is that by 2030 the concrete industry is expected to have grown roughly five times larger than in 1990, with close to five billion tonnes sold annually worldwide (Humphreys and Mahasenan, 2002). Concern about human induced climate change and its impacts are increasing. Due to this fact, it in important to quantify $CO_2e$ emissions from all industries and the concrete industry in South Africa is no exception.

# Literature review

## Background

Currently, the $CO_2e$ emissions of the concrete industry in South Africa are not known. Some individual companies within the industry have examined their specific carbon emissions, however, no one has ever quantified the concrete industry as a whole. Climate change is a topic of great concern. As the world is striving towards increased environmental awareness and sustainable development the major contributors of anthropogenic GHG's should be quantified (Lippiatt and Ahmad, 2004). Thus, it will be valuable to determine the concrete industry's $CO_2e$ emissions (Van Oss and Padovani, 2002*a*; Van Oss and Padovani, 2002*b*).

This study will provide an inventory of industry specific information that will allow the development of GHG management and reduction strategies. Information from the

inventory can also be used to compare concrete to other construction materials or combinations of materials.

## Projecting the growth of greenhouse gas emissions

In order to fully understand the importance and need for carbon emission calculations it is necessary to examine global emission trends. According to the IPCC (2001), the current atmospheric concentration of GHG's is 430 ppm (parts per million) $CO_2e$ and increasing at three to four ppm per annum (Figure 1.1). This value can be broken down to 380 ppm $CO_2$ and 50 ppm of other GHG's. Currently the world is producing 42 Gt $CO_2e$ per year, with energy consumption accounting for approximately 60 percent (26 Gt), (IPCC (2001). At the current rate of production on the path of 'business as usual', there will be significant climate impacts.

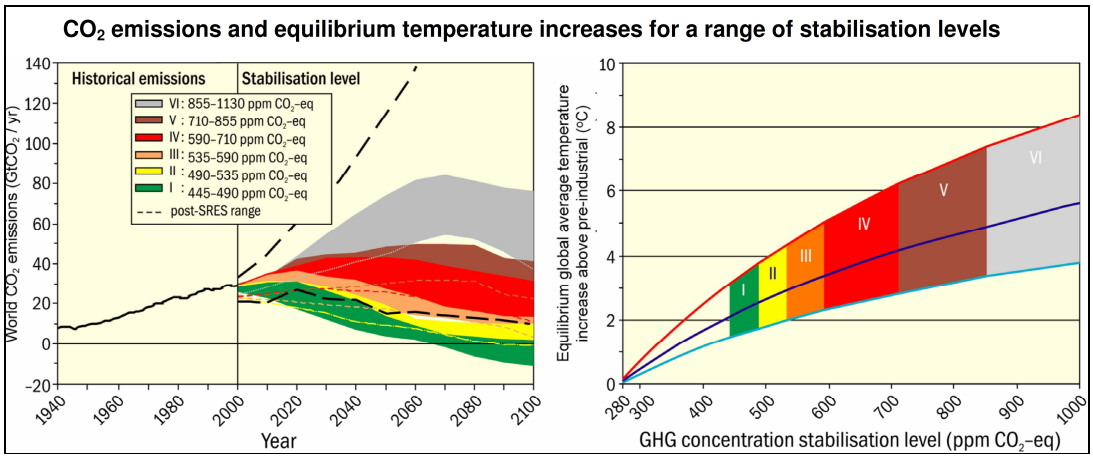


**Figure 1.1. $CO_2$ emissions and equilibrium temperature increases for a range of stabilisation levels (IPCC, 2006)**

Global warming can be substantiated by research done into arctic ice cores. It has been noted that temperature has a correlation to the concentration of $CO_2$ present in the atmosphere (Miller, 2004). There is usually a 1000 to 2500 year time lapse between the peak $CO_2$ concentration and peak temperature (Miller, 2004). Notably, $CO_2$ levels are currently 27 percent higher than the world has experienced within the past 650 000

years (Miller, 2004). Flannery (2006, p357) stated that “whether we allow the global average temperature to rise by a single degree or three, we will decide the fate of hundreds of thousands of species and most probably billions of people”. According to Miller (2004, p246) “for every one degree Celsius the earths average temperature rises, climate belts will shift 100 to 150 kilometers away from the tropics, equivalent of 150m upward in altitude”. Stabilisation will be the hardest feat to achieve and will be the ultimate goal of any climate policy. Even if emissions halt immediately, the amount of GHG’s already emitted will cause a change in climates around the world. James Lovelock (2006, p25) the developer of the Gaia theory states that “we have driven the earth to a crisis state from which it may never, on a human time scale recover”. Increasing temperatures are causing ice caps to melt and with this a rise in sea levels. Apart from rising sea levels, the most significant impact that global warming will have will be on the “changes in the frequencies, intensities and locations of climate extremes, especially droughts and floods” (Houghton, 2004, p351). The earth has experienced many temperature fluctuations in the form of glacial and inter-glacial periods. Thus, climate change can not be examined on a human time scale (Figure 1.2).

Emissions from anthropogenically induced climate change have been steadily increasing as the worlds ‘thirst’ for fossil-fuels increase. Two leading reasons for the high GHG levels is firstly deforestation and secondly population. Over the past 50 years forest cover has decreased by approximately 11 million square kilometres. It has also been noted that by 2100 most of the top ten deforesting nations will have cleared their forests (Ramankutty and Foley, 1999; Goldewijk, 2001). Currently the world’s population is approximately 6.6 billion people and is expected to rise to approximately 9.5 billion by 2050. Emissions of $CO_2$ increase proportionately as populations grow. This is because population size is associated with energy consumption and thus, energy-related emissions.

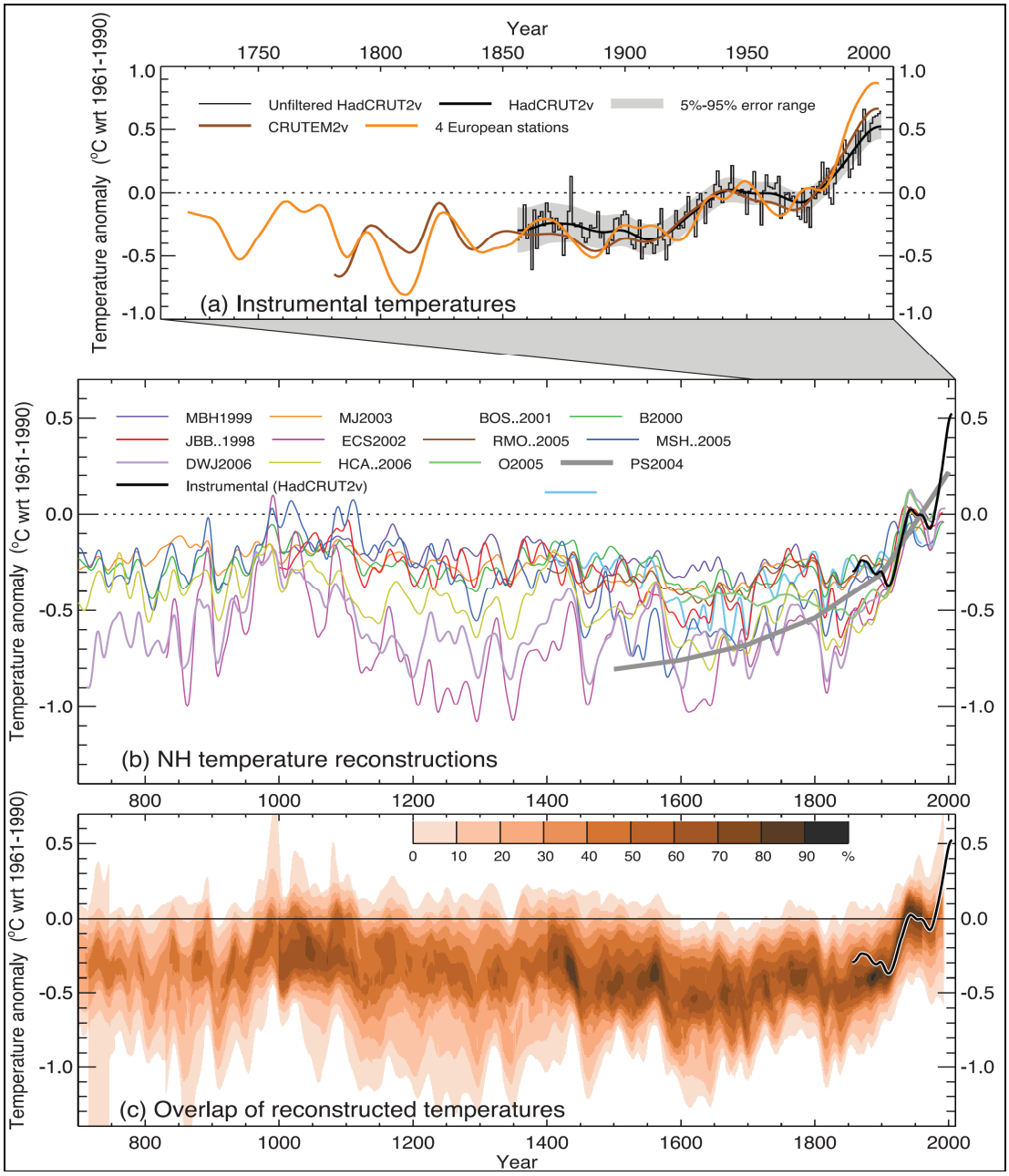


**Figure 1.2. Reconstructed annual temperature variations over the past 1200 years (IPCC, 2006)**

The Kyoto Protocol was developed to reduce GHG emissions. It is an international accord that is linked to the UNFCCC (United Nations Framework Convention on Climate Change). A major aspect of the Kyoto Protocol is that it sets obligatory goals for 37 industrialised countries worldwide. The savings quantify to approximately five

per cent compared to 1990 levels over the five-year period of 2008 to 2012 (UNFCCC, 2008). North America and Europe are the two major contributors, producing approximately 70 percent of the global anthropogenic GHG emissions (IPCC, 2006).

Through this discussion stabilisation levels have been discussed. On a relatively short time scale the levels may seem stable, but there is never a stable period. One of the hardest feats to achieve with regards to stabilisation is acceptance and effort from governments and industries around the world. A major producer of $CO_2$ is the cement industry. It is estimated that the cement activity contributes five to eight percent of global anthropogenic $CO_2$ emissions. Cement is only a constituent of concrete and accounts for 15 to 30 percent of a mix.

## The importance of quantifying carbon emissions

As has been noted in the previous section, greenhouse gas emissions are increasing and climate change is a reality. It is due to this fact that it is of great importance for major emitters of greenhouse gases to monitor and disclose their $CO_2e$ emissions. The measurement of a company's carbon emissions is a good step towards increased environmental awareness and sustainable development. It is also a platform from which carbon trading can develop, as has been seen in Europe.

According to the Carbon Trust (2008), there are two main reasons why a company or organisation may decide to report their specific $CO_2e$ emissions. The first would be to manage their emissions as well as reduce emissions over time. The second is to report their emissions accurately to a third party for public disclosure. Apart from these two reasons when a company measures the carbon related emissions to its products it can use this to market itself as a 'green' corporation. There are several GHG's (Table 1.1) to consider, however, the primary gas of concern to the concrete industry is $CO_2$.

**Table 1.1. Global warming potential of primary GHG's (IPCC, 2006)**

| Gas | Symbol | Global warming potential | Percentage contribution of emissions to concrete |
|---|---|---|---|
| Carbon Dioxide | $CO_2$ | 1 | 99 % |
| Methane | $CH_4$ | 23 | 1% |
| Nitrous Oxide | $N_2O$ | 296 | <1% |
| Hydrofluorocarbons | HFCs | 10-12 000 | <1% |
| Perfluorocarbons | PFCs | > 5 000 | <1% |
| Sulphur hexafluoride | $SF_6$ | 22 200 | <1% |

## Identification and determination of emissions

The first step that is required before emission sources can be identified is to select a reporting boundary. It was decided that an operational boundary (Figure 1.3) will be applied (GHG protocol, 2004). The operational boundary can be defined as the scope of emissions (direct, indirect and other indirect), for operations which fall within a company's established organisational boundary.

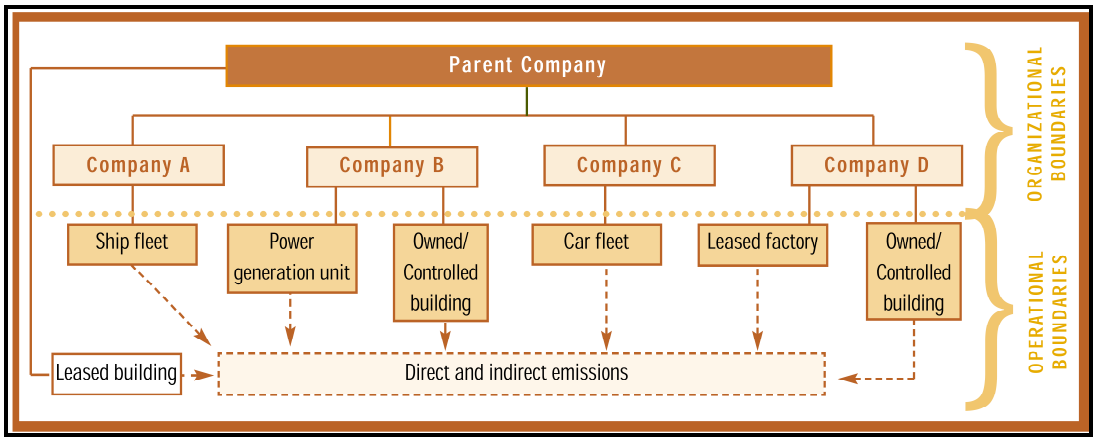


**Figure 1.3. Company $CO_2$ boundaries (GHGProtocol, 2004, p25)**

There are three main scopes of emissions that will need to be examined within each activity, namely direct, indirect and other indirect (Figure 1.4).

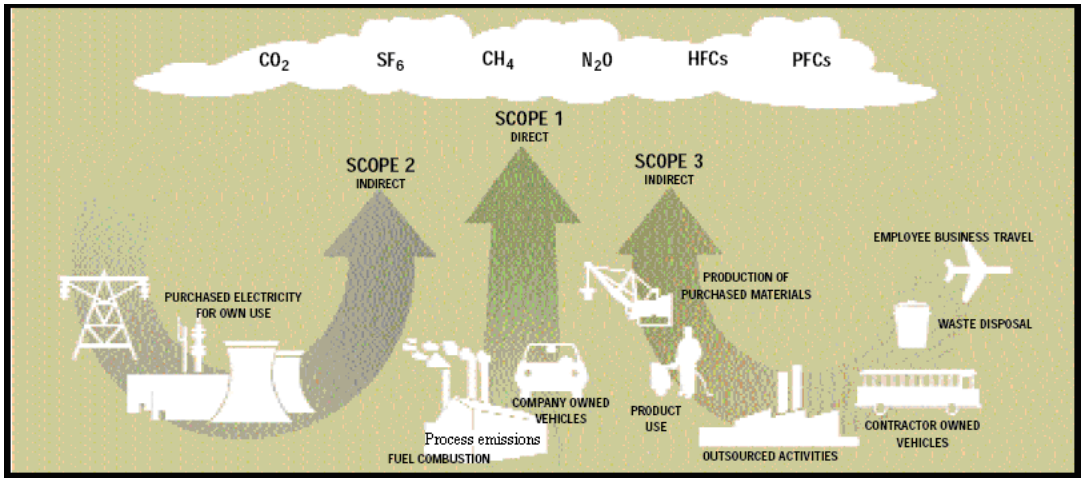


**Figure 1.4. Overview of $CO_2$ emission sources (GHGProtocol, 2004, p26)**

- Direct GHG emissions:

  Direct GHG emissions primarily result from on site consumption of fossil fuels. Other sources include waste water treatment, on site landfill and incinerators.

- Indirect GHG emissions:

  The main GHG emission source results from the purchase of grid electricity. Other minor sources include municipal water consumption, landfills and sewerage works.

- Other indirect GHG emissions:

  The definition of other indirect GHG emissions may depend on internal reporting requirements and CDP requirements. Organisational activities resulting in other indirect emissions include: staff commuting, final production transportation by a third party and outsourced activities

All of these sources will count towards an activity's greenhouse gas emissions inventory. It should be noted that the GHG Protocol aims to prevent double counting by breaking the emissions into the categories of direct, indirect and other indirect. The GHG protocol has been strictly followed and thus double counting has been avoided. The concrete industry can be subdivided into several activities, with associated

emissions. When considering the $CO_2$ emissions from the concrete industry each individual activity (noted in yellow) needed to be examined (Figure 1.5). Every activity has been dealt with individually and then combined to determine the overall emissions of the concrete industry.

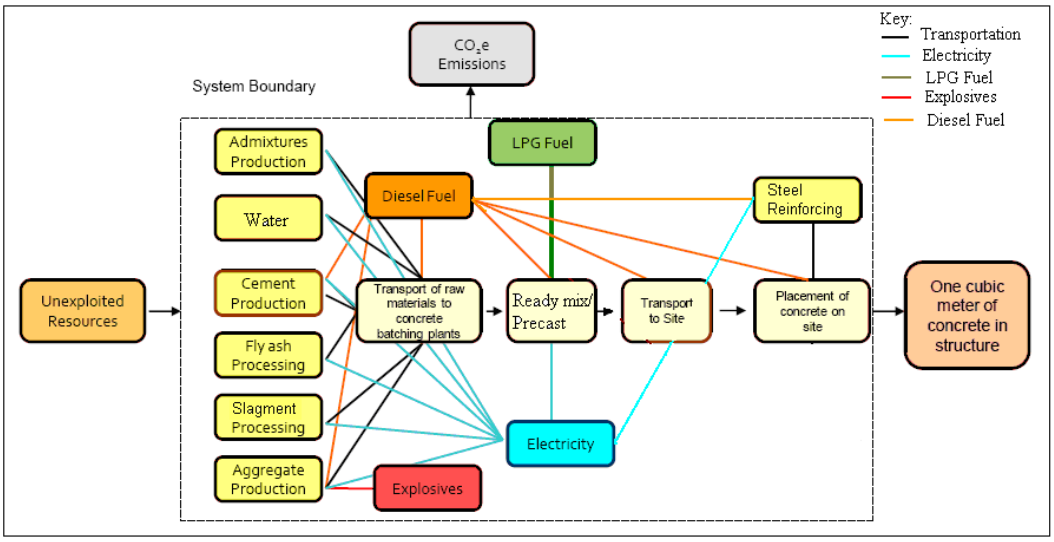


**Figure 1.5. Concrete $CO_2$e process emission sources (After Flower and Sanjayan, 2007)**

The activity data that was gathered are process specific and for comparative purposes, selection of other indirect emissions will be carefully chosen (Pade and Guimaraes, 2006; Hammond and Jones, 2008). This is due to the fact that the inclusion of some other indirect emissions may not lend the results well for comparative purposes. In an extensive examination of international trends and industry standards, it should be noted that emissions produced from the delivery of products to the customer will be included under other indirect emissions (GHGProtocol, 2004; CSI Cement Protocol V2, 2005; Pade and Guimaraes, 2006; Hammond and Jones, 2008).

## Activities of the concrete industry

Concrete is a hardened construction material that is produced by mixing a specific ratio of components together. These include aggregate which is a combination of gravel, crushed stone and sand which is chemically inert, binder (portland cement),

chemical admixtures, in some cases extender (fly ash or slagment), steel reinforcing and water. The components of concrete are altered in varying proportions to attain the strength and flexibility necessary for a particular application (Made how, 2001; Vanderley and Politécnica, 2003).

Portland cement is the type of cement most often used in concrete. It is made from a blend of a calcareous material and silica as well as alumina compounds which are found as clay or shale. Aggregates comprise 75 percent of concrete by volume and predominantly enhance the structural performance of concrete. Fly ash and slagment are used as extenders to reduce the cost of cement. Fly ash is a by-product from a coal-burning power plant and slagment is a by-product of the steel industry. Admixtures are chemicals added to a concrete mix, the most commonly added is a plasticizer (Made how, 2001; Humphreys and Mahasenan, 2002; NRMCA, 2008). Reinforcing is added to improve the tensile strength of concrete. In South Africa, steel rebar is the most common reinforcing material.

Once the above mentioned materials have been produced, the process of concrete prediction can commence. This involves the materials being transported to a concrete batching site, or directly to site where a contractor may choose to site mix. The cement is prepared and the other components will be added in varying proportions, specific to the desired application. The concrete will then either be set in a precast mould or it will be pumped into a truck, wheelbarrow or belt conveyor and transported to site. Once the concrete is on site it must be placed and compacted. These two processes occur simultaneously (Made how, 2001; Battle, 2002; NRMCA, 2008).

Emissions resulting from the production of concrete are primarily due to energy consumption. Thus, to determine the $CO_2e$ emissions related to each activity it is necessary to quantify the energy consumption of each activity. The only exception to this rule is the production of cement. It is estimated that 50 percent of the emissions result from the decomposition of limestone in the kiln, with the remaining 50 percent of emissions resulting from the use of electricity and fuel. (Humphreys and Mahasenan, 2002; CIF, 2003)

A phenomenon called carbonisation is responsible for the absorption of $CO_2$ post concrete production (Liang *et al.*, 2000; Pade and Guimaraes, 2006). The effect of carbonisation is still being researched, however, the basic process is that the 'free lime' in the concrete reacts with $CO_2$ in the atmosphere to produce $CaCO_3$ (calcium carbonate). This process can be represented by the equation:

$$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O \quad (1.1)$$

According to Flower and Sanjayan (2007), only small quantities of $CO_2$ are absorbed by concrete structures due to the fact that only the first two centimeters of a structure can react. Thus, the absorption during the concrete's life time is very small and will not be considered in the calculation in this research. Extensive research, discussions and estimates on the effects of carbonisation on concrete can be found in Pade and Guimaraes (2006). The main activities of the concrete industry can be noted in Figure 1.5 and the primary emission sources in Table 1.2. Following this table, an overview of the main activities will be provided.

**Table 1.2. Emission sources from each activity of concrete.**

| Activity | Direct | Indirect | Other Indirect |
|---|---|---|---|
| **Fly ash** | On site fuel - vehicles | Electricity | Delivery of raw materials to site |
| **Slagment** | On site fuel – vehicles | Electricity | Delivery of raw materials to site |
| **Cement** | Coal firing of kiln<br>On site fuel – vehicles<br>On site fuel – kiln start up<br>Calcination of raw materials | Electricity | Delivery of raw materials to site |
| **Aggregates** | On site fuel – vehicles<br>Explosives | Electricity | Delivery of raw materials to site |
| **Admixtures** | On site fuel – vehicles | Electricity | Delivery of raw materials to site |
| **Reinforcing** | On site fuel – vehicles<br>On site fuel – furnace | Electricity | Delivery of raw materials to site |
| **Precast products** | Coal, gas firing of boilers for water heating | Electricity | Delivery of raw materials to site |
| **Readymix** | On site fuel - loader | Electricity | Delivery of raw materials to site |

**In-situ concrete and precast overview**

All of the concrete components are used to produce two types of concrete which are used for different applications. These types are in-situ (readymix) or precast. Thus, these two processes are not part of a mix, rather they are services to the industry.

In-situ concrete is made to a set mix design and is produced at a batching site or on site. The product is then delivered to site by trucks with mounted mixers. Due to the fact that a set mix design is used, this allows for specialty mixtures to be produced. Readymix concrete assists construction as builders do not have to make concrete mixes on site. This also allows for a continuous supply of concrete to the site.

Precast concrete is not part of a concrete mix, rather it is an alternative form of construction. Concrete is cast in a reusable mould, which is allowed to set under controlled conditions. The cast is the transported to site and placed. Precast is frequently used in applications such as highway barriers, walls, tunnels as well as storm water and sewerage lines.

*In-situ concrete and precast$CO_2$e emission sources*

The emissions resulting from the processes involved in the preparation of readymix and precast will be very low. This is due to the fact that the processes are not energy intensive. Readymix sites produce the concrete mix and transport it to site. Whereas precast sites will mix the concrete, place it in a mould and allow it to set and then transport it to site. It is expected that emissions will result primarily from fuel use, followed by emissions from electricity.

**Slagment and Fly ash overview**

Both slag and fly ash are used as extenders in cement and concrete mixes. The primary difference between the two is that fly ash is a pozzolan. Pozzolans are pure siliceous or siliceous and aluminous substances which in themselves have little or no cementitious properties. Only when finely ground will they react at ambient temperatures with calcium hydroxide (Portlandite Ca ($OH_2$)) dissolved in water. There are two possible sources of calcium hydroxide namely lime, or Portland cement. Once this reaction has occurred pozzolans are able to form high strength bonds developing calcium aluminate and calcium silicate compounds (Ash resources, 2007).

Slagment is a by-product of the steel and iron industry. It is also referred to as slag cement, GGBS or GGBFS (ground granulated blast furnace slag). The granular by-product is dried and ground down to a fine powder. The application of slagment is primarily used as an optional additive to cement, readymix and concrete mixes, with a primary function of increased durability and workability. A key characteristic of slag is that it is not a pozzolan thus, it possesses self cementing properties. Research has noted that slagment has the capability to double the lifespan of buildings (US FHA, 2008). Slagment is a direct replacement for ordinary Portland cement by weight and typically 40 to 50 percent replacement is used.

There are also certain architectural and engineering benefits to adding slag to the mix. Slag will affect certain characteristics of the concrete, namely appearance, durability and strength. Slagment can alter the colouration of concrete to a near-white colour. This can be achieved by using 50 to 70 percent replacement levels, up to a maximum of 85 percent replacement. The high slag content also produces a smoother more defect free surface (US FHA, 2008). Slagment has the ability to provide protection from both chloride and sulphate attack as well as reduce the thermal gradient generated when pouring the concrete. This will in turn reduce the likelihood of micro cracking which would reduce the structure's strength (US FHA, 2008). Slag enhances the strength due to the fact that it has a high proportion of calcium silicate hydrates (US FHA, 2008).

Fly ash is a by-product from the combustion of coal that is used as an extender (partial replacement) for cement in concretes. Fly ash can decrease the water demand as well as increase the workability of concrete (Ash resources, 2007). The primary constituents of fly ash in South Africa (Table 1.3) include $SiO_2$ (silica dioxide) and aluminium trioxide ($Al_2O_3$) as well as many toxic elements (NRMCA, 2008; USEPA, 2007). Fly ash has low carbon emissions as it is a by-product, however, it has significant environmental impacts at landfill sites creating human health and ecological concerns (USEPA, 2007).

**Table 1.3. Chemical composition of fly ash (Ash resources, 2007)**

| | |
|---|---|
| Silicon ($SiO_2$) | 47.0 - 55.0 |
| Aluminium ($Al_2O_3$) | 25.0 - 35.0 |
| Iron ($Fe_2O_3$) | 3.0 - 4.0 |
| Manganese ($Mn_2O_3$) | 0.1 - 0.2 |
| Calcium (CaO) | 4.0 - 10.0 |
| Magnesium (MgO) | 1.0 - 2.5 |
| Phosphorus ($P_2O_5$) | 0.5 - 1.0 |
| Potassium ($K_2O$) | 0.5 - 1.0 |
| Sodium ($Na_2O$) | 0.2 - 0.8 |
| Titanium ($TiO_2$) | 1.0 - 2.0 |
| Sulphur ($SO_3$) | 0.1 - 0.5 |
| Loss On Ignition (LOI) | 0.5 - 2.0 |

The composition of fly ash is primarily impacted by the quality and grade of the coal being fired (Khandekar *et al.,* 1999). Fly ash that is being used for concrete manufacture does not need to meet any environmental standards. The only requirement is that the particles have a fineness of less than 46 µm (micrometer). Thus, raw fly ash may be required to undergo mechanical or air separation. Fly ash is a pozzolan thus, possessing no self cementing properties. South Africa only produces a class C fly ash due to the low grade lignite and sub-bituminous coal used. By using fly ash as a substitute for a portion of cement, less landfill sites are required and also less cement is required (USEPA, 2007).

*Emission sources from slag and fly ash*

The emissions sources from slagment are mainly from indirect (electricity). This is due to the fact that the process requires grinders which are powered by electricity. It has been seen that indirect emissions can account for up to 65 percent of total emissions. The largest direct emissions source results from fuel used for on site vehicles.

Emissions resulting from fly ash are the inverse to emissions from slagment. The bulk of emissions result from diesel use in on site trucks, which is a direct emission source.

**Cement overview**

The cement component has received the most attention out of all of the activities that contribute to concrete and has been comprehensively scrutinised (Humphreys and Mahasenan, 2002; CIF, 2003). This is due to the fact that it has a relatively high emission of $CO_2e$ and is produced in large quantities. In 2007, there were over 14.1 million tonnes of cement produced in South Africa. The process of cement production releases large quantities of $CO_2e$ from the kiln where limestone is degraded. This process releases half a tonne of $CO_2e$ for every tonne of CaO (Calcium Oxide) produced (Price *et al.*, 1999; Ellis, 2000; Flower and Sanjayan, 2007). The high energy consumption of the kiln also adds to direct and indirect emissions (Huhta, 1992). Emission figures for cement from around the world range between 0.7 t to one t $CO_2e$ per ton of cement (Josa *et al.*, 2003; Gartner, 2004). This has been determined through the extensive research into emissions from cement (Worrell *et al.*, 2001, Humphreys and Mahasenan, 2002; Lippiatt and Ahmad, 2004; Huntzinger and Eatmon, 2008).

The ACMP (Association of Cementitious Material Producers) monitors $CO_2$ emissions from the cement sector. ACMP have noted a steady reduction of $CO_2$ emissions from 1990 to 2006 (Figure 1.6). This is due to the fact that this industry has

made huge investments to improve efficiency, however, technology efficiencies still vary between sites (Bösche, 1993, Worrell *et al.*, 1997). A large portion of emissions which need to be included, result from the grinding of clinker (Von Seebach, 1996; Folsberg, 1997). The current South African average of 670 kg $CO_2$ per tonne of cement only takes direct emissions into consideration. They are able to publish this value due to the fact that the international cement protocol only requires direct emissions to be disclosed. This is not an accurate representation of the emissions resulting from cement.

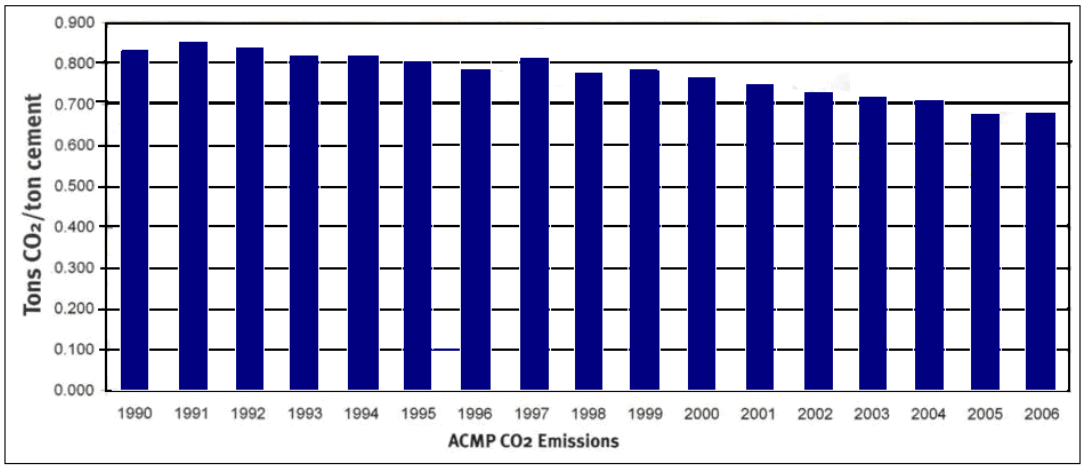


**Figure 1.6. $CO_2$ emissions resulting from cement (ACMP, 2008)**

There are many authors who have attempted to quantify global as well as localised cement emission factors. There are large inconsistencies in this respect where some authors have only considered direct emissions. If we examine Table 1.4, it can be noted that the emissions factors in green produced by the authors Climate Change Information Center, 2003; Lippiatt and Ahmad, 2004 only take direct emissions into consideration. There is also some deviation when direct as well as indirect emissions are considered. The values noted in yellow range between 810 and 890 kg $CO_2$ per tonne cement. The average emissions value is 846 kg $CO_2$ per tonne of cement. The European cement association (2004) noted that depending on the on the efficiency of the process, fuels used, extension and specific type of cement produced the range of emissions is 650 to 950 kg $CO_2$ per tonne of cement.

**Table 1.4. Published average $CO_2$ emissions per tonne of cement**

| Author | Scope of emissions (average) | kg $CO_2e$ per t cement |
|---|---|---|
| Lippiatt and Ahmad, 2004 | World | 440 |
| Climate Change Information Center , 2003 | World | 499 |
| Holcim: Annual Review & Sustainability Report 2006 | Sri Lanka | 665 |
| ACMP, 2008 | South Africa | 690 |
| Humphreys and Mahasenan, 2002; Worrell *et al.*, 2004 | Western Europe | 700 |
| Humphreys and Mahasenan, 2002; Worrell *et al.*, 2004 | Japan & South Korea | 730 |
| Huntzinger and Eatmon, 2008 | World | 810 |
| Worrell *et al.*, 2004 | World | 814 |
| Humphreys and Mahasenan, 2003 | World | 870 |
| European cement association , 2006 | World | 890 |
| Humphreys and Mahasenan, 2002; Worrell *et al.*, 2004 | China | 900 |
| Humphreys and Mahasenan, 2002; Worrell *et al.*, 2004 | India | 930 |
| Humphreys and Mahasenan, 2002; Worrell *et al.*, 2004 | United States of America | 935 |

The main emission sources identified by the GHG Protocol (2004), which are related to cement production, are calcination, fuel use (kiln and on site transport), explosives and electricity.

*Direct cement emissions*

The primary direct emission source results from calcination, followed by diesel and explosives. The process of calcination is generally the largest source of GHG emissions associated with this activity and can be expressed by the equation:

$$CaCO_3 + \text{heat} \rightarrow CaO + CO_2 \qquad (1.2)$$

In order for calcination to occur, the kiln is required to reach temperatures in excess of 2000°C. Depending on the raw materials and the actual production process, a cement site can under normal circumstances consume fuel at a rate between 3,200 and 5,500

megajoules per tonne of clinker (Ellis, 2000). Diesel is used to start kilns and once heated, coal is used as the fuel source. The resulting emissions can be expressed by the equation:

$$C + O_2 \rightarrow CO_2 \quad (1.3)$$

Diesel is used for quarry haul trucks, front end loaders, forklifts and personnel transport. Small amounts of fuel are also sometimes used to fuel heaters to dry coal and other raw materials, depending on site design. Explosives are used to loosen bedrock to access the limestone reserves (Meyer *et al.*, 2007). The cement protocol deems this as immaterial, relative to the other emission sources (CSI cement protocol V2, 2005). Despite this, emissions resulting from explosives will be included in this study to provide an all-encompassing representation.

*Indirect cement emissions*

The main indirect emissions source is grid electricity consumption. Cement sites are large energy intensive industrial sites (Hendriks *et al.*, 1999; Humphreys and Mahasenan, 2002). In South Africa, Eskom is the primary provider of electricity and relies on coal combustion to produce electricity.

*Other indirect cement emissions*

These main other indirect emissions result from off-site transport of raw or intermediate products by road, rail and trucks. Transport does not normally have a significant impact on the total $CO_2$ emissions of cement production due to the large quantity of emissions from direct and indirect sources (Worrell *et al.*, 2001).

**Aggregate overview**

The production of aggregates does not have a large amount of $CO_2e$ emissions related to it, however, there are significant environmental impacts due to quarrying

(Schuurmans *et al.,* 2005). Aggregate is a coarse material which is a component of a concrete mix. Aggregate is a broad term which includes gravel, slag, sand, crushed stone and recycled concrete (Schuurmans *et al.,* 2005). The primary function of aggregates is to add strength to a concrete structure and is a key activity in foundation mixes. Aggregates are mined in quarries where high quality bedrock exists such as limestone, marble or granite (Schuurmans *et al.,* 2005). The bedrock is then milled into a useable product. The crushing of the rock does require electricity. Due to the quantities being produced, aggregate has a very low emissions factor per tonne.

*Aggregate emission sources*

There are very few emissions resulting from aggregate production. The small amounts include on site transport and explosives contributing to direct emissions as well as electricity contributing to indirect emissions. Indirect emissions account for up to 70 percent of emissions from aggregate production. Aggregate production will rarely exceed 25 kg $CO_2$e per tonne produced, with an average aggregate resulting in 15 to 20 kg $CO_2$e per tonne (Schuurmans *et al.,* 2005).

**Admixture overview**

Admixtures are additives which enhance or reduce certain properties of a concrete mix. These properties may be workability, extension or strength (Humphreys and Mahasenan, 2002; Flower and Sanjayan, 2007). The $CO_2$e emission factors of admixtures are very high, however, very small quantities of admixture are required in a mix (Flower and Sanjayan, 2007). A typical concrete mix will at most have two litres of admixtures per cubic meter. Even though the $CO_2$e emission contribution from admixtures is small, it will be included in the calculations for completeness.

*Admixture emission sources*

The primary emission sources from admixtures are from fuel and electricity. In South Africa the main admixture that is used is a plasticizer. Plasticisers are also referred to as water reducers. Plasticisers are in either a liquid or powdered form with the base chemical being lignosulfonates or sulfonated lignins. Lignosulfonate is a by-product from the paper industry and is recovered from the pulping liquids (Flower and Sanjayan, 2007). Plasticisers are usually added in concentrations of 0.25 to 0.8 percent by weight of cement and have a water reduction potential of up to ten percent.

**Steel reinforcing overview**

Reinforcing is an essential component to concrete. Concrete has got a high compression, however, very low tensile strength. Due to this fact reinforcing or rebar is necessary to provide added strength (González *et al.*, 1995). The most common form of rebar is metal, however, other materials which can be used include plastic or glass fibres. A vital characteristic of reinforcing is that it must have a similar thermal expansion coefficient to that of concrete (González *et al.*, 1995; Kranc and Sagüés, 2001; Tamer *et al.*, 2003). This ensures that there are no unnecessary perpendicular or longitudinal stresses during setting which may weaken the structure (Tamer *et al.*, 2003). Rebar is bent and hooked within the concrete and set into structural members. Concrete normally has a pH of 12 or more, which prevents decay and rusting of the reinforcing material. This is essential to prevent structural failure (González *et al.*, 1995; Tamer *et al.*, 2003).

Only recently advanced reinforcement such as glass-fibre and reinforced thermo-set resins (generally classified as fibre-reinforced polymer bar) are being used in applications such as highly corrosive environments. Rebar is not a standard bar, there are different grades available dependent on the application. The grade and specifications will vary in composition, tensile strength, percentage of elongation as

well as yield strength. Rebar strength is measured in ksi, were one ksi is equal to 1000 psi. Common grades include 40, 60 and 75 ksi (Tamer *et al.,* 2003).

*Steel reinforcing emission sources*

The bulk of emissions from steel reinforcing results from direct sources such as on site diesel and coal. This is due to the fact that furnaces are fired by these source fuels. Electricity is also expected to contribute with few emissions from other indirect sources. It is known that steel refineries are very energy intensive and it is due to this fact that it has a very large amount of GHG's associated with its production (Tamer *et al.,* 2003). Steel production results in 12 000 kg $CO_2$e per cubic meter produced. This equates to approximately 1.52 t $CO_2$e pet ton of steel (González *et al.,* 1995). This factor is lower than the factor of 2.73 t $CO_2$e per ton of steel produced in South Africa (Mittal, 2009). This is because South Africa is predominantly producing virgin steel, whereas internationally recycling of steel is a lot more prevalent.

## Primary emission sources and factors applied in the model

In order to determine the emissions associated with the activity data acquired, the following default emission factors were used (Table 1.5). All the IPCC defaults are from the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Vol. II, Chapter 1 (IPCC, 2006). Following Table 1.5, each of these categories has been extensively examined.

The emissions that will be quantified result from the processes involved in the production of the final product. Some of the specific activities include transport (fossil fuels), quarry blasting (explosives) and on site buildings which alter the natural biome and prevent $CO_2$ from being cycled.

**Table 1.5. Primary emission factors applied to activity data.**

| Category | Other Sources | IPCC Default Emissions Factor (kg $CO_2$ per GJ) | IPCC Default Emissions Factor (TJ per Gg) | Density Kg per $m^3$ | IPCC Derived CV |
|---|---|---|---|---|---|
| **Fossil fuels** | | | | | |
| Coal | | 96.0 | 25.8 | | |
| diesel oil | | 74.1 | 43.0 | 0.84 | 35.9 MJ per l |
| gasoline (petrol) | | 69.3 | 44.3 | 0.75 | 33.2 MJ per l |
| LPG | | 63.1 | 47.3 | | |
| **Explosives** | | | | | |
| Explosives Mix | 0.2 | t/t | | | |
| **Land Use Change** | | | | | |
| Forest | 18.3 | t/ha | | | |
| Fynbos | 9.2 | t/ha | | | |
| Grassland | 9.2 | t/ha | | | |
| Nama Karoo | 9.2 | t/ha | | | |
| Savanna | 9.2 | t/ha | | | |
| Succulent Karoo | 0.9 | t/ha | | | |
| Thicket | 9.2 | t/ha | | | |
| **On site waste** | | | | | |
| On site waste water | 0.004 | t $CO_2e$ /kl | | | |
| On site landfill | 1.05 | t $CO_2e$ /t | | | |
| **Muncipal services** | | | | | |
| waste water | 0.002 | t $CO_2e$ /$m^3$ | | | |
| water consumption | 0.009 | t $CO_2e$ /kl | | | |
| landfill | 0.98 | t $CO_2e$ /t | | | |
| **Transport** | | | | | |
| Diesel trucks | 0.001 | t $CO_2e$ /km | | | |
| Flights | 0.0001 | t $CO_2e$ /km /person | | | |
| Domestic car | 0.0002 | t $CO_2e$ /km | | | |
| **Electricity** | | | | | |
| Eskom Factor | 1.021 | t $CO_2$/MWh | | | |

**Fossil fuels as a GHG source in the production of concrete**

$CO_2e$ emissions are directly related to fossil fuel usage due to the fact that their primary composition is carbon. When broken down in the presence of oxygen the carbon binds with the oxygen to form $CO_2$. The on site and offsite consumption of diesel, petrol and LPG by transport, kiln ignition and heating, result in direct emissions of combustion gases which have a global warming potential. Coal and anthracite are also used to fire kilns and incinerators which produce $CO_2$. The IPCC was used as a source for all of the emissions factors for fossil fuels. No locally applicable values could be found and it was felt that these would most accurately represent emissions for South Africa (IPCC, 2006).

**Explosives as a GHG source in the production of concrete**

Explosives are used for blasting at aggregate and lime quarries. The cement protocol deems these emissions as immaterial, relative to the other emission sources. It should be noted that emissions from explosives have been included for completeness. The IPCC provides emission factors for explosives (Table 1.6), however, the IPCC emission factors were not used due to the fact that a South African emissions factor was obtained. A very commonly used product is Sasol explogel which has got an emissions factor or 0.2 t $CO_2e$ per tonne product (Spiteri, 2009).

**Table 1.6. Emission factors for explosives (IPCC, 2006)**

| Explosive type | Tonne $CO_2$ per t product |
|---|---|
| ANFO | 0.17 |
| Heavy ANFO | 0.18 |
| Emulsion | 0.17 |

An explosive is a chemical material that, under the influence of thermal or mechanical shock, decomposes extremely rapidly and spontaneously with the evolution of large amounts of heat and gas (Meyer, 2007). Since an adequate supply of oxygen cannot be

drawn from the air, a source of oxygen must be incorporated into the explosive mixture. Some explosives, such as trinitrotoluene (TNT), are single chemical species, but most explosives are mixtures of several ingredients. As in other combustion reactions, a deficiency of oxygen favours the formation of carbon monoxide and unburned organic compounds and produces little, if any, nitrogen oxides. An excess of oxygen causes more nitrogen oxides and less carbon monoxide and other unburned organics. For ammonium nitrate and fuel oil (ANFO) mixtures, a fuel oil content of more than 5.5 percent creates a deficiency of oxygen (Meyer, 2007).

The emissions from explosives detonation are influenced by many factors such as explosive composition, product expansion, method of priming, length of charge, and confinement. These factors are difficult to measure and control in the field and are almost impossible to duplicate in a laboratory test facility. With the exception of a few studies in underground mines, most studies have been performed in laboratory test chambers that differ substantially from the actual environment (Meyer, 2007). Any quantification of emissions from explosives must be regarded as an approximation (IPCC, 2006). This is not an issue as explosives account for a very small percentage of the overall resulting emissions from concrete.

**Land Use Change as a contributor to GHG's in the production of concrete**

The alteration of land from its natural state to a disturbed state impacts negatively on the ability of the vegetation to absorb $CO_2$ thus, impacting on the ecosystems carbon sink (Miller, 2004). Due to the fact that we are quantifying the impact of the production process of concrete we need to take land use into consideration. On site infrastructure would include roads, offices, waste dumps and factories. These structures inhibit the natural vegetation, which is a carbon sink, from cycling $CO_2$.

A carbon sink is a reservoir that can sequester $CO_2$ from the atmosphere (Houghton *et al.,* 1999, Pacala *et al.,* 2001). Through the process of photosynthesis, site species absorb $CO_2$ from the atmosphere. They retain the carbon activity and release oxygen

back into the atmosphere. The quantity of carbon which is contained in these sites is known as the carbon stock (Houghton, 2003, Schimel *et al.*, 2001).

The national biomes of South Africa need to be examined to determine the type of land cover at the site. It can for example be noted that the grasslands biome is found chiefly on the high central plateau of South Africa (Rutherford and Westfall, 1994). This form of land cover generally has vegetation dominated by perennial grasses, which are a single-layered herbaceous community of tussock (or bunch) grasses. Grasslands are typified by below ground carbon due to large underground storage structures (Rutherford and Westfall, 1994). Thus, carbon is mainly contained in roots and soil organic matter. Once the biome type has been identified (Figure 1.7) the emissions factor will be determined using the IPCC default values (Table 1.7).

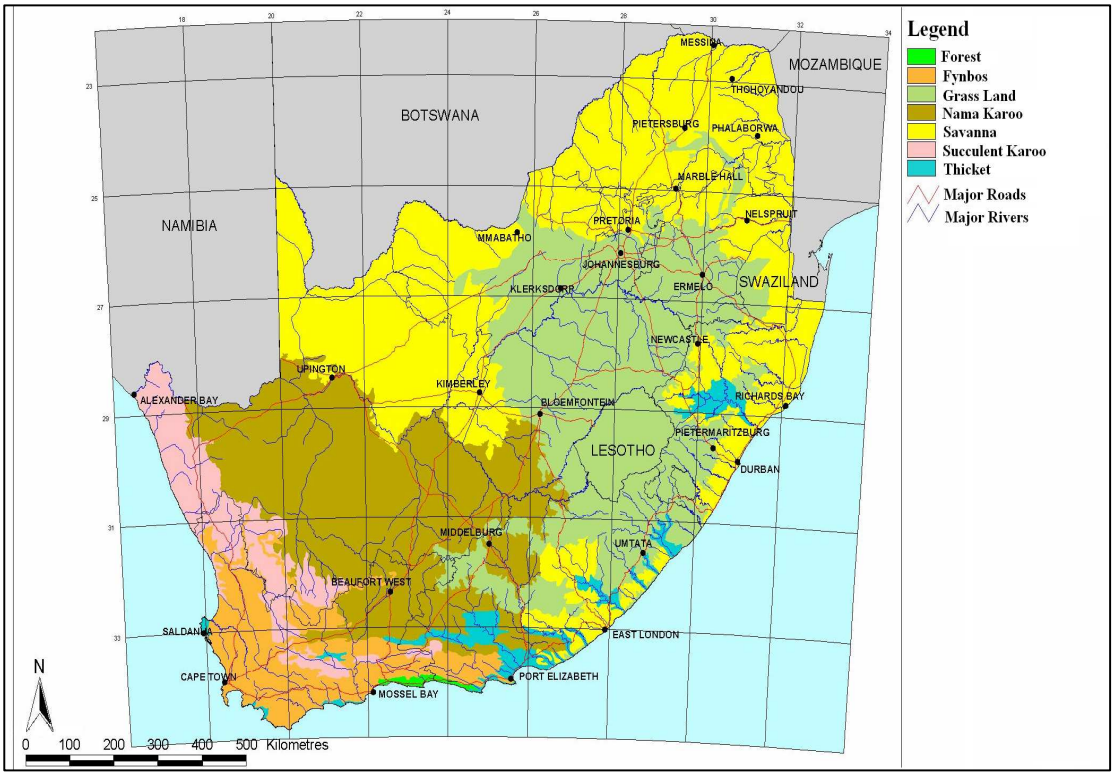


**Figure 1.7: Biomes of South Africa, (Enviro-info, 2001)**

**Table 1.7. IPCC biome default emission factors (IPCC, 2006)**

| Climatic temperature regime | IPCC default (tonne C.ha$^{-1}$.yr$^{-1}$) |
|---|---|
| Boreal to Cold Temperature | 0.25 |
| Warm Temperature | 2.5 |
| Tropical to Sub-Tropical | 5 |

**Wastewater treatment as a GHG source in the production of concrete**

Wastewater can be a source of $CH_4$ (methane) and $N_2O$ (nitrous oxide) emissions when undergoing treatment. Carbon dioxide ($CO_2$) emissions from wastewater are not considered in the IPCC Guidelines. This is due to the fact that this $CO_2$ is from a biogenic origin (i.e. organic non-fossil material produced by biological processes of living organisms). Therefore, these $CO_2$ emissions are considered 'carbon neutral'. There are two broad types of waste water treatment sites, namely aerobic and anaerobic.

Aerobic digestion is only used for small scale sewerage treatment (Lee and Welander, 1996). The process involves breaking down the material in the presence of oxygen (Tay *et al.,* 2003; Lee and Welander, 1996). Anaerobic digestion produces a high quality effluent which once sterilised can be used for surface irrigation (Gander; 2000).

Anaerobic digestion is used for large scale sewerage treatment. The process involves micro-organisms which break down the biodegradable material in an oxygen depleted environment (Lettinga *et al.*, 2000). Anaerobic digestion can be used as a source of renewable energy. This is because the processes produce methane which can be captured and used for energy production. There is also a nutrient rich waste which is a by-product of digestion and can be used as a fertiliser (Lettinga *et al.,* 2000).

The extent of $CH_4$ production depends on factors such as degradable organic material, temperature and type of treatment system. The principal factor in determining the $CH_4$

generation potential of wastewater is the amount of degradable organic material in the wastewater (Tay *et al.,* 2003). The rate of $CH_4$ production also increases with increasing temperature. A common parameter used to measure the organic activity of the wastewater is the Chemical Oxygen Demand (COD). Under the same conditions, wastewater with higher COD will generally yield more $NH_4$. The COD measures the total material available for chemical oxidation including both biodegradable and non-biodegradable sources (IPCC, 2006).

The degradation of nitrogen activities such as urea and protein in the wastewater produce $N_2O$. Domestic wastewater includes human sewerage mixed with other household wastewater (Lettinga *et al.,* 2000). Depending on the type of treatment site, a specific methane correction factor (value from zero to 1), needs to be taken into consideration when determining site emissions. Sites which are aerobic emit little (almost no) methane, while anaerobic sites emit considerably more methane and thus have a larger methane correction factor and hence a much larger carbon footprint (IPCC, 2006).

**Electricity as a GHG source in the production of concrete**

Once again, due to the fact that we are quantifying all process emissions, electricity needs to be taken into account. The emissions resulting from the use of electricity affect all sites. These emissions are not emitted directly by the site but the emissions are a result of the sites need for electricity (Slanina, 2004). The GHG protocol classifies these emissions as direct, indirect and other indirect emission (GHG protocol, 2004). A local emissions factor is available from South Africa's leading electricity supplier Eskom. Calculated using the ACM 0002; IPCC default values on calorific value and Eskom average calorific data for grid Eskom had an emission factor of 1021 kg $CO_2$ per MWh of electricity consumed in 2006 (CDM, 2006). The 2006 value was the closest available factor to apply to this study which is based on 2007 data. This factor needs to be multiplied by the sites consumption to determine electricity related emissions.

**Transport as a GHG source in the production of concrete**

Transport is a source of emissions that needs to be taken into consideration. Emissions from transport result from the combustion fuel during the transport of products between sites and to customers. All these emissions result directly due to being involved in the concrete industry. The emission factor for South African trucks (1.1 kg $CO_2e.km^{-1}$) was obtained from BP and Shell (2007). The reporting of transport related emissions is not compulsory due to the fact that the GHG protocol classifies these emissions as other indirect emissions. Transport emissions will be included in this study for completeness.

# Research goals and design

## Research objectives

The objective of this study is to identify the key emission sources contributing to the GHG emissions from concrete. Following this it will be possible to quantify the emissions resulting from the production of a cubic meter of concrete. These calculations can then be extrapolated to depict the emissions resulting on a national level as well as in the various sectors of end use. The final, logical objective is to evaluate possible mitigation strategies to decrease the $CO_2e$ emissions from concrete production.

These research objectives can be simplified into the following three main goals to be achieved:

- determine the $CO_2e$ emissions per cubic meter of concrete produced in South Africa and benchmark internationally;
- quantify the national, provincial and sector $CO_2e$ emissions from concrete in South Africa; and
- evaluate possible mitigation strategies to decrease the associated emissions.

## Research design

The aim of this research is to investigate the $CO_2e$ emissions resulting from the concrete industry in South Africa. Specific activity data on direct, indirect and other indirect emissions will be collected from industry supporting concrete manufacture across South Africa. Extensive research will be covered and the GHG cement protocol implemented in the determination of associated emissions. This data will be collected in the form of a questionnaire which will be used as an input to a model to determine the GHG emissions resulting from the industry. This model will be developed specifically for this research and will be based on the GHG protocol. It will also apply IPCC default values where country specific values were not available. Once the $CO_2e$ emissions have been estimated for South Africa, the figures obtained will be benchmarked against available international data providing valuable insight to the South African results. Once the national, provincial and sector $CO_2e$ emissions have been quantified, possible mitigation strategies will be evaluated. This will be done by performing a desk top study of available technologies and techniques and their applicability to the South African situation.

**********

The $CO_2e$ emissions resulting from concrete production will be investigated using closed ended questionnaires distributed to industries that support concrete manufacture across South Africa. It was justified that carbon emission inventories are of great importance and the state of global GHG emissions was discussed and uncertainties noted. The key emissions sources were identified and evaluated.

# Chapter 2

# Data and Methodology

Data collection, modelling and analysis procedures for data interpretation are discussed in this chapter. The questionnaire and sampling methods used for data collection are described. Activity data from 128 activity processes was obtained to quantify the $CO_2e$ emissions. Each of the activities examined had a personalised questionnaire. These were then compiled into a final model.

## Measurement of $CO_2$ emissions

The calculation of $CO_2e$ emissions can be obtained in one of two ways, namely, calculations from production data or through direct measurement. Direct measurement of emissions is almost always impractical unless it is being done in connection with an air quality audit. This study has gathered activity data, used default emissions factors and applied inferential methodologies to determine the $CO_2e$ emissions. Activity production data covering direct, indirect and other indirect emissions have been collected for all of the activities. The sites sampled are located throughout South

Africa. A large site sample was used so that this study produced an accurate representation of the industry in South Africa (McGrew and Monroew, 2000).

Historically the cement industry has been using the GHG protocol cement rules and the World Business Council for Sustainable Development (WBCSD) model to determine $CO_2e$ emissions (WBSCD, 2005). By using the existing model as a basis, a new model has been developed taking all the process and activity of concrete production into consideration. The standard principles of the GHG protocol are followed as highlighted in this chapter.

## Choice of accepted reporting standard

Firstly a reporting standard needed to be chosen and two main protocols are currently in use. In its Clean Development Mechanism (CDM) information pack the Chamber of Mines (CoM) makes reference to the fact that a number of mining houses are making use of the Greenhouse Gas Protocol as developed by the World Resources Institute (WRI) and the World Council for Sustainable Development (WBCSD) (CoM, 2007). This is especially popular for reporting initiatives adhering to the Carbon Disclosure Project (CDP) principles. The Global Reporting Initiative (GRI) also recommends the use of the GHG protocol (GRI, 2008). Seeing that the "Greenhouse Gas Protocol" has already been adopted for the cement activity worldwide, this project continues the use of this protocol (WBCSD, 2005).

## The reporting window

Normal practice for baseline quantification and determination of carbon emissions is to consider performance over the last two years (GHG protocol, 2004). In many cases the GHG emissions can be determined inferentially from production and related information (GHG protocol, 2004). The IPCC has developed a large number of carbon equivalent emission factors that make it easier to calculate organisation emissions (IPCC, 2006). This is especially useful in cases when emissions include not only

carbon dioxide but also methane and nitrous oxide for example, which are not normally measured continuously at point of source. If on the other hand, emissions would include some of the other GHG's (hydroflourocarbons, perfluorocarbons and sulphur hexafluoride) then inferential calculations would have to suffice for historical determinations, but reliable measurements for future reporting would have to be instituted by the companies or operations concerned (IPCC, 2006). The data for this study was collected for 2006, 2007 and 2008. All of the sites responded with 2007 data and due to this fact, this study is based on 2007 data.

## Questionnaire compilation and measurement procedures

The $CO_2e$ emissions of the concrete industry are being investigated using a model and questionnaire developed specifically for this research. This model was based on the WRI (World Resources Institute) and WBCSD (World Business Council for Sustainable Development) cement protocol, which was developed following the guidelines of the GHG protocol (WBCSD, 2005). The model and questionnaire account for all emissions from activities contributing to the industry.

The final questionnaire and model for each activity take into consideration the GHG protocols emissions reporting main principles. These include the following aspects:

- Relevance - the application of the GHG cement protocol is appropriate to the intended users, both internal and external.
- Completeness - all material GHG emissions within the chosen boundaries are included in the worksheet. Direct, indirect and other indirect emissions are reported, but are done so separately.
- Consistency - methodologies recommended are applied consistently across all collected data.

- Transparency - all relevant issues and recommended sources of data are clearly explained.
- Accuracy - bias and uncertainties have been reduced as far as realistically possible by following the prescribed GHG protocol guidelines.

This study is based on data acquired from 130 sites located across South Africa contributing to the concrete industry (Table 2.1). The data gathering process was initiated on 1 August 2008 using a closed ended questionnaire that required input of data for 2006, 2007 and 2008 (Appendices 1 - 7). Each of the activities of the concrete industry had a tailored questionnaire. The emission factors obtained were then inputted into a concrete $CO_2e$ determination model to establish the emissions per cubic meter of a specific concrete mix.

**Table 2.1 Distribution of respondents by province**

| Province | Number of responding sites |
|---|---|
| Eastern Cape | 5 |
| Free State | 4 |
| Gauteng | 45 |
| Kwazulu-natal | 27 |
| Limpopo | 6 |
| Mpumalanga | 8 |
| North West | 12 |
| Northern Cape | 4 |
| Western Cape | 16 |
| Data source | 3 |
| Total | 130 |

An appropriate measurement of emissions intensity needed to be selected. In the case of the concrete industry, the intensity format of kg $CO_2e$ emitted per cubic meter of concrete produced was used.

Questions were designed to gather specific activity data covering all emission sources. Some of the sources include fuel and electricity consumption as well as total raw product sold. The aim is to determine the average $CO_2e$ emissions per cubic meter of concrete, estimate provincial and national emissions as well as evaluate the top consumers of concrete in South Africa. It is expected that provinces with high development rates such as Gauteng will have higher concrete consumption in comparison to provinces such as the Northern Cape which is sparsely populated.

## Analysis and modeling procedures

Average regional and national $CO_2e$ emissions in South Africa are discussed. Regional emissions are broken down into the nine provinces within the country. It is expected that the three most developed regions in the country will contribute the most to concrete related $CO_2e$ emissions. These centres include Johannesburg (Gauteng), Durban (Kwa-zulu Natal) and Cape Town (Western province). The values that have been extrapolated to national and provincial levels are considered representative. This is due to the fact that almost all the companies that supply the materials contributing the most emissions (98 percent of emissions) were sampled. These main materials being steel reinforcing and cement, with 100% and 78% of market share being sampled.

An average mix is used to determine the $CO_2e$ contribution of each activity to the concrete industry as a whole. These total emissions are then examined on a national, regional and application specific level. The calculations represent realistic mix designs and are intended to provide an indication of resulting emissions.

The $CO_2e$ emissions of the concrete industry are being investigated using a model developed specifically for this research on the basis of the GHG protocols model for cement emissions evaluation. The model represents the emissions from all contributing activities to the industry. Site data was then consolidated with all the sites from that specific activity. The original WBCSD reporting model is available for public download on their web site.

## Description of the model

The existing WBCSD model was used as a guideline and a new model was generated. The model is based in excel and requires activity data input from the sites of the concrete industry. The new model has the following main characteristics:

- reports direct, indirect and other indirect site specific emissions;
- takes into consideration delivery transport ; and
- consolidation to determine emissions per tonne of product.

The data were gathered by means of questionnaires (Appendices 1 – 7). This data were then consolidated and inputted into the model to determine the associated $CO_2e$ emissions. This was done by linking the activity data with an emissions factor (Table 1.5). No advanced statistical techniques needed to be applied for data analysis and the resulting specific emissions indicator of $CO_2e$ per year for each of the emission sources was obtained for each component of the concrete industry (Table 2.2). The figures obtained were then totalled and divided by the total product produced to determine an emission factor. These results were then used as the emission factor input into the final, concrete mix $CO_2e$ model. This final model allows the user to input various concrete mixes and compare the resulting emissions per cubic meter.

**Table 2.2. Model extract of the resulting $CO_2$ emissions table**

| **$CO_2e$ EMISSIONS** | | | | |
|---|---|---|---|---|
| **Direct $CO_2e$ Emissions** | | | | |
| | **$CO_2e$ from primary energy sources** | | | **2007** |
| | | Fossil fuels | [t $CO_2$ e/yr] | |
| | | Explosives | [t $CO_2$ e/yr] | |
| | | Land use change | [t $CO_2$ e/yr] | |
| | | On site waste water treatment | [t $CO_2$ e/yr] | |
| | | On site landfill | [t $CO_2$ e/yr] | |
| | **Total direct $CO_2e$ Emissions** | | | |
| | | Total direct $CO_2e$ all sources | [t $CO_2$ e/yr] | |

| Indirect $CO_2e$ Emissions (Main Sources) | | | |
|---|---|---|---|
| | **$CO_2e$ from external secondary sources** | | **2007** |
| | External power generation - ESKOM | [t $CO_2$ e/yr] | |
| | On site third party vehicles | [t $CO_2$ e/yr] | |
| | Municipal waste water treatment | [t $CO_2$ e/yr] | |
| | Municipal water consumption | [t $CO_2$ e/yr] | |
| | Municipal landfill | [t $CO_2$ e/yr] | |
| | **Total indirect $CO_2e$ Emissions** | | |
| | Total indirect $CO_2e$ all sources | [t $CO_2$ e/yr] | |

| Other Indirect $CO_2e$ Emissions | | | |
|---|---|---|---|
| | **$CO_2e$ from external tertiary sources** | | **2007** |
| | $CO_2e$ from flights | [t $CO_2$ e/yr] | |
| | $CO_2e$ from Business car travel | [t $CO_2$ e/yr] | |
| | $CO_2e$ from staff commuting car travel | [t $CO_2$ e/yr] | |
| | Raw material collection | [t $CO_2$ e/yr] | |
| | Product delivery emissions | [t $CO_2$ e/yr] | |
| | **Total other indirect $CO_2e$ Emissions** | | |
| | Total other indirect $CO_2e$ all sources | [t $CO_2$ e/yr] | |

| **$CO_2e$ SPECIFIC INDICATORS** | | |
|---|---|---|
| | | **2007** |
| **Direct $CO_2e$ Emissions** | [kg $CO_2e$ /t Product] | |
| **Indirect $CO_2e$ Emissions** | [kg $CO_2e$ /t Product] | |
| **Other Indirect $CO_2e$ Emissions** | [kg $CO_2e$ /t Product] | |
| **Total $CO_2e$ Emissions** | [kg $CO_2e$ /t Product] | |

| **ELECTRICITY SPECIFIC INDICATORS** | | |
|---|---|---|
| | | **2007** |
| **Electricity efficiency** | (kWh / t Product] | |

## Employment of the model

The model was designed in excel format and allows a user to input a specific concrete mix design, by weight contribution to the total mix (Appendix 8). The data input cells are linked to the emission factors that have been determined from the activity data questionnaires. The model allows the user to simultaneously input three varying mix designs for comparative purposes. The $CO_2e$ associated with each concrete mix is quantified by the model, any slight variance in mix composition will alter the associated emissions.

## Data shortcomings

The single shortcoming is that the site being surveyed may have inputted incorrect answers, thereby producing inaccurate results. In order to try and curb any of these incidents negatively impacting on the results, all major producers within each activity were approached. Thus, any 'random inputs' will not significantly influence the final results due to the number of questionnaires collected. Some of the site activity data was submitted by external consultants, which ensures its integrity. A few sites also submitted their electricity consumption accounts and production logs. The required activity data was manually extracted from these documents.

**********

The $CO_2e$ emissions are investigated using activity data gathered across South Africa. Questionnaires were distributed at site level to all of the activities of the concrete industry. Primary data required includes tonnage produced, fuel use and electricity consumption. The data are used to determine the relative $CO_2e$ contribution of each activity. The emission factors obtained from each activity were then inputted into a final $CO_2e$ emissions determination model for the concrete industry as a whole. This model allows the user to input specific mix designs to determine the associated $CO_2e$ emissions. An average mix design was used to determine the total emissions resulting from the industry as a whole. These results were then examined on a national, regional and application specific level.

# Chapter 3

# Research Results

This chapter outlines the key findings of this research. The emission factors that were determined are noted and discussed. The $CO_2e$ emissions per cubic meter, per province, per sector and for the whole of South Africa are evaluated. The resulting emission factors are then benchmarked against data acquired from the U.K. and Australia.

## Overview

Once all the activity data were consolidated, emission factors for each component were determined (Table 3.1). This was done by taking the total $CO_2e$ emissions that resulted from each component and dividing it by the amount of product produced. All of the results presented are based on 2007 data. Each of the components of the concrete industry will first be separately detailed, following this, the $CO_2e$ emissions per cubic meter, per province, per sector and for the whole of South Africa will then be calculated. However, first it is important to detail the limitations of these results.

Table 3.1. Activities/processes surveyed and emission factors obtained

| Activity | | Number of respondents | Estimated percentage of market | Emission Factors 2007 | Comment |
|---|---|---|---|---|---|
| 1 | Admixture | 1 | 25 % | 220.0 | kg $CO_2$e per ton |
| 2 | Aggregate | 27 | 10% | 5.4 | |
| 4 | Fly Ash | 3 | 50 % | 1.5 | |
| 5 | Slagment | 3 | 30 % | 128.6 | |
| 6 | Water | 1* | 100 % | 0.9 | |
| 7 | Reinforcing | 1** | 100 % | 2735.0 | |
| 8 | Precast | 12 | 25 % | 23.9 | |
| 9 | Readymix | 68 | 30 % | 10.5 | |
| 10 | Cement (CEM I) | 13 | 78 % | 985.4 | |

* Data Source: Friedrich *et al.*, 2005

** Data Source: Mittal, 2007

## Limitations of results

The limitations of the results presented in this chapter are as follows:

- The component spread sheets and the concrete model were developed using the WBCSD GHG emissions tool as a basis, strictly following the rules set out in the GHG protocol.

- The boundary of the study took all relevant direct, indirect and other indirect emissions into consideration. These were considered within the operational control of each site and the specific boundary can be defined as:
    - The start boundary can be defined as when the raw materials enter the site.
    - The end boundary can be defined as the placement of concrete on site.

- $CO_2$e emissions were determined by inferential techniques based on the following formula: Activity Data x Emission Factor = $CO_2$e emission factor

- ‘Activity data’ being the source data used to in the model calculations to infer emissions.
- ‘Emission factors’ being the factors used in the model calculation together with “Activity” data to infer emissions.

- The accuracy of the specific emissions of each component are limited to the accuracy of the activity data supplied by the respective sites.

- The activity data has been checked for anomalies but not verified. The data only represents a sample of the data available in the industry seeing as not all the members of the C&CI responded, and seeing that not all companies in the industry are members of the C&CI.

- The accuracy of the model is limited to the quality of the emission factors that have been used. Where publically available, local emission factors have been used. IPCC international default factors were used where local factors were unavailable. These factors were applied to the activity data that was collected from the various components of the concrete industry. It is common practice to determine the associated emissions from an activity or process by means of IPCC emission factors.

## $CO_2$e emissions from in-situ concrete and precast activities

As has been noted, all the components are used in the in-situ or precast activities. The cumulative process emissions are high, however, in-situ and precast activities themselves contribute few $CO_2$ emissions. The main emission sources for these activities are from electricity, which is an indirect source and on site fuel use, which is direct source (Figure 3.1 and Figure 3.2). When all scopes of emissions are included, in-situ concrete and precast activities account for approximately 8.5 percent of a mix’s emissions.

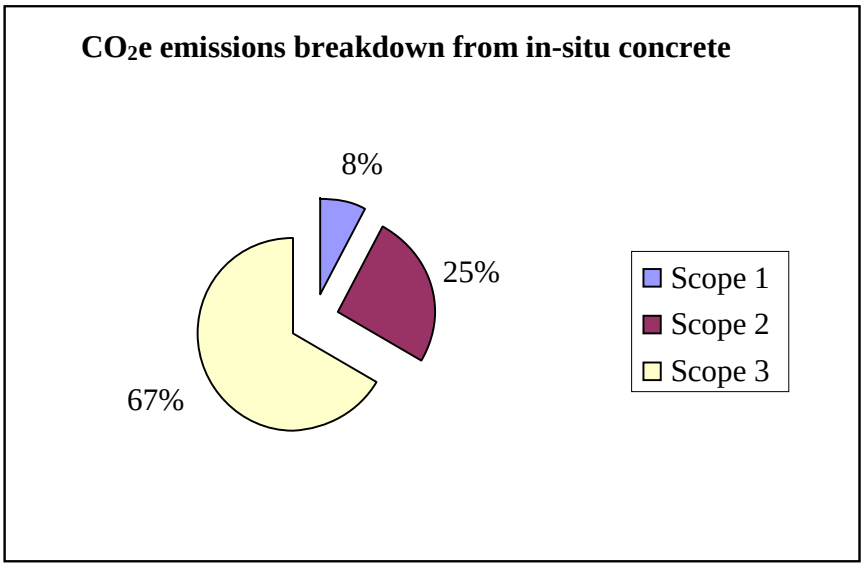


**Figure 3.1. $CO_2$ emissions breakdown from in-situ concrete**

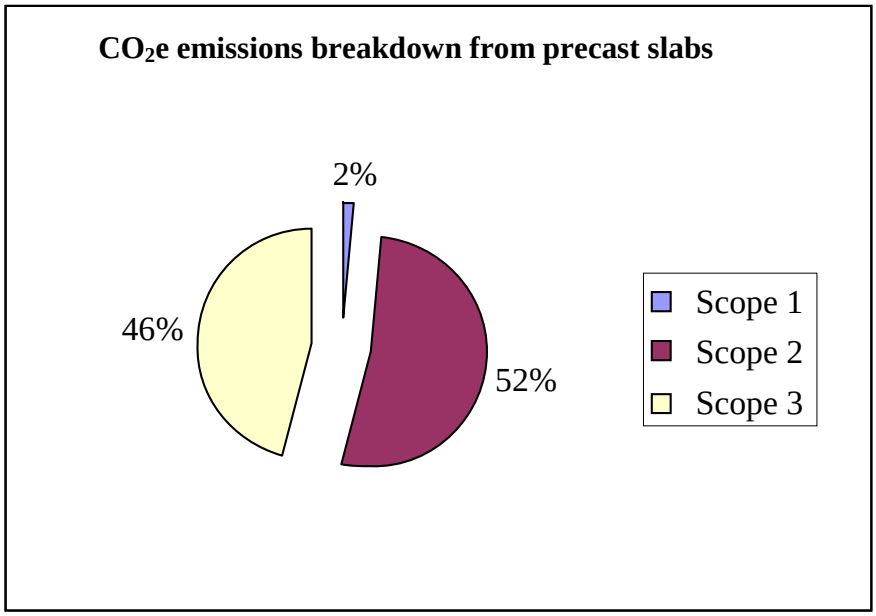


**Figure 3.2. $CO_2$ emissions breakdown from precast slabs**

## $CO_2e$ emissions from water and admixture components

The $CO_2e$ emissions from water and admixture components have been included in the emission calculations for completeness. Water and admixture contribute the least $CO_2e$ emissions to a concrete mix, on average 0.06 and 0.15 percent respectively.

Admixtures have a small contribution due to the fact that they are used in very small quantities of less than one litre per cubic meter of concrete. An in-depth study by Friedrich *et al.*, (2005) found the life cycle emissions associated with municipal water in South Africa to be 0.93 kg $CO_2e$ per kilolitre (Figure 3.3). Direct emissions resulting from on site water purification contributes 56 percent followed by indirect electricity emissions from pumping and capture.

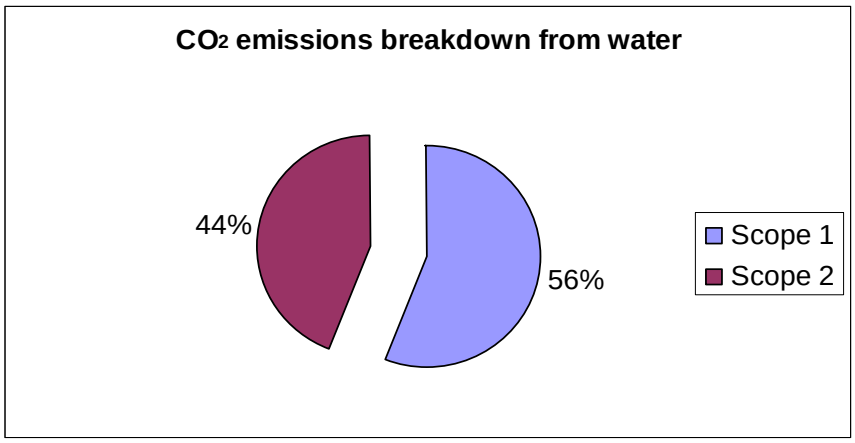


**Figure 3.3. $CO_2$ emissions breakdown from water**

## $CO_2e$ emissions from the production of extenders

The two extenders that are in use are slagment and fly ash. The figures that were obtained took into consideration that both materials are by-products of the steel and power industries respectively. Thus, the product would be produced regardless of demand from the concrete and cement industries. Therefore, the emissions factors only took activities into consideration post production. This includes capture, milling,

refining as well as transport processes. The breakdown of emissions from fly ash and slagment can be seen in Figure 3.4 and Figure 3.5.

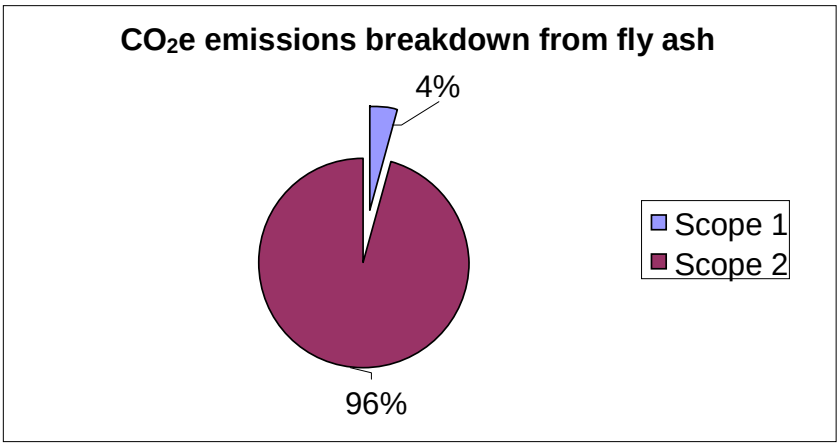


**Figure 3.4. $CO_2$ emissions from fly ash production.**

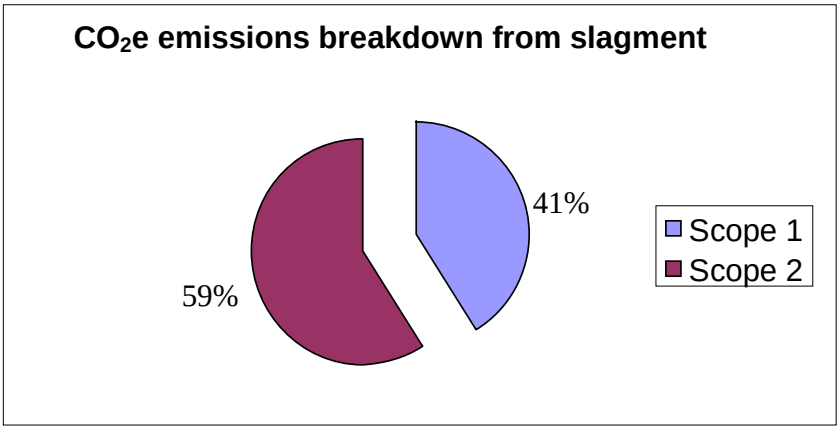


**Figure 3.5. $CO_2$ emissions from slagment production**

## $CO_2$e emissions from cement production

The values that were obtained for cement were based on data from three major suppliers of cement in South Africa. They have a combined market share of 78 percent and a capacity of over 12 million tonnes per annum. The primary emissions resulting from cement production is from carbonisation in the kiln, followed by direct sources from fuel emissions and finally indirect, electricity emissions (Figure 3.6).

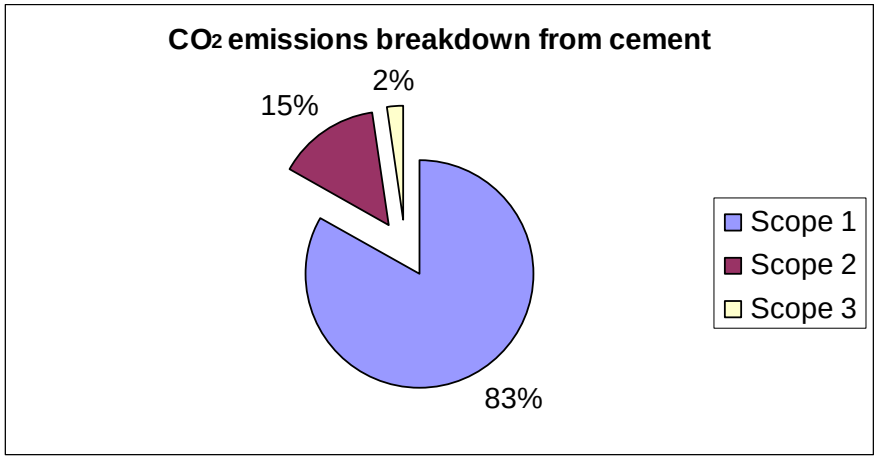


**Figure 3.6. $CO_2$ emissions from cement production**

## $CO_2$e emissions from aggregate production

Twenty eight aggregate quarries were sampled which is sufficient to provide an accurate representation. The emissions factor obtained is 12.2 kg $CO_2$ per tonne produced. The bulk of emissions resulted from in electricity consumption, followed by the direct source of diesel consumption (Figure 3.7). Due to the fact that explosives are consumed in such small amounts there are very few associated emissions despite its high emissions factor.

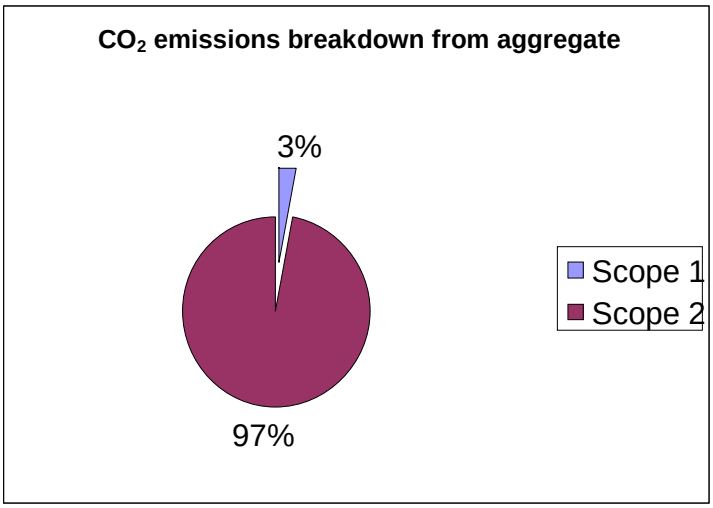


**Figure 3.7. Breakdown of $CO_2$ emissions for aggregate production**

## $CO_2e$ emissions from steel reinforcing production

In South Africa, steel rebar is the primary reinforcing used. It is known that the steel industry is very energy intensive, leading to it having the highest emissions factor of 2750 kg $CO_2$/t. The primary emissions source is from on-site coal consumption (Figure 3.6).

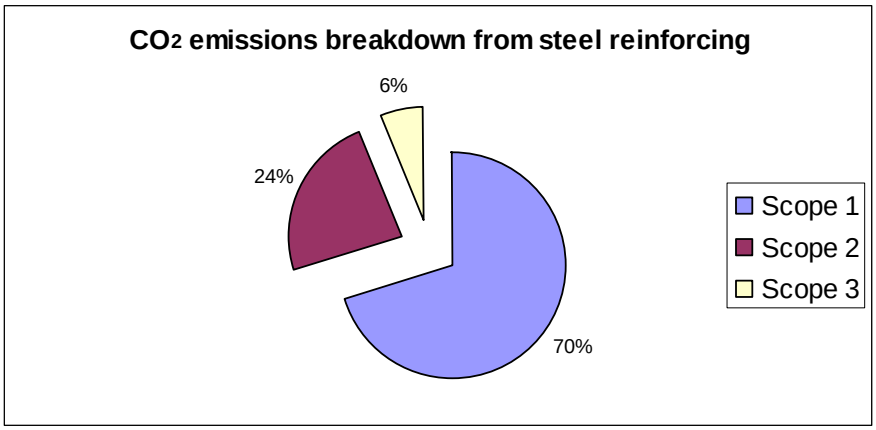


**Figure 3.8. $CO_2$ emissions from steel reinforcing production**

## **$CO_2$**e emissions per cubic meter of concrete production

In order to evaluate the resulting $CO_2e$ emissions, eight commonly used concrete mixes where designed (Appendices 9 to 16). It was found that an average[1] cubic meter of in-situ concrete, including all scopes of emissions resulted in a range of 215 to 240 kg $CO_2e$ per cubic meter (Figure 3.9, Figure 3.10). The overall range for the eight common mix designs tested was between 215 kg $CO_2e$ per $m^3$ and 501.8 kg $CO_2e$ per $m^3$.

[1] Average: CEM I 42.5, extension, admixture, strength of 30 MPa (Mega pascal) (Theodosiou, 2009)

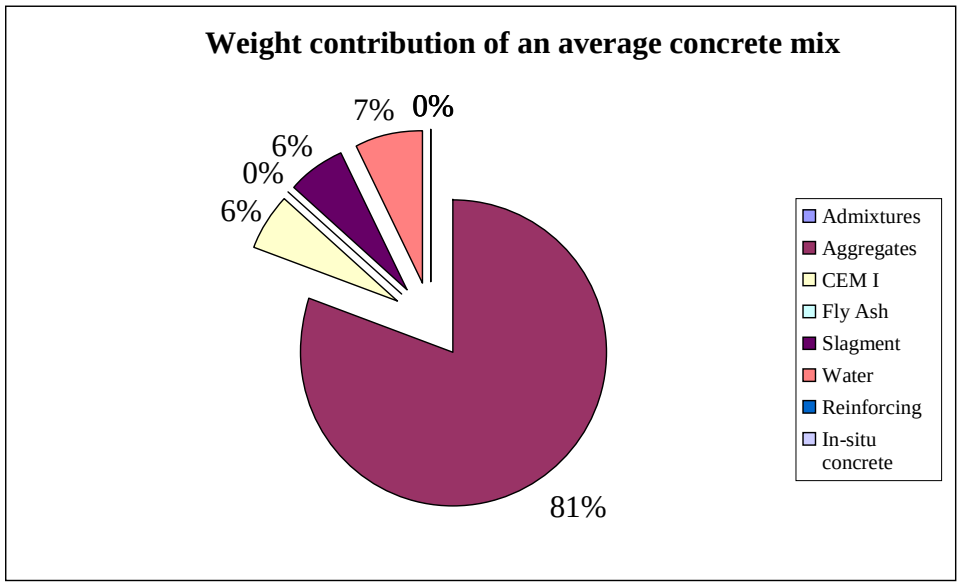


**Figure 3.9. Weight contribution of an average concrete mix.**

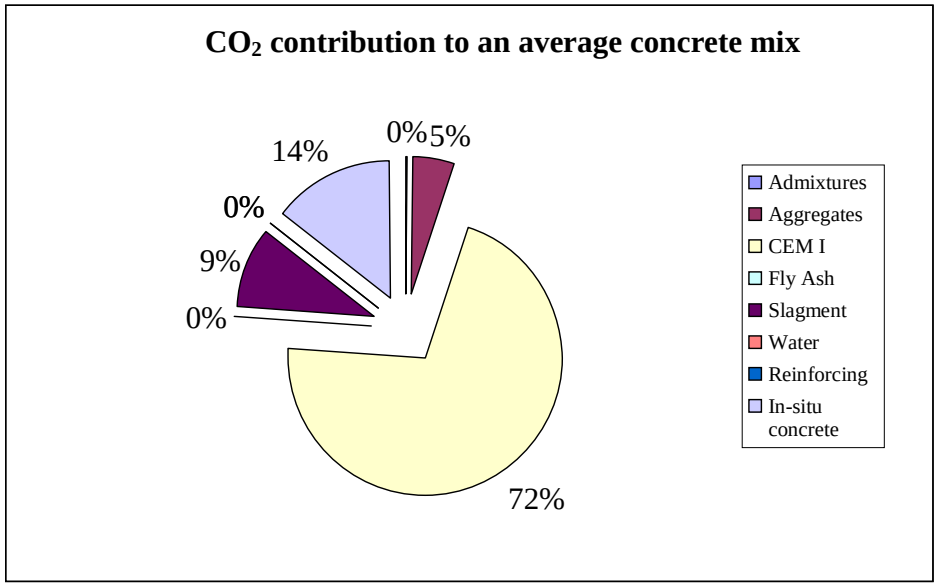


**Figure 3.10. $CO_2$ breakdown of an average concrete mix**

## National and Provincial $CO_2e$ emissions from concrete production

In 2007 there were just over 40 million cubic meters of concrete produced in South Africa. This resulted in the release of approximately 18 million tonnes of $CO_2e$ into the atmosphere. The province accounting for the bulk of these emissions was Gauteng with seven million tonnes $CO_2e$ (Figure 3.11, Figure 3.12).

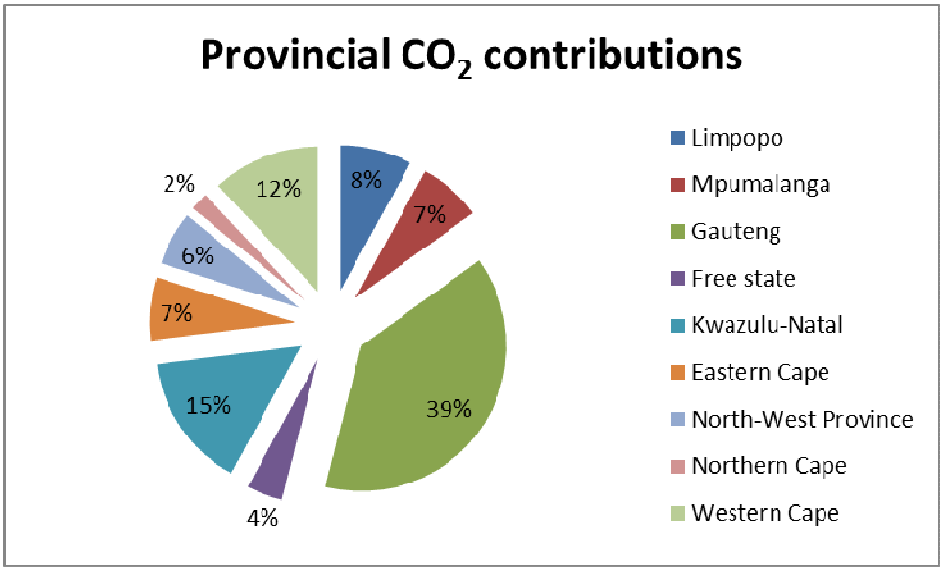


**Figure 3.11. Percentage $CO_2e$ emissions from concrete by province in S.A.**

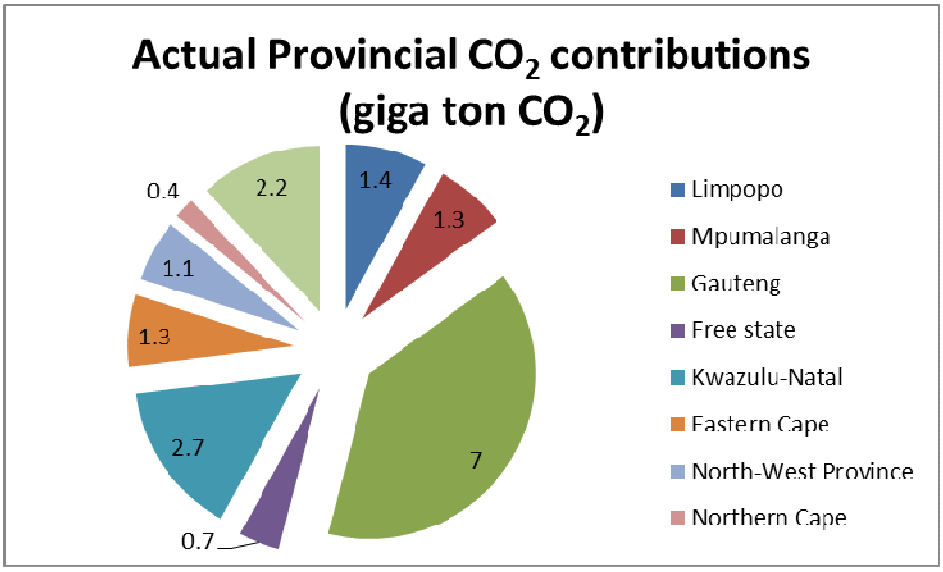


**Figure 3.12. Actual $CO_2e$ emissions from concrete by province in S.A.**

## $CO_2e$ emissions from concrete production per sector

The main consumer of concrete in 2007 was resellers. The resellers distribute the product to the general public as well as small ready mix sites. This sector accounted for 47 percent of the consumption of concrete and resulted in approximately eight million tonnes of $CO_2e$ emissions (Figure 3.13, Figure 3.14).

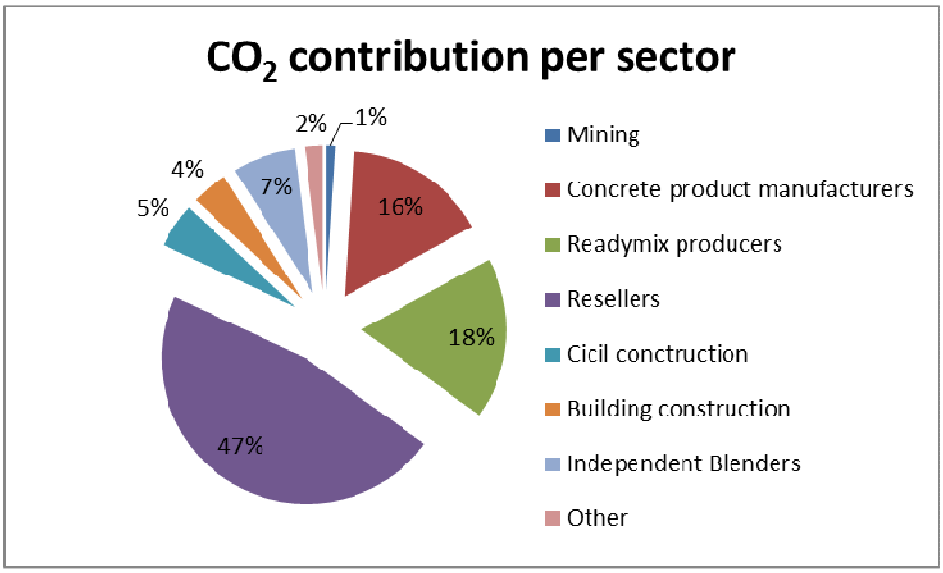


**Figure 3.13. Percentage $CO_2e$ emissions from concrete by sector in S.A**

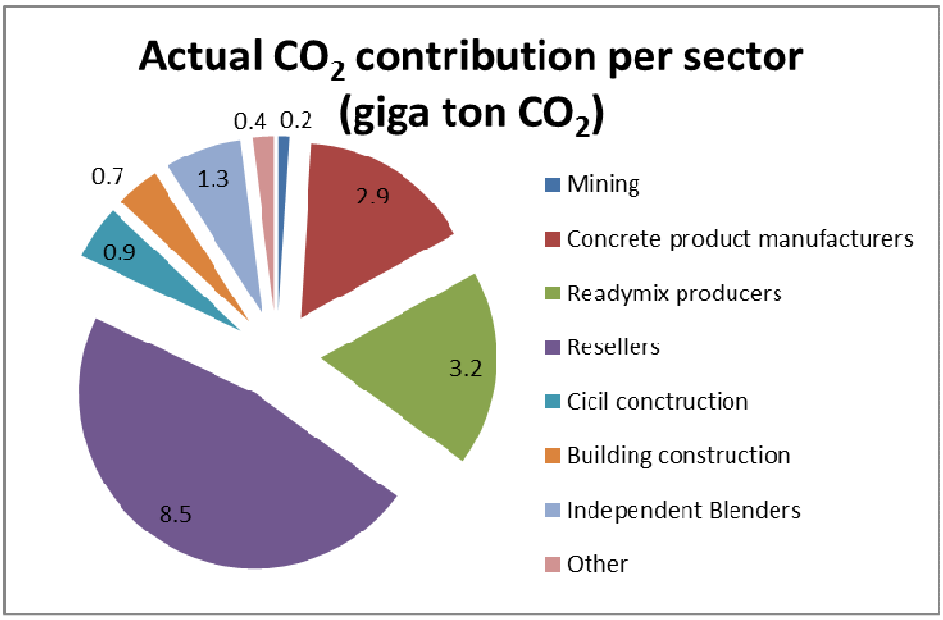


**Figure 3.14. Actual $CO_2e$ emissions from concrete by sector in S.A**

## Bench marking

There are only two similar studies which examine emissions due to concrete. The research was conducted by Flower and Sanjayan (2007) for Australia and the concrete centre (2008) for the United Kingdom. Upon examination of the Australian research, one major factor which needs to be taken into consideration is their sample size. The life cycle inventory data which was used to base their research was collected from three aggregate quarries, six concrete batching sites and 'several other sources'. This data is insufficient to produce an accurate statistical representation of the industry. It is still of value to examine their methods and results obtained. The U.K study on the other hand, takes all sites if the country into consideration. This is due to the fact that inventory data reporting is mandatory. This allows the centre to have all required data immediately on hand, there are around 3200 quarries and concrete production sites in the U.K.

The main components that were taken into consideration where cement, aggregates, slagment and fly ash. Some components where not taken into consideration for the Australian study namely, in-situ concrete, precast, water, admixtures and reinforcing. The U.K. study also excluded emissions resulting from reinforcing. The Australian study did examine emissions related to water and admixtures, but excluded the results in the calculations due to the fact that they deemed the emissions insignificant.

An important fact which Flower and Sanjayan (2007, p282) noted is that "reliable estimates of greenhouse gas emission footprint of various construction materials are becoming important, because of the environmental awareness of the users of construction material". It is essential to take all components of concrete into consideration to develop a representative and reliable $CO_2$ emissions inventory. This data can then be used to compare competing construction materials such as steel and glass (Jönsson *et al.,* 1998). If the data gathered does not represent the total emissions of a particular material, inaccurate results will be obtained. Thus, it is essential that all

constituents of concrete are considered. The emission factors that where obtained can be seen in Table 3.2.

The methodology that was used to produce these emission factors for the U.K study is very similar to the methodology that this research has applied. Flower and Sanjayan (2007), however, performed energy audits on the sites over a period of six months to obtain their data. This seems somewhat unnecessary as sites do keep detailed energy consumption logs which can be inputted into spreadsheets to obtain the required data. Another factor which could skew their results is that they only collected data for the sites over a six month period. It is a known fact that cement sites shut down their kilns for maintenance once a year. If the data were collected over this period, significantly reduced indirect emissions from electricity consumption would have been obtained. Some sites also observe annual consumption demand shifts where there are high and low periods of demand.

**Table 3.2. Final $CO_2$ emission factors, (Flower and Sanjayan, 2007, p282; The concrete centre, 2008, p16)**

| Activity | Emission factor | | | Unit | Discussions |
|---|---|---|---|---|---|
| | Australia | U.K. | S.A. | | |
| Aggregates average | 32 | 4 | 5 | kg $CO_2$-e/tonne | S.A. and the U.K. figures are very close. The Australia figure is higher due to the high electricity consumption due to grinding. |
| Cement (Direct, CEM 1) | 822 | 819 | 818 | kg $CO_2$-e/tonne | All of the cement figures are very comparable and S.A. narrowly results in the lowest $CO_2$ emissions when compared to the two other case studies. |
| Fly ash | 27 | 4 | 2 | kg $CO_2$-e/tonne | The emissions from fly ash in Australia are higher due to the location of batching sites relative to the power sites and on average require 100 km of transport. The U.K and S.A. figures are very similar. |
| Slagment | 143 | 52 | 128 | kg $CO_2$-e/tonne | In the U.K. their slag does not require as extensive grinding as Australian or South African Slag. It is owing to this that the U.K. has a much lower factor. |
| In-situ concrete (Direct) | 12 | 4 | 9 | kg $CO_2$-e/$m^3$ | This process in general results in very small quantities of $CO_2$. The resulting emissions are from electricity use and from the transport of raw materials to the concrete batching site or so the site. |
| Admixtures | - | 380 | 220 | kg $CO_2$-e/l | This value for South Africa is an internet derived value for a Plasticizer. The resulting emissions are insignificant due to the small quantities used. The affect of the admixture is the main reason that it has been included. The figure used for S.A. is lower than the U.K, due to the fact that in the U.K. the admixture is usually in a powder form and thus requires drying and milling. In S.A, a liquid form is usually applied. |
| Precast | - | 14 | 18 | kg $CO_2$-e/tonne | This process in general results in very small quantities of $CO_2$ with the resulting emissions from electricity. The transport emissions are accounted for under the concrete transport activity (8 kg $CO_2$/ t). |

The overall findings of the Australian study were that $CO_2$ emissions resulting from concrete manufacture in 2007 where between 290 and 320 kg $CO_2/m^3$. It should be noted that they only included direct emissions. Another factor is that not all the components were taken into consideration, a major one being reinforcing and a poor sample was used. Thus, this is an inaccurate representation of the actual emissions of a cubic meter of concrete. The U.K study reported minimum emissions of 266 kg $CO_2/ m^3$ excluding reinforcement. This study aims to present a more accurate representation of the industry in South Africa.

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The $CO_2e$ emissions per cubic meter, per province, per sector as well as for the country have been determined. The main sources of emissions are cement and steel reinforcing contributing 98 percent of emissions.

# Chapter 4

# Mitigation of $CO_2e$ emissions

Mitigation of emissions is of great importance. This section deals with three main opportunities for the greatest emissions reduction in the concrete production process. These have been selected as they contribute the most emissions to the mix. Cement production, steel reinforcing production and the specific concrete mix design will be examined for potential reduction in $CO_2$.

## Mitigation of $CO_2e$ emissions resulting from concrete production

The mitigation of $CO_2e$ emissions from concrete is a complex topic. Due to the fact that concrete contributes significant amounts of anthropogenic $CO_2$ emissions it is an extensively researched topic. Small reductions in $CO_2$ per cubic meter produced will have a considerable impact in emission reductions. This section of the report will provide a brief overview of the methods available to mitigate $CO_2$ emissions. The core focus of this research is the actual GHG emissions resulting from the industry.

There are three activities which will be examined for mitigation strategies namely varying a concrete mix, cement and reinforcing. The first mitigation strategy to be examined is the potential for advancement in varying concrete mix design to produce a high strength, low $CO_2$ concrete. Cement and steel reinforcing have been selected due to the fact that combined they contribute 98 percent of the emissions to a concrete mix.

## Mitigation of GHG emissions by varying a concrete mix

The key to reducing emissions from concrete as a product is by varying the mix design. Same strength mixes can be produced by varying the inputs into a mix and in turn the associated $CO_2$ emissions are impacted. The Cement and Concrete Institute appointed the company 'concrete testing services' to produce several mix designs to quantify the impact on $CO_2$ of the various components. All the mix designs used the raw materials in varying amounts to evaluate the effects of fly ash, slagment, admixture and aggregate water demand on $CO_2$ emissions.

Specifics about mixes:
A total of eight mixes where designed to have strength of 30 MPa and used a CEM I. The variations manipulated the CEM I content, dependent on the mix, to attain the same 30 MPa strength. Mixes were done with and without an admixture (Appendices 9-16):

- CEM I;
- 70/30 Fly ash;
- 50/50 Slagment; and
- Decomposed granite sand.

Steel reinforcing has not been included due to the fact that reinforcing is not included in a mix design. It is only included for tensile strength in structure. The emissions breakdown has provided valuable results and due to the fact that identical feed materials were used the $CO_2$ emission variations are proportional to the individual components of the specific mix, the red line in Figure 4.1 is inserted at the level of the CEM I emissions. This factor is going to be used as the baseline from which the other

mixes will be compared. This is due to the fact that it does not contain any additives to decrease the $CO_2$ emissions.

**Table 4.1. Resulting $CO_2$ emissions from varying concrete mix designs**

| Mix Design | Percentage $CO_2$ variation |
|---|---|
| CEM I mix: no admix | 0.0 |
| CEM I mix with admix | -15.3 |
| 70/30 fly ash: no admix | -27.6 |
| 70/30 fly ash with admix | -36.3 |
| 50/50 slagment: no admix | -34.6 |
| 50/50 slagment with admix | -42.8 |
| Decomposed granite sand: No admix | +33.3 |
| Decomposed granite sand with admix | +7.4 |

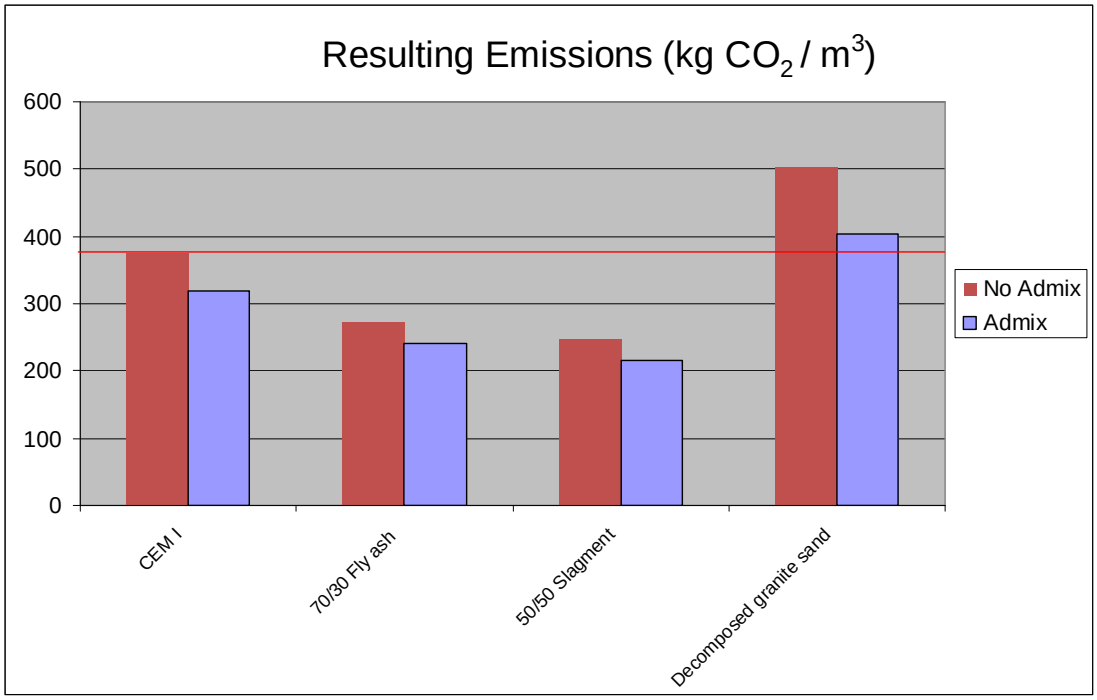


**Figure 4.1. $CO_2$ emissions resulting from varying mix designs**

This section of the report has not included a mix design comparing the effects of including limestone in a cement mix. This is due to the fact that it is the Cement and Concrete Institute's view that fly ash and slagment extend the life of the concrete, whereas as limestone does not have these same benefits. Thus, they would rather promote the use of fly ash and slagment as extenders. We do acknowledge that it does

account for a portion of the blends within South Africa, however, this will need to be examined in a further expansion of this report if the Institute deems it necessary.

Figure 4.2 compares the $CO_2$ variations between the designed mixes. It can be noted that whenever an admixture is used the emissions resulting from cement are decreased. Due to the fact that cement has a relatively large emissions factor small changes in content will result in significant $CO_2$ variations.

When examining the CEM I mix design it can be noted that the emissions are 376 kg $CO_2$ per ton. This factor is going to be used as the baseline against which the other mixes will be compared.

**Opportunities of $CO_2$ reduction from admixture**

When admixture was added to the mix design, the water requirement was reduced by 10 percent resulting in a decreased cement requirement of 17.6 percent. Overall the admixture resulted in a $CO_2$ emissions reduction of 15.3 percent. This immediately highlights the impact of the plasticizer admixture. Overall the mix density was increased by 1.5 percent due to the increase of aggregate.

**Opportunities of $CO_2$ reduction from fly ash**

Fly ash has the capability to reduce associated emissions by 27.6 percent and when used in association with admixture, emissions are reduced by a further 8.6 percent, totalling a 36.3 percent reduction.

**Opportunities of $CO_2$ reduction from slagment**

Due to the inherent properties of slagment, substitution rates are up to 50 percent, compared to fly ash with 30 percent. Slagment has the potential to reduce the associated $CO_2$ emissions by 34.6 percent and when used with an admixture by 42.5 percent.

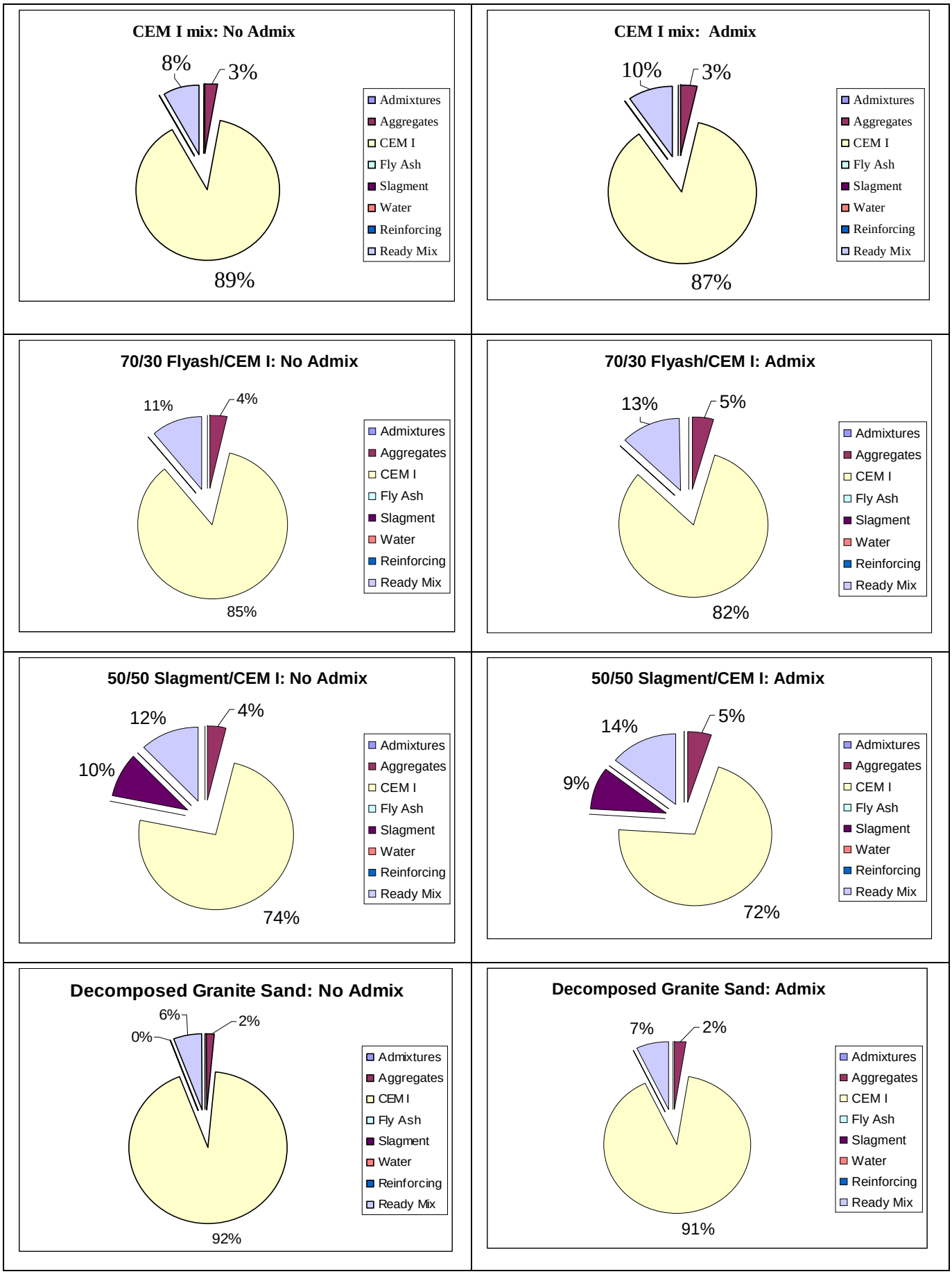


**Figure 4.2. Component emissions contribution of varying mix designs**

**Opportunities of $CO_2$ reduction from aggregate/sand**

The final test that was done made use of decomposed granite sand as an aggregate input. The aim of this is to show that the selection of aggregate also has a potential to reduce $CO_2$ emissions. The decomposed granite sand mix has a very high water requirement (76% higher) which in turn leads to an increased cement requirement of 53 %. Overall this increases the $CO_2$ emissions of the decomposed granite sand mix by 33.3 percent when compared to the CEM I. When an admixture is included in the mix the cement and water requirement was increased by 16 and 18.4 percent respectively leading to an overall increase of only 16.7 percent in emissions compared to the CEM I.

It should be noted that the decomposed granite sand mix with no admixture has the highest associated $CO_2$ emissions (501.8 kg $CO_2$/t). It was also found the 50/50 slagment mix with admixture has the lowest associated emissions (215.1 kg $CO_2$/t). The ability of extension to reduce $CO_2$ emissions in a concrete mix should be noted. When fly ash is used the mix density is reduced by 1.5 percent (40 kg), due to the decreased water and aggregate requirement. When slagment is used, the mix density is reduced by 2 percent (55 kg) due to the decreased aggregate requirement. This proves that the minor decrease in concrete mix is insignificant (less than two percent) and far outweighed by the environmental benefits of the reduction in $CO_2$ emissions. It was also noted that whenever admixture was used emissions were reduced by on average 10 percent.

In order to reduce $CO_2$ emissions related to concrete the following steps can be taken:

- use an extender, like fly ash or slagment;
- use an admixture; and
- use a good quality aggregate and sand with a low water demand.

## Mitigation of GHG emissions from cement

As has been noted by Worrell *et al.* (2001) the cement industry accounts for approximately five percent of global anthropogenic GHG emissions motivating the need for mitigation strategies. The primary GHG emissions result from direct, on site sources. These include fuel consumption (diesel and coal) as well as process emissions from the decalcination of limestone. There is extensive literature covering cement industry reduction strategies. This research will provide a brief overview of some methods available and list more generalised concepts (Table 5.1). Each of the potentials noted in Table 5.1 are well documented in Martin *et al.* (1999). The process of heat recovery from a dry type cement kiln is examined extensively by Engin and Ari (2004).

### Improving energy efficiency of production

The cement production process is very energy intensive. With improvement in energy efficiency indirect, electricity and direct fuel emissions will be reduced. There is generally significant cost involved in increasing efficiency, however, which will be offset by energy savings. There are also established CDM (clean development mechanism) methodologies which assist the cement industry in energy efficiency improvement and carbon reduction projects. Due to the significant costs involved the factor of additionality is easily met with most cement site energy efficiency improvement and funding is granted to assist sites. Larger projects can also apply for carbon credits further reducing project payback time.

**Table 5.1. Practices to reduce GHG emissions in cement production (Martin et al., 1999, p18)**

| | |
|---|---|
| **Raw Materials Preparation**<br>Efficient transport systems<br>Raw meal blending systems (dry process)<br>Conversion to closed circuit wash mill<br>High-efficiency roller mills (dry cement)<br>High-efficiency Classifiers (dry cement) | |
| **Clinker Production (Wet)** | **Clinker Production (Dry)** |
| Kiln combustion system improvements<br>Kiln shell heat loss reduction<br>Use of waste fuels<br>Conversion to modern grate cooler<br>Optimize grate coolers<br>Conversion to pre-heater, pre-calciner kilns<br>Conversion to semi-wet kilns | Kiln combustion system improvements<br>Kiln shell heat loss reduction<br>Use of waste fuels<br>Conversion to modern grate cooler<br>Heat Recovery for Power Generation<br>Low pressure drop cyclones for suspension pre-heaters<br>Long dry kiln conversion to multi-stage pre-heater kiln<br>Optimize grate coolers<br>Long dry kiln conversion to multi-stage pre-heater, pre-calciner kiln<br>Addition of pre-calciner to pre-heater kiln |
| **Finish Grinding (applies to both wet and dry cement production)**<br>Improved grinding media (ball mills)<br>High-pressure roller press<br>High efficiency classifiers<br>Improve mill internals | |
| **General Measures** | |
| Preventative Maintenance (insulation, compressed air losses, maintenance)<br>Reduced Kiln Dust Wasting<br>Energy Management and Process Control<br>High efficiency motors<br>Efficient fans with variable speed drives | |
| **Product Changes** | |
| Blended Cements<br>Reducing the Concentration of $C_3S$ in cements<br>Reducing fineness of cement for selected uses | |

Energy efficiency improvements can be achieved by installing new technologies or upgrading old equipment. The largest source of fuel consumption in the cement production process results during clinker production from the kiln. There are two types of kiln systems, dry and wet processes with the dry process having higher energy efficiency. The wet kiln system is a very old technology and very energy inefficient. These systems were phased out of South Africa in 1984, however, some were re-commissioned in 1996 for a few months due to a boom in the market and then shut down forever. Worrell *et al.* (2001) identified several opportunities for energy efficiency improvements, namely conversion from a wet to a dry process as well as the installation of a pre-calcinater and pre-heaters, improved grinding systems, high-efficiency motor systems, high-efficiency classifiers. Hendriks *et al.* (1999) and Martin *et al.* (1999) also note that process control systems, optimisation of the clinker

cooler, improvement of preheating efficiency, improved burners as well as process control and management systems can provide energy savings. A study by Feng *et al.* (1995) examined processes in China. They found that technologies such as improved mechanisation, bed distribution, insulation as well as control systems have been developed to increase the energy efficiency of shaft kilns. Technology is continually developing and Worrell *et al.* (2001) propose that this development could lead to future energy reductions of up to 48 percent and GHG reductions of 27 percent. They also note that the economic potential of such energy reductions is estimated in the region of 24 percent. They do not, however, discuss the potential of CDM or carbon credits to improve the viability of potential energy efficiency improvements. Martin *et al.* (1999) detailed the energy efficiency opportunities in the US cement industry. They identified 29 energy efficient, commercially available technologies that could still be applied to some extent by the US cement industry with a potential energy efficiency improvement of 40 percent. They also discounted many improvements due to economic viability and did not take CDM or carbon credits into consideration. This is most likely due to the fact that the carbon market had not fully established when these studies were completed and if reviewed the current market and technological improvements may warrant viability.

## Replacement of high-Carbon fuels with low-Carbon fuels

By exchanging a high-Carbon fuel with a low-Carbon fuel, less $CO_2$ is released per unit of product produced. A typical example is replacing the use of coal with natural gas. Cement kilns can also make use of waste fuels. There are several issues when using waste fuels that need to be considered that Worrell *et al.* (2001) have identified:

- energy efficiency of waste combustion in cement kilns;
- constant cement product and fuel quality;
- emissions to atmosphere;
- trace elements and heavy metals;
- alternative fate of waste; and
- production of secondary waste.

Worrell *et al. (2001)* note that these "disadvantages may be the adverse effects on the cement quality and increased emission of harmful gases". Kilns can utilise a wide range of alternative fuels such as gaseous fuel sources (natural or landfill gas), liquid fuel (waste oil, halogen-free spent solvents or distillation residues), as well as solid fuels (sewerage sludge, wood from waste or alien species, rubber tires and plastic). The GHG emission reduction potential depends largely on the specific characteristics of the waste product used (Hendriks *et al.,* 1999). Using waste as a fuel source has the potential to reduce GHG emissions by 100 to 500 kg per tonne of cement produced when compared to the use of high Carbon fossil fuels. The use of waste as a fuel source is current practice in South Africa and is feasible.

## Blending Cement to increase volume

The motivation for blending cement is that a portion of the ground clinker is replaced with fly ash or slagment. As has been noted, both these substitutes are by-products and thus have significantly lower associated GHG's. In the process of cement manufacture, the production of clinker is the most energy intensive. There are significant process, electricity and kiln fuel emissions. Most cement companies in South Africa sell blended cement, however, few do still sell pure unblended CEM I cement. In South Africa CEM I is bought up by private blenders, ready mix and precast sites and is blended to suit the specific application. Worrell *et al.* (2001), estimate that there is a potential reduction of five to 20 percent of total GHG emissions from cement manufacture that can be associated to blending.

Due to the fact that South Africa's electricity industry is dominated by coal power stations there is no shortage of fly ash. There are also several large steel producing sites providing slagment. There are some cement factories which are located in isolated locations and do not have access to slag or fly ash. These factories use limestone to extend their cement, however, limestone does not have a significant impact on decreasing $CO_2$ as it is just a bulking agent. The extensive use of fly ash and slag in South Africa prevent large amounts of this waste being landfilled. Thus, apart

from reducing the GHG emissions associated with cement, the use of these by-products promotes general environmental wellbeing.

### Carbon dioxide removal from stack emissions

The capture and storage of $CO_2$ from stack emissions is still a very new technology and is not implemented in the South African cement industry. This technique involves the capture and removal of $CO_2$ emissions during or after the decalcination of limestone in the kiln. These emissions would then be stored in natural underground cavities or disposed of out of the atmosphere. Worldwide there are no practical experiences with this technique within the cement industry (Hendriks *et al.,* 1999). Worrell *et al.* (2001) notes that "in principle this process could be applied to the cement production process and that in comparison with the production site without $CO_2$ removal, a number of aspects need further exploration such as control of leakage of air into the kiln; cooling of the cement after the kiln; energy balance of the system; consequence of the higher $CO_2$ partial pressure on the calcination process; and control to reduce emission of $CO_2$ during start/stops of the cement site". The application of this technique is not yet cost effective in the cement industry. Possibly as technology develops and the need to reduce carbon emissions intensifies $CO_2$ reduction and storage may become technically and commercially applied (Hendriks *et al.,* 1999).

## Mitigation of GHG emissions from steel reinforcing

Due to the fact that the process of steel production is very energy intensive the primary reduction potential would be to reduce the amount of fossil fuels used. Worrell *et al.* (2001) provides a comprehensive analysis of all of the technologies noted (Table 5.2).

**Table 5.2. State-of-the-art energy efficiency measures in the iron and steel industry (Worrell et al., 2001)**

| Overall Measures (measures apply to both integrated and secondary plants) | |
|---|---|
| Preventative maintenance<br>Energy monitoring and management systems<br>Variable speed drives for flue gas control, pumps, and fans<br>Cogeneration | |
| Integrated Steel Making Measures | Secondary Steel Making Measures |
| Iron Ore Preparation (Sintermaking)<br>Sinter plant heat recovery<br>Use of waste fuels in the sinter plant<br>Reduction of air leakage<br>Increasing bed depth<br>Improved process control<br>Coke Making<br>Coal moisture control<br>Programmed heating<br>Variable speed drive on coke oven gas compressors<br>Coke dry quenching<br>Iron Making - Blast Furnace<br>Pulverized coal injection (medium and high levels)<br>Injection of natural gas<br>Top pressure recovery turbines (wet type)<br>Recovery of blast furnace gas<br>Hot blast stove automation<br>Recuperator on the hot blast stove<br>Improved blast furnace control<br>Steel making — Basic oxygen furnace<br>BOF gas & sensible heat recovery (supressed combustion)<br>Variable speed drive on ventilation fans | Electric Arc Furnace<br>Improved process control (neural networks)<br>Flue gas monitoring and control<br>Transformer efficiency measures<br>Bottom stirring/gas injection<br>Foamy slag practices<br>Oxy-fuel burners/lancing<br>Post-combustion<br>Eccentric bottom tapping (EBT)<br>Direct current (DC) arc furnaces<br>Scrap preheating<br>Consteel process<br>Fuchs shaft furnace<br>Twin shell DC arc furnace |
| Casting and rolling (measures apply to integrated and secondary plants unless otherwise specified) | |
| Casting<br>Adopt continuous casting<br>Efficient ladle preheating<br>Thin slab casting<br>Rolling<br>Hot charging<br>Recuperative burner in the reheating furnace<br>Controlling oxygen levels and variable speed drives on combustion air fans<br>Process control in the hot strip mill<br>Insulation of furnaces<br>Energy efficient drives in the hot rolling mill<br>Waste heat recovery from cooling water<br>Heat recovery on the annealing line (integrated only)<br>Automated monitoring & targeting system<br>Reduced steam use in the pickling line | |

The future outlook for the South African concrete industry is bright. Currently concrete produced in South Africa has relatively low amounts of associated $CO_2$. As the industry continues to develop and green buildings become more prolific, South Africa is poised as industry leaders in 'low $CO_2$ emissions' concrete.

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> Various mitigation strategies have been noted for cement, steel reinforcing as well as concrete mix design. They should all be used in conjunction with each other to achieve a maximum reduction. It should be noted that without any change in technology simply varying the concrete mix design can influence emissions by up to 42 percent.

# Summary and Conclusions

This study has revealed some very important findings that can be used to promote the sale of concrete as a greener building material over alternatives such as steel or glass. The questionnaires that have been developed focus on the main activities of the concrete industry. The direct, indirect & other indirect emissions associated with the products are determined in the questionnaires and are then consolidated and the resulting emissions factor per tonne of that specific product. These emission factors are linked to a model which allows the user to input concrete mix variations and compare the resulting $CO_2$ emissions. This project has brought along with it a number of lessons learnt and specific outcomes. The ability to quantify the carbon footprint of a concrete mix of a specific mix design, allows the user to evaluate the effect of all the components in that mix. This increases a user's understanding of what influences the various components of a concrete mix have on the associated GHG emissions. The user of the model now has insight into the interrelationships that occur between components and how to best optimise a mix to reduce GHG emissions. The model that has been developed is a valuable tool that can be used within the industry by cement manufacturers, ready mix producers, site engineers and architects to name a few.

The resulting emissions from the industry in South Africa compared well to international base lines. It was determined that cement and steel reinforcing contributed the majority of emissions accounting up to 98 percent of emissions.

The key findings of this report are the associated emissions due to concrete. Cement is often in the spot light due to its associated emissions and concrete is pulled under the same range of emissions. The mix design comparisons that have been done find that

the range of an average concrete mix in South Africa based on a 30 MPa strength fly ash and slagment blended cement with an admixture is 239.8 to 215 kg $CO_2$ per cubic meter. These figures include all scopes of emission sources and can be brought back to the resulting emissions per tonne range of 85 to 95 kg $CO_2$ per t.

In terms of mitigation strategies, various options have been noted. Overall, due to the high energy requirement from the production of cement and steel reinforcing the primary source of $CO_2$ emissions reduction is by increased energy efficiency of the production process, increasing the use of low-carbon fuels, as well as increased blending. South African cement producers have already shifted from the wet to the dry production process. The steel industry has also got room for energy efficiency improvement. In the short term, if cement mix design is monitored and low $CO_2$ concrete is promoted, this would be the most cost-effective measure to reduce $CO_2$ emissions.

A key ideology which needs to be broken is that global warming and climate change is a problem of the future. Due to the fact that change will occur over decades, the current generations are not being impacted and current climate deviations are being classified as '100 year extreme events'. Humans generally tend to deal with disaster management, not disaster prevention which may inevitably lead to the demise of the human race.

Thus, overall the research has been a success and revealed some valuable and significant data about the $CO_2e$ emissions of the concrete industry in South Africa. The concrete sector is leading by example in terms of energy efficiency and disclosing its $CO_2$ emissions on the environment. Unfortunately, the South African economy is still very power intensive, overall resulting in very large $CO_2$ emissions. It is due to this fact that the country currently stands as the $16^{th}$ largest consumer of fossil fuels. With world trends leaning towards decreasing carbon emissions, South African residents, industry and Government are going to have to take a proactive stance on increasing efficiencies and decreasing overall demand.

# Recommendations

Some possible further considerations suggested by this research are:

- review of subsidies, grants and legislation in place by the South African government in terms of the use of energy efficient machinery within the concrete (industrial) activity;
- an in-depth analysis and examination of current as well as possible future climate policy options in South Africa; and
- examine possible life cycle optimisation options to reduce greenhouse gas emissions through possible policies.

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# Appendix 1: Aggregate questionnaire

InEnergy

## $CO_2e$ Footprint: Aggregate Quarry

**Company Information**

| Mine Information | | |
|---|---|---|
| 1 | Company | |
| 2 | Plant | |
| 3 | Province | |

| Inventory Boundaries: Coverage of Main Process Steps | Example | 2006 | 2007 | 2008 | Comment |
|---|---|---|---|---|---|
| Extraction | Yes | | | | |
| Crushing & Screening | Yes | | | | |
| Dispatching | Yes | | | | |
| On-site (internal) transport | Yes | | | | |
| Off-site (external) transport | Yes | | | | |
| (add other processes as appropriate) | -- | | | | |

**Activity Data**

| Production Information | | | Example | 2006 | 2007 | 2008 | Comment |
|---|---|---|---|---|---|---|---|
| Total rock extracted and sold | | [t/yr] | 201,008 | | | | |
| Product A | 22mm stone | [t/yr] | 52,000 | | | | |
| Product B | 13mm stone | [t/yr] | 36,000 | | | | |
| Product C | crusher run | [t/yr] | 24,000 | | | | |
| Product D | river sand | [t/yr] | 89,008 | | | | |
| Product E | | [t/yr] | - | | | | |
| Product F | | [t/yr] | - | | | | |

| Direct Emission Sources | | Example | 2006 | 2007 | 2008 | Comment |
|---|---|---|---|---|---|---|
| **Primary Energy Sources in Total** | | | | | | |
| Diesel | [kl/yr] | 4,000 | 0 | 0 | 0 | |
| Petrol | [kl/yr] | 1,300 | 0 | 0 | 0 | |
| LPG | [t/yr] | 200 | 0 | 0 | 0 | |
| Coal | [t/yr, dry weight] | 0 | 0 | 0 | 0 | |
| Other | [t/yr] | 0 | 0 | 0 | 0 | |
| *On-site Vehicles (Own)* | | | | | | |
| *Diesel* | *[kl/yr]* | *2,000* | | | | |
| *Petrol* | *[kl/yr]* | *1,000* | | | | |
| *Other* | *[kl/yr]* | | | | | |
| *Room Heating* | | | | | | |
| *LPG* | *[t/yr]* | *100* | | | | |
| *Coal* | *[t/yr, dry weight]* | | | | | |
| *Other* | *[kl/yr]* | | | | | |
| *On-site Electricity Generation* | | | | | | |
| *Consumption of power produced on-site* | *[MWh/yr]* | *1,000* | | | | |
| *Diesel* | *[kl/yr]* | *2,000* | | | | |
| *Petrol* | *[kl/yr]* | *300* | | | | |
| *LPG* | *[t/yr]* | *100* | | | | |
| *Coal* | *[t/yr, dry weight]* | *0* | | | | |
| *Other* | *[kl/yr]* | *0* | | | | |
| *Other Energy Sources* | | | | | | |
| *Diesel* | *[kl/yr]* | | | | | |
| *Petrol* | *[kl/yr]* | | | | | |
| *LPG* | *[t/yr]* | | | | | |
| *Coal* | *[t/yr, dry weight]* | | | | | |
| *Other* | *[kl/yr]* | | | | | |
| **Rock Extraction** | | | | | | |
| Net area of natural land taken up by mining | [hectares/yr] | 100 | | | | |
| Amount of explosives used for blasting | [t/yr] | 1,000 | | | | |
| Net land disturbed for stockpiles, offices, ... | [hectares/yr] | 10 | | | | |
| Description of land disturbed | [MWh/yr] | Grassland | | | | |
| **Wastewater Treatment** | | | | | | |
| Contaminated water discharged to sewage works | [$m^3$/yr] | 200,000 | | | | |
| Relative usage of sewage works for industrial wastes | [%] | 0 | | | | |
| Number of persons using sewage facility | [people/yr] | 1,000 | | | | |

| Indirect Emission Sources | | Example | 2006 | 2007 | 2008 | Comment |
|---|---|---|---|---|---|---|
| **External Electricity Generation** | | | | | | |
| Consumption of power produced externally | [MWh/yr] | 150,000 | | | | |
| **On-site Vehicles (Third Party)** | | | | | | |
| Petrol | [kl/yr] | 0 | | | | |
| Diesel | [kl/yr] | | | | | |
| Vehicle Type | | FEL | | | | |
| Distance Travelled | [km/yr] | 1,000 | | | | |

## Appendix 2: Admixture questionnaire

InEnergy

### $CO_2e$ Footprint: Admixture Plant

**Company Information**

| Site Information | | |
|---|---|---|
| 1 | Company | |
| 2 | Plant | |
| 3 | Province | |

| Inventory Boundaries: Coverage of Main Process Steps | | Example | 2006 | 2007 | 2008 | Comment |
|---|---|---|---|---|---|---|
| | Raw Material Off-loading | Yes | | | | |
| | Mixing | Yes | | | | |
| | Warehousing | Yes | | | | |
| | Loading | Yes | | | | |
| | Off-site (external) transport | Yes | | | | |
| | (add other processes as appropriate) | -- | | | | |

**Activity Data**

| Production Information | | | Example | 2006 | 2007 | 2008 | Comment |
|---|---|---|---|---|---|---|---|
| | Total Admixtures Produced | [t/yr] | 50,000 | | | | |

| Direct Emission Sources | | | Example | 2006 | 2007 | 2008 | Comment |
|---|---|---|---|---|---|---|---|
| | **Primary Energy Sources in Total** | | | | | | |
| | Diesel | [kl/yr] | 4,000 | 0 | 0 | 0 | |
| | Petrol | [kl/yr] | 1,000 | 0 | 0 | 0 | |
| | LPG | [t/yr] | 100 | 0 | 0 | 0 | |
| | Coal | [t/yr, dry weight] | 0 | 0 | 0 | 0 | |
| | Other | [t/yr] | 0 | 0 | 0 | 0 | |
| | ***On-site Vehicles (Own)*** | | | | | | |
| | *Diesel* | *[kl/yr]* | *2,000* | | | | |
| | *Petrol* | *[kl/yr]* | *1,000* | | | | |
| | *Other* | *[kl/yr]* | | | | | |
| | ***Room Heating*** | | | | | | |
| | *LPG* | *[t/yr]* | *100* | | | | |
| | *Coal* | *[t/yr, dry weight]* | | | | | |
| | *Other* | *[kl/yr]* | | | | | |
| | ***On-site Electricity Generation*** | | | | | | |
| | *Consumption of power produced on-site* | *[MWh/yr]* | *10* | | | | |
| | *Diesel* | *[kl/yr]* | *2,000* | | | | |
| | *Petrol* | *[kl/yr]* | *0* | | | | |
| | *LPG* | *[t/yr]* | *0* | | | | |
| | *Coal* | *[t/yr, dry weight]* | *0* | | | | |
| | *Other* | *[kl/yr]* | *0* | | | | |
| | ***Other Energy Sources*** | | | | | | |
| | *Diesel* | *[kl/yr]* | | | | | |
| | *Petrol* | *[kl/yr]* | | | | | |
| | *LPG* | *[t/yr]* | | | | | |
| | *Coal* | *[t/yr, dry weight]* | | | | | |
| | *Other* | *[kl/yr]* | | | | | |

| Indirect Emission Sources | | | Example | 2006 | 2007 | 2008 | Comment |
|---|---|---|---|---|---|---|---|
| | **External Electricity Generation** | | | | | | |
| | Consumption of power produced externally | [MWh/yr] | 5,000 | | | | |
| | **On-site Vehicles (Third Party)** | | | | | | |
| | Petrol | [kl/yr] | 500 | | | | |
| | Diesel | [kl/yr] | 500.00 | | | | |
| | Vehicle Type | | Truck | | | | |
| | Distance Travelled | [km/yr] | 10,000 | | | | |

| Other Indirect Emission Sources | | | Example | 2006 | 2007 | 2008 | Comment |
|---|---|---|---|---|---|---|---|
| | **Product Delivery (Total distance travelled)** | | | | | | |
| | Final product delivery by own road truck - distance | [ave km] | 50 | | | | |
| | Final product delivery by own road truck - litres | [l] | 25,000 | | | | |
| | Final product delivery by third party road truck - distance | [ave km] | 50 | | | | |
| | Final product delivery by third party road truck - litres | [l] | 25,000 | | | | |
| | Final product delivery average load size - litres | [l] | 500 | | | | |

# Appendix 3: Cement questionnaire

| Based on WBCSD Cement Sustainability Initiative and $CO_2$ Emissions Inventory Protocol, Version 2.0 | Plant Level |
|---|---|

| Date of latest update | 13 Oct 2008 |
|---|---|

**INFORMATION**

| General Plant Information | | |
|---|---|---|
| 1 | Plant | |
| 2 | Company | |

| Clinker and Cement Production | | | 2006 | 2007 | 2008 | Comments |
|---|---|---|---|---|---|---|
| | **Clinker:** | | | | | |
| 8 | Clinker production | [t/yr] | | | | |
| 9 | Clinker bought | [t/yr] | | | | |
| 10 | Clinker sold | [t/yr] | | | | |
| 10a | Change in clinker stocks | [t/yr] | | | | |
| 11 | Total clinker consumed | [t/yr] | | | | |

| | Mineral components (MIC) used to produce Portland and blended cements: | | 2006 | 2007 | 2008 | Comments |
|---|---|---|---|---|---|---|
| 12 | Gypsum | [t/yr, dry weight] | | | | |
| 13 | Limestone | [t/yr, dry weight] | | | | |
| 14 | Slag | [t/yr, dry weight] | | | | |
| 15 | Fly ash (for blending) | [t/yr, dry weight] | | | | |
| 16 | Puzzolana | [t/yr, dry weight] | | | | |
| 17 | Others (e.g., CKD added to cement mill) | [t/yr, dry weight] | | | | |
| 18 | Total MIC consumed for Portland and blended cements (dry weight) | [t/yr, dry weight] | | | | |

| | Mineral components (MIC) used as cement substitutes | | 2006 | 2007 | 2008 | Comments |
|---|---|---|---|---|---|---|
| 19a | MIC consumed for production of pure slag cement | [t/yr, dry weight] | | | | |
| 19b | Fly ash and puzzolana (direct sales) | [t/yr, dry weight] | | | | |
| 19 | Total pure MIC products used as cement substitutes | [t/yr, dry weight] | | | | |

| Kiln Fuel Consumption (Aggregate) | | | 2006 | 2007 | 2008 | Comments |
|---|---|---|---|---|---|---|
| 25 | Total heat consumption of kilns | [TJ/yr] | | | | |
| 26 | Conventional fossil fuels | [TJ/yr] | | | | |
| 27 | Alternative fossil fuels | [TJ/yr] | | | | |
| 28 | Biomass fuels | [TJ/yr] | | | | |

| Non-Kiln Fuel Consumption | | | 2006 | 2007 | 2008 | Comments |
|---|---|---|---|---|---|---|
| 30 | Equipment and on-site vehicles | [TJ/yr] | | | | |
| 31a | Room heating / cooling | [TJ/yr] | | | | |
| 31b | Drying of raw materials and mineral components | [TJ/yr] | | | | |
| 31c | On-site power generation | [TJ/yr] | | | | |
| 32 | Total non-kiln fuel consumption | [TJ/yr] | | | | |

| Indirect Emission Source: Power Consumption | | | 2006 | 2007 | 2008 | Comments |
|---|---|---|---|---|---|---|
| 33a | Consumption of power produced on-site | [MWh/yr] | | | | |
| 33b | CO2 per power unit produced on-site | [kg CO2/MWh] | | | | |
| 33c | Consumption of power produced externally | [MWh/yr] | | | | |

## Appendix 4: Fly ash questionnaire

InEnergy

# $CO_2e$ Footprint: Fly Ash Plant

**Company Information**

| Mine Information | | |
|---|---|---|
| 1 | Company | |
| 2 | Plant | |
| 3 | Province | |

| Inventory Boundaries: Coverage of Main Process Steps | Example | 2006 | 2007 | 2008 | Comment |
|---|---|---|---|---|---|
| Raw Material Loading | Yes | | | | |
| Classification | Yes | | | | |
| Dispatching | Yes | | | | |
| On-site (internal) transport | Yes | | | | |
| Off-site (external) transport | Yes | | | | |
| (add other processes as appropriate) | -- | | | | |

**Activity Data**

| Production Information | | Example | 2006 | 2007 | 2008 | Comment |
|---|---|---|---|---|---|---|
| Total fly ash sold | [t/yr] | 100,000 | | | | |

| Direct Emission Sources | | Example | 2006 | 2007 | 2008 | Comment |
|---|---|---|---|---|---|---|
| **Primary Energy Sources in Total** | | | | | | |
| Diesel | [kl/yr] | 2,030 | 0 | 0 | 0 | |
| Petrol | [kl/yr] | 1,000 | 0 | 0 | 0 | |
| LPG | [t/yr] | 100 | 0 | 0 | 0 | |
| Coal | [t/yr, dry weight] | 0 | 0 | 0 | 0 | |
| Other | [t/yr] | 0 | 0 | 0 | 0 | |
| *On-site Vehicles (Own)* | | | | | | |
| *Diesel* | *[kl/yr]* | *2,000* | | | | |
| *Petrol* | *[kl/yr]* | *1,000* | | | | |
| *Other* | *[kl/yr]* | | | | | |
| *Room Heating* | | | | | | |
| *LPG* | *[t/yr]* | *100* | | | | |
| *Coal* | *[t/yr, dry weight]* | | | | | |
| *Other* | *[kl/yr]* | | | | | |
| *On-site Electricity Generation* | | | | | | |
| *Consumption of power produced on-site* | *[MWh/yr]* | *10* | | | | |
| *Diesel* | *[kl/yr]* | *30* | | | | |
| *Petrol* | *[kl/yr]* | *0* | | | | |
| *LPG* | *[t/yr]* | *0* | | | | |
| *Coal* | *[t/yr, dry weight]* | *0* | | | | |
| *Other* | *[kl/yr]* | *0* | | | | |
| *Other Energy Sources* | | | | | | |
| *Diesel* | *[kl/yr]* | | | | | |
| *Petrol* | *[kl/yr]* | | | | | |
| *LPG* | *[t/yr]* | | | | | |
| *Coal* | *[t/yr, dry weight]* | | | | | |
| *Other* | *[kl/yr]* | | | | | |

| Indirect Emission Sources | | Example | 2006 | 2007 | 2008 | Comment |
|---|---|---|---|---|---|---|
| **External Electricity Generation** | | | | | | |
| Consumption of power produced externally | [MWh/yr] | 15,000 | | | | |
| **On-site Vehicles (Third Party)** | | | | | | |
| Petrol | [kl/yr] | 0 | | | | |
| Diesel | [kl/yr] | 0 | | | | |
| Vehicle Type | | | | | | |
| Distance Travelled | [km/yr] | 0 | | | | |
| **Land Use Change** | | | | | | |
| Net area of land avoided being disturbed by landfilling | [hectares/yr] | 10 | | | | |
| Type of land | | Grassland | | | | |

## Appendix 5: Slagment questionnaire

InEnergy

# $CO_2e$ Footprint: Slagment Plant

**Company Information**

| Mine Information | | |
|---|---|---|
| 1 | Company | |
| 2 | Plant | |
| 3 | Province | |

| Inventory Boundaries: Coverage of Main Process Steps | Example | 2006 | 2007 | 2008 | Comment |
|---|---|---|---|---|---|
| Raw Material Loading | Yes | | | | |
| Drying | Yes | | | | |
| Milling | Yes | | | | |
| Blending | Yes | | | | |
| Packing | Yes | | | | |
| Dispatching | Yes | | | | |
| On-site (internal) transport | Yes | | | | |
| Off-site (external) transport | Yes | | | | |
| (add other processes as appropriate) | -- | | | | |

**Activity Data**

| Production Information | | Example | 2006 | 2007 | 2008 | Comment |
|---|---|---|---|---|---|---|
| Total slagment milled | [t/yr] | 100,000 | | | | |
| Total cement used for blending | [t/yr] | 20,000 | | | | |

| Direct Emission Sources | | Example | 2006 | 2007 | 2008 | Comment |
|---|---|---|---|---|---|---|
| **Primary Energy Sources in Total** | | | | | | |
| Diesel | [kl/yr] | 4,030 | 0 | 0 | 0 | |
| Petrol | [kl/yr] | 1,000 | 0 | 0 | 0 | |
| LPG | [t/yr] | 100 | 0 | 0 | 0 | |
| Coal | [t/yr, dry weight] | 25,000 | 0 | 0 | 0 | |
| Other | [t/yr] | 0 | 0 | 0 | 0 | |
| ***On-site Vehicles (Own)*** | | | | | | |
| *Diesel* | *[kl/yr]* | *2,000* | | | | |
| *Petrol* | *[kl/yr]* | *1,000* | | | | |
| *Other* | *[kl/yr]* | | | | | |
| ***Slag Drying*** | | | | | | |
| *Diesel* | *[kl/yr]* | *2,000* | | | | |
| *Coal* | *[t/yr]* | *25,000* | | | | |
| *Other* | *[kl/yr]* | | | | | |
| ***Room Heating*** | | | | | | |
| *LPG* | *[t/yr]* | *100* | | | | |
| *Coal* | *[t/yr, dry weight]* | | | | | |
| *Other* | *[kl/yr]* | | | | | |
| ***On-site Electricity Generation*** | | | | | | |
| *Consumption of power produced on-site* | *[MWh/yr]* | *10* | | | | |
| *Diesel* | *[kl/yr]* | *30* | | | | |
| *Petrol* | *[kl/yr]* | *0* | | | | |
| *LPG* | *[t/yr]* | *0* | | | | |
| *Coal* | *[t/yr, dry weight]* | *0* | | | | |
| *Other* | *[kl/yr]* | *0* | | | | |
| ***Other Energy Sources*** | | | | | | |
| *Diesel* | *[kl/yr]* | | | | | |
| *Petrol* | *[kl/yr]* | | | | | |
| *LPG* | *[t/yr]* | | | | | |
| *Coal* | *[t/yr, dry weight]* | | | | | |
| *Other* | *[kl/yr]* | | | | | |

| Indirect Emission Sources | | Example | 2006 | 2007 | 2008 | Comment |
|---|---|---|---|---|---|---|
| **External Electricity Generation** | | | | | | |
| Consumption of Eskom power (excluding blending & packing plant) | [MWh/yr] | 15,000 | | | | |
| Consumption of Eskom power (total) | [MWh/yr] | 16,000 | | | | |
| **On-site Vehicles (Third Party)** | | | | | | |
| Petrol | [kl/yr] | 0 | | | | |
| Diesel | [kl/yr] | 0 | | | | |
| Vehicle Type | | | | | | |
| Distance Travelled | [km/yr] | 0 | | | | |
| **Land Use Change** | | | | | | |
| Net area of land avoided being disturbed by landfilling | [hectares/yr] | 1 | | | | |
| Type of land | | Grassland | | | | |

## Appendix 6: Precast questionnaire

InEnergy

### $CO_2e$ Footprint: Precast Product Plant

**Company Information**

| Mine Information | | |
|---|---|---|
| 1 | Company | |
| 2 | Plant | |
| 3 | Province | |

| Inventory Boundaries: Coverage of Main Process Steps | Example | 2006 | 2007 | 2008 | Comment |
|---|---|---|---|---|---|
| Raw Material Loading | Yes | | | | |
| Batching & Casting | Yes | | | | |
| Curing & Processing | Yes | | | | |
| Dispatching | Yes | | | | |
| On-site (internal) transport | Yes | | | | |
| Off-site (external) transport | Yes | | | | |
| (add other processes as appropriate) | – | | | | |

**Activity Data**

| Production Information | | Example | 2006 | 2007 | 2008 | Comment |
|---|---|---|---|---|---|---|
| Total cement consumed | [t/yr] | 100,000 | | | | |
| Total slagment consumed | [t/yr] | | | | | |
| Total fly ash consumed | [t/yr] | | | | | |
| Other components | [t/yr] | | | | | |
| Total mass of products | [t/yr] | 20,000 | | | | |

| Direct Emission Sources | | Example | 2006 | 2007 | 2008 | Comment |
|---|---|---|---|---|---|---|
| **Primary Energy Sources in Total** | | | | | | |
| Diesel | [kl/yr] | 4,030 | 0 | 0 | 0 | |
| Petrol | [kl/yr] | 0 | 0 | 0 | 0 | |
| LPG | [t/yr] | 1,001 | 0 | 0 | 0 | |
| Coal | [t/yr, dry weight] | 100 | 0 | 0 | 0 | |
| Other | [t/yr] | 0 | 0 | 0 | 0 | |
| ***On-site Vehicles (Own)*** | | | | | | |
| *Diesel* | *[kl/yr]* | *2,000* | | | | |
| *Petrol* | *[kl/yr]* | *0* | | | | |
| *Other* | *[kl/yr]* | | | | | |
| ***Curing*** | | | | | | |
| *Diesel* | *[kl/yr]* | *2,000* | | | | |
| *LPG* | *[t/yr]* | *1,000* | | | | |
| *Coal* | *[t/yr]* | *100* | | | | |
| *Other* | *[kl/yr]* | | | | | |
| ***Room Heating*** | | | | | | |
| *LPG* | *[t/yr]* | *1* | | | | |
| *Coal* | *[t/yr, dry weight]* | | | | | |
| *Other* | *[kl/yr]* | | | | | |
| ***On-site Electricity Generation*** | | | | | | |
| *Consumption of power produced on-site* | *[MWh/yr]* | *10* | | | | |
| *Diesel* | *[kl/yr]* | *30* | | | | |
| *Petrol* | *[kl/yr]* | *0* | | | | |
| *LPG* | *[t/yr]* | *0* | | | | |
| *Coal* | *[t/yr, dry weight]* | *0* | | | | |
| *Other* | *[kl/yr]* | *0* | | | | |
| ***Other Energy Sources*** | | | | | | |
| *Diesel* | *[kl/yr]* | | | | | |
| *Petrol* | *[kl/yr]* | | | | | |
| *LPG* | *[t/yr]* | | | | | |
| *Coal* | *[t/yr, dry weight]* | | | | | |
| *Other* | *[kl/yr]* | | | | | |

| Indirect Emission Sources | | Example | 2006 | 2007 | 2008 | Comment |
|---|---|---|---|---|---|---|
| **External Electricity Generation** | | | | | | |
| Consumption of Eskom power | [MWh/yr] | 16,000 | | | | |
| **On-site Vehicles (Third Party)** | | | | | | |
| Petrol | [kl/yr] | 0 | | | | |
| Diesel | [kl/yr] | 0 | | | | |
| Vehicle Type | | | | | | |
| Distance Travelled | [km/yr] | 0 | | | | |

| Other Indirect Emission Sources | | Example | 2006 | 2007 | 2008 | Comment |
|---|---|---|---|---|---|---|
| **Product Delivery** | | | | | | |
| Final product delivery by own road truck - round trip distance | [ave km] | 250 | | | | |
| Final product delivery by own road truck - tonnage | [t] | 50,000 | | | | |
| Final product delivery by third party road truck - round trip distance | [ave km] | 300 | | | | |
| Final product delivery by third party road truck - tonnage | [t] | 50,000 | | | | |
| Final product delivery average road truck load size | [t] | 25 | | | | |

## Appendix 7: Readymix questionnaire

InEnergy

### $CO_2e$ Footprint: Readymix Plant

**Company Information**

| Mine Information | | |
|---|---|---|
| 1 | Company | |
| 2 | Plant | |
| 3 | Province | |

| Inventory Boundaries: Coverage of Main Process Steps | | Example | 2006 | 2007 | 2008 | Comment |
|---|---|---|---|---|---|---|
| | Raw Material Loading | Yes | | | | |
| | Batching | Yes | | | | |
| | Dispatching | Yes | | | | |
| | On-site (internal) transport | Yes | | | | |
| | Off-site (external) transport | Yes | | | | |
| | (add other processes as appropriate) | -- | | | | |

**Activity Data**

| Production Information | | | Example | 2006 | 2007 | 2008 | Comment |
|---|---|---|---|---|---|---|---|
| | Total readymix sold | [t/yr] | 50,000 | | | | |

| Direct Emission Sources | | | Example | 2006 | 2007 | 2008 | Comment |
|---|---|---|---|---|---|---|---|
| | **Primary Energy Sources in Total** | | | | | | |
| | Diesel | [kl/yr] | 4,000 | 0 | 0 | 0 | |
| | Petrol | [kl/yr] | 1,000 | 0 | 0 | 0 | |
| | LPG | [t/yr] | 100 | 0 | 0 | 0 | |
| | Coal | [t/yr, dry weight] | 0 | 0 | 0 | 0 | |
| | Other | [t/yr] | 0 | 0 | 0 | 0 | |
| | *On-site Vehicles (Own)* | | | | | | |
| | *Diesel* | *[kl/yr]* | *2,000* | | | | |
| | *Petrol* | *[kl/yr]* | *1,000* | | | | |
| | *Other* | *[kl/yr]* | | | | | |
| | *Room Heating* | | | | | | |
| | *LPG* | *[t/yr]* | *100* | | | | |
| | *Coal* | *[t/yr, dry weight]* | | | | | |
| | *Other* | *[kl/yr]* | | | | | |
| | *On-site Electricity Generation* | | | | | | |
| | *Consumption of power produced on-site* | *[MWh/yr]* | *10* | | | | |
| | *Diesel* | *[kl/yr]* | *2,000* | | | | |
| | *Petrol* | *[kl/yr]* | *0* | | | | |
| | *LPG* | *[t/yr]* | *0* | | | | |
| | *Coal* | *[t/yr, dry weight]* | *0* | | | | |
| | *Other* | *[kl/yr]* | *0* | | | | |
| | *Other Energy Sources* | | | | | | |
| | *Diesel* | *[kl/yr]* | | | | | |
| | *Petrol* | *[kl/yr]* | | | | | |
| | *LPG* | *[t/yr]* | | | | | |
| | *Coal* | *[t/yr, dry weight]* | | | | | |
| | *Other* | *[kl/yr]* | | | | | |

| Indirect Emission Sources | | | Example | 2006 | 2007 | 2008 | |
|---|---|---|---|---|---|---|---|
| | **External Electricity Generation** | | | | | | |
| | Consumption of power produced externally | [MWh/yr] | 15,000 | | | | |
| | **On-site Vehicles (Third Party)** | | | | | | |
| | Petrol | [kl/yr] | 500 | | | | |
| | Diesel | [kl/yr] | 500.00 | | | | |
| | Vehicle Type | | Truck | | | | |
| | Distance Travelled | [km/yr] | 15,000 | | | | |

| Other Indirect Emission Sources | | | Example | 2006 | 2007 | 2008 | |
|---|---|---|---|---|---|---|---|
| | **Product Delivery (Total distance travelled)** | | | | | | |
| | Final product delivery by own road truck - distance | [ave km] | 50 | | | | |
| | Final product delivery by own road truck - tonnage | [t] | 25,000 | | | | |
| | Final product delivery by third party road truck - distance | [ave km] | 50 | | | | |
| | Final product delivery by third party road truck - tonnage | [t] | 25,000 | | | | |
| | Final product delivery average load size | [t] | 25 | | | | |

| Other Indirect Emission Sources of Suppliers | | | Example | 2006 | 2007 | 2008 | |
|---|---|---|---|---|---|---|---|
| | **Raw Material Receipts** | | | | | | |
| | Total tons of cement received/used | [t] | 25,000 | | | | |
| | Average distance from cement supplier | [km] | 50 | | | | |
| | Cement delivery average load size | [t] | 25 | | | | |
| | Total tons of fly ash received/used | [t] | 10,000 | | | | |
| | Average distance from fly ash supplier | [km] | 100 | | | | |
| | Fly Ash delivery average load size | [t] | 25 | | | | |
| | Total tons of slagment received/used | [t] | 10,000 | | | | |
| | Average distance from slagment supplier | [km] | 150 | | | | |
| | Slagment delivery average load size | [t] | 25 | | | | |
| | Total tons of aggregate received/used | [t] | 4,000 | | | | |
| | Average distance from aggregate supplier | [km] | 200 | | | | |
| | Aggregate delivery average load size | [t] | 25 | | | | |
| | Total tons of other received/used | [t] | 1,000 | | | | |
| | Average distance from other supplier | [km] | 70 | | | | |
| | Aggregate delivery average load size | [t] | 25 | | | | |

# Appendix 8: Final model

InEnergy

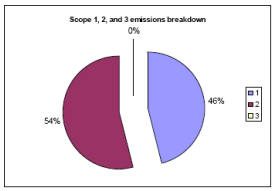
## $CO_2e$ Footprint : Concrete Industry

### C&CI Model

Enter the concrete mix in **kilograms of raw product** into the cells in yellow

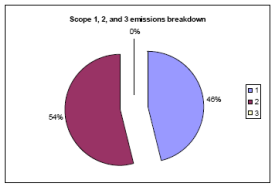
**Mix 1**

| | | Main Components of Concrete Mix | Input | Units | Mix % | $CO_2$ (kg/$m^3$) | CO2 % | Scope emissions CO2 (kg/m3) 1 | 2 | 3 |
|---|---|---|---|---|---|---|---|---|---|---|
| Components | 1 | Admixtures | | kg | #DIV/0! | 0.0 | 0.00% | 0.0 | 0.0 | 0.0 |
| | 2 | Aggregates | | kg | #DIV/0! | 0.0 | 0.00% | 0.0 | 0.0 | 0.0 |
| | 3 | Cement | | kg | #DIV/0! | 0.0 | 0.00% | 0.0 | 0.0 | 0.0 |
| | 4 | Fly Ash | | kg | #DIV/0! | 0.0 | 0.00% | 0.0 | 0.0 | 0.0 |
| | 5 | Slagment | | kg | #DIV/0! | 0.0 | 0.00% | 0.0 | 0.0 | 0.0 |
| | 6 | Water | | kg | #DIV/0! | 0.0 | 0.00% | 0.0 | 0.0 | 0.0 |
| | 7 | Reinforcing | | kg | #DIV/0! | 0.0 | 0.00% | 0.0 | 0.0 | 0.0 |
| | 8 | Pre-Cast | | kg | #DIV/0! | 0.0 | 0.00% | 0.0 | 0.0 | 0.0 |
| Services | 9 | Ready Mix | 1 | m3 | 100.00% | 2.5 | 100.00% | 1.2 | 1.4 | 0.0 |
| | | Resulting CO2e Emissions (kg CO2/m3 concrete): | | | | 2.5 | 100% | 1.2 | 1.4 | 0.0 |
| | | Mix Density (kg/$m^3$) | 0 | Note: High % variation from industry average density of 2400 kg/m3. | | | | | | |



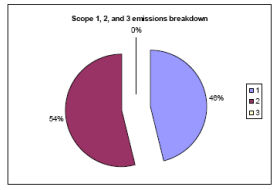

**Mix 2**

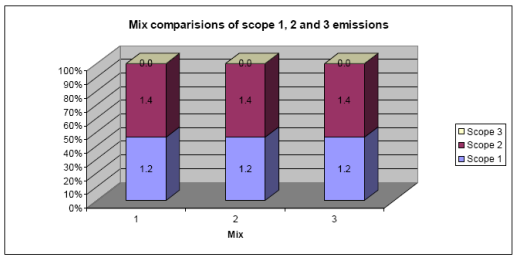
| | | Main Components of Concrete Mix | Input | Units | Mix % | $CO_2$ (kg/m3) | CO2 % | Scope emissions 1 | 2 | 3 |
|---|---|---|---|---|---|---|---|---|---|---|
| Components | 1 | Admixtures | | kg | #DIV/0! | 0.0 | 0.00% | 0.0 | 0.0 | 0.0 |
| | 2 | Aggregates | | kg | #DIV/0! | 0.0 | 0.00% | 0.0 | 0.0 | 0.0 |
| | 3 | Cement | | kg | #DIV/0! | 0.0 | 0.00% | 0.0 | 0.0 | 0.0 |
| | 4 | Fly Ash | | kg | #DIV/0! | 0.0 | 0.00% | 0.0 | 0.0 | 0.0 |
| | 5 | Slagment | | kg | #DIV/0! | 0.0 | 0.00% | 0.0 | 0.0 | 0.0 |
| | 6 | Water | | kg | #DIV/0! | 0.0 | 0.00% | 0.0 | 0.0 | 0.0 |
| | 7 | Reinforcing | | kg | #DIV/0! | 0.0 | 0.00% | 0.0 | 0.0 | 0.0 |
| | 8 | Pre-Cast | | kg | #DIV/0! | 0.0 | 0.00% | 0.0 | 0.0 | 0.0 |
| Services | 9 | Ready Mix | 1 | m3 | 100.00% | 2.5 | 100.00% | 1.2 | 1.4 | 0.0 |
| | | Resulting CO2e Emissions (kg CO2/m3 concrete): | | | | 2.5 | 100% | 1.2 | 1.4 | 0.0 |
| | | Mix Density (kg/$m^3$) | 0 | Note: High % variation from industry average density of 2400 kg/m3. | | | | | | |




**Mix 3**

| | | Main Components of Concrete Mix | Input | Units | Mix % | $CO_2$ (kg/m3) | CO2 % | Scope emissions 1 | 2 | 3 |
|---|---|---|---|---|---|---|---|---|---|---|
| Components | 1 | Admixtures | | kg | #DIV/0! | 0.0 | 0.00% | 0.0 | 0.0 | 0.0 |
| | 2 | Aggregates | | kg | #DIV/0! | 0.0 | 0.00% | 0.0 | 0.0 | 0.0 |
| | 3 | Cement | | kg | #DIV/0! | 0.0 | 0.00% | 0.0 | 0.0 | 0.0 |
| | 4 | Fly Ash | | kg | #DIV/0! | 0.0 | 0.00% | 0.0 | 0.0 | 0.0 |
| | 5 | Slagment | | kg | #DIV/0! | 0.0 | 0.00% | 0.0 | 0.0 | 0.0 |
| | 6 | Water | | kg | #DIV/0! | 0.0 | 0.00% | 0.0 | 0.0 | 0.0 |
| | 7 | Reinforcing | | kg | #DIV/0! | 0.0 | 0.00% | 0.0 | 0.0 | 0.0 |
| | 8 | Pre-Cast | | kg | #DIV/0! | 0.0 | 0.00% | 0.0 | 0.0 | 0.0 |
| Services | 9 | Ready Mix | 1 | m3 | 100.00% | 2.5 | 100.00% | 1.2 | 1.4 | 0.0 |
| | | Resulting CO2e Emissions (kg CO2/m3 concrete): | | | | 2.5 | 0% | 1.2 | 1.4 | 0.0 |
| | | Mix Density (kg/$m^3$) | 0 | Note: High % variation from industry average density of 2400 kg/m3. | | | | | | |



## Appendix 9: CEM I mix design

| CONCRETE TESTING SERVICES | Date: 09/10/2009 |
|---|---|
| CONCRETE MIX DESIGN | Contract No.: 9879 |
| Client: CEMENT & CONCRETE INSTITUTE. | Mix Design No.: 06 |
| Contract: C02 TRIALS | Page No.: 2 OF 3 |

**MIX PROPORTIONS**

TABLE 1. - by dry mass kg/m3.

| MATERIALS | SPECIFIED 28 DAY COMPRESSIVE STRENGTH MPa | | | | | | |
|---|---|---|---|---|---|---|---|
| | 20 | 30 | 40 | | | | |
| WATER | 200 | 200 | 205 | | | | |
| CEM 1 42,5<br>PPC HERCULES | 310 | 340 | 390 | | | | |
| DOLOMITE SUPER SAND<br>PPC MOOIPLAAS | 950 | 920 | 865 | | | | |
| 19mm DOLOMITE STONE<br>ZIMBIWA DOLOMITE | 1050 | 1050 | 1050 | | | | |
| TARGET SLUMP (mm) | 75 | 75 | 75 | | | | |
| CEMENT/WATER RATIO | 1.55 | 1.70 | 1.90 | | | | |
| WATER/CEMENT RATIO | 0.65 | 0.59 | 0.53 | | | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
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| | | | | | | | |

Adjustments must be made on site to take into account moisture in the aggregates.

## Appendix 10: CEM I mix design with admixture

| CONCRETE TESTING SERVICES | Date: 09/10/2009 |
|---|---|
| CONCRETE MIX DESIGN | Contract No.: 9879 |
| Client: CEMENT & CONCRETE INSTITUTE. | Mix Design No.: 03 |
| Contract: C02 TRIALS | Page No.: 2 OF 3 |

**MIX PROPORTIONS**

TABLE 1. - by dry mass kg/m3.

| MATERIALS | SPECIFIED 28 DAY COMPRESSIVE STRENGTH MPa | | | | | | |
|---|---|---|---|---|---|---|---|
| | 20 | 30 | 40 | | | | |
| WATER | 180 | 180 | 185 | | | | |
| CEM 1 42,5<br>PPC HERCULES | 250 | 280 | 325 | | | | |
| DOLOMITE SUPER SAND<br>PPC MOOIPLAAS | 1060 | 1035 | 980 | | | | |
| 19mm DOLOMITE STONE<br>ZIMBIWA DOLOMITE | 1050 | 1050 | 1050 | | | | |
| OMEGA 136 (ml)<br>CHRYSO SA | 1500 | 1680 | 1950 | | | | |
| TARGET SLUMP (mm) | 75 | 75 | 75 | | | | |
| CEMENT/WATER RATIO | 1.40 | 1.55 | 1.75 | | | | |
| WATER/CEMENT RATIO | 0.71 | 0.65 | 0.57 | | | | |
| | | | | | | | |
| | | | | | | | |
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| | | | | | | | |

Adjustments must be made on site to take into account moisture in the aggregates.

## Appendix 11: 70/30 Fly ash

| CONCRETE TESTING SERVICES | Date: 09/10/2009 |
|---|---|
| CONCRETE MIX DESIGN | Contract No.: 9879 |
| Client: CEMENT & CONCRETE INSTITUTE. | Mix Design No.: 04 |
| Contract: C02 TRIALS | Page No.: 2 OF 3 |

**MIX PROPORTIONS**

TABLE 1. - by dry mass kg/m3.

| MATERIALS | SPECIFIED 28 DAY COMPRESSIVE STRENGTH MPa | | | | | | |
|---|---|---|---|---|---|---|---|
| | 20 | 30 | 40 | | | | |
| WATER | 190 | 190 | 195 | | | | |
| CEM 1 42,5<br>PPC HERCULES 70% | 235 | 255 | 285 | | | | |
| DURAPOZZ PRO<br>ASH RESOURCES MATLA 30% | 100 | 110 | 125 | | | | |
| DOLOMITE SUPER SAND<br>PPC MOOIPLAAS | 925 | 895 | 835 | | | | |
| 19mm DOLOMITE STONE<br>ZIMBIWA DOLOMITE | 1050 | 1050 | 1050 | | | | |
| TARGET SLUMP (mm) | 75 | 75 | 75 | | | | |
| CEMENT/WATER RATIO | 1.75 | 1.90 | 2.10 | | | | |
| WATER/CEMENT RATIO | 0.57 | 0.53 | 0.48 | | | | |
| | | | | | | | |
| | | | | | | | |
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| | | | | | | | |

Adjustments must be made on site to take into account moisture in the aggregates.

## Appendix 12: 70/30 Fly ash with admixture

| CONCRETE TESTING SERVICES | Date: 09/10/2009 |
|---|---|
| CONCRETE MIX DESIGN | Contract No.: 9879 |
| Client: CEMENT & CONCRETE INSTITUTE. | Mix Design No.: 01 |
| Contract: C02 TRIALS | Page No.: 2 OF 3 |

**MIX PROPORTIONS**

TABLE 1. - by dry mass kg/m3.

| MATERIALS | SPECIFIED 28 DAY COMPRESSIVE STRENGTH MPa | | | | | | |
|---|---|---|---|---|---|---|---|
| | 20 | 30 | 40 | | | | |
| WATER | 165 | 165 | 170 | | | | |
| CEM 1 42,5<br>PPC HERCULES 70% | 165 | 200 | 255 | | | | |
| DURA POZZ PRO<br>ASH RESOURCES MATLA 30% | 70 | 85 | 110 | | | | |
| DOLOMITE SUPER SAND<br>PPC MOOIPLAAS | 1090 | 1040 | 950 | | | | |
| 19mm DOLOMITE STONE<br>ZIMBIWA DOLOMITE | 1050 | 1050 | 1050 | | | | |
| OMEGA 136 (ml)<br>CHRYSO SA | 1410 | 1710 | 2190 | | | | |
| TARGET SLUMP (mm) | 75 | 75 | 75 | | | | |
| CEMENT/WATER RATIO | 1.45 | 1.75 | 2.15 | | | | |
| WATER/CEMENT RATIO | 0.69 | 0.57 | 0.47 | | | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |

Adjustments must be made on site to take into account moisture in the aggregates.

## Appendix 13: 50/50 Slagment

| CONCRETE TESTING SERVICES | Date: 09/10/2009 |
|---|---|
| CONCRETE MIX DESIGN | Contract No.: 9879 |
| Client: CEMENT & CONCRETE INSTITUTE. | Mix Design No.: 05 |
| Contract: C02 TRIALS | Page No.: 2 OF 3 |

**MIX PROPORTIONS**

TABLE 1. - by dry mass kg/m3.

| MATERIALS | SPECIFIED 28 DAY COMPRESSIVE STRENGTH MPa | | | | | | |
|---|---|---|---|---|---|---|---|
| | 20 | 30 | 40 | | | | |
| WATER | 200 | 200 | 205 | | | | |
| CEM 1 42,5<br>PPC HERCULES 50% | 170 | 185 | 210 | | | | |
| GGBS<br>SLAGMENT 50% | 170 | 185 | 210 | | | | |
| DOLOMITE SUPER SAND<br>PPC MOOIPLAAS | 865 | 835 | 765 | | | | |
| 19mm DOLOMITE STONE<br>ZIMBIWA DOLOMITE | 1050 | 1050 | 1050 | | | | |
| TARGET SLUMP (mm) | 75 | 75 | 75 | | | | |
| CEMENT/WATER RATIO | 1.70 | 1.85 | 2.05 | | | | |
| WATER/CEMENT RATIO | 0.59 | 0.54 | 0.49 | | | | |
| | | | | | | | |
| | | | | | | | |
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Adjustments must be made on site to take into account moisture in the aggregates.

## Appendix 14: 50/50 Slagment with admixture

| CONCRETE TESTING SERVICES | Date: 09/10/2009 |
|---|---|
| CONCRETE MIX DESIGN | Contract No.: 9879 |
| Client: CEMENT & CONCRETE INSTITUTE. | Mix Design No.: 02 |
| Contract: C02 TRIALS | Page No.: 2 OF 3 |

**MIX PROPORTIONS**

TABLE 1. - by dry mass kg/m3.

| MATERIALS | SPECIFIED 28 DAY COMPRESSIVE STRENGTH MPa | | | | | | |
|---|---|---|---|---|---|---|---|
| | 20 | 30 | 40 | | | | |
| WATER | 180 | 180 | 185 | | | | |
| CEM 1 42,5<br>PPC HERCULES 50% | 140 | 155 | 175 | | | | |
| GGBS<br>SLAGMENT 50% | 140 | 155 | 175 | | | | |
| DOLOMITE SUPER SAND<br>PPC MOOIPLAAS | 1025 | 1000 | 945 | | | | |
| 19mm DOLOMITE STONE<br>ZIMBIWA DOLOMITE | 1050 | 1050 | 1050 | | | | |
| OMEGA 136 (ml)<br>CHRYSO SA | 1680 | 1860 | 2100 | | | | |
| TARGET SLUMP (mm) | 75 | 75 | 75 | | | | |
| CEMENT/WATER RATIO | 1.55 | 1.70 | 1.90 | | | | |
| WATER/CEMENT RATIO | 0.65 | 0.59 | 0.53 | | | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |

Adjustments must be made on site to take into account moisture in the aggregates.

## Appendix 15: Decomposed granite sand

| CONCRETE TESTING SERVICES | Date: 09/10/2009 |
|---|---|
| CONCRETE MIX DESIGN | Contract No.: 9879 |
| Client: CEMENT & CONCRETE INSTITUTE. | Mix Design No.: 08 |
| Contract: C02 TRIALS | Page No.: 2 OF 3 |

**MIX PROPORTIONS**

TABLE 1. - by dry mass kg/m3.

| MATERIALS | SPECIFIED 28 DAY COMPRESSIVE STRENGTH MPa | | | | | | |
|---|---|---|---|---|---|---|---|
| | 20 | 30 | 40 | | | | |
| WATER | 260 | 260 | 265 | | | | |
| CEM 1 42,5<br>PPC HERCULES | 430 | 470 | 530 | | | | |
| DECOMPOSED GRANITE SAND<br>HALFWAY HOUSE | 670 | 635 | 565 | | | | |
| 19mm DOLOMITE STONE<br>ZIMBIWA DOLOMITE | 1050 | 1050 | 1050 | | | | |
| TARGET SLUMP (mm) | 75 | 75 | 75 | | | | |
| CEMENT/WATER RATIO | 1.65 | 1.80 | 2.00 | | | | |
| WATER/CEMENT RATIO | 0.61 | 0.56 | 0.50 | | | | |
| | | | | | | | |
| | | | | | | | |
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| | | | | | | | |

Adjustments must be made on site to take into account moisture in the aggregates.

## Appendix 16: Decomposed granite sand with admixture

| CONCRETE TESTING SERVICES | Date: 09/10/2009 |
|---|---|
| CONCRETE MIX DESIGN | Contract No.: 9879 |
| Client: CEMENT & CONCRETE INSTITUTE. | Mix Design No.: 07 |
| Contract: C02 TRIALS | Page No.: 2 OF 3 |

**MIX PROPORTIONS**

TABLE 1. - by dry mass kg/m3.

| MATERIALS | SPECIFIED 28 DAY COMPRESSIVE STRENGTH MPa | | | | | | |
|---|---|---|---|---|---|---|---|
| | 20 | 30 | 40 | | | | |
| WATER | 245 | 245 | 250 | | | | |
| CEM 1 42,5<br>PPC HERCULES | 370 | 405 | 465 | | | | |
| DECOMPOSED GRANITE SAND<br>HALFWAY HOUSE | 770 | 735 | 670 | | | | |
| 19mm DOLOMITE STONE<br>ZIMBIWA DOLOMITE | 1050 | 1050 | 1050 | | | | |
| OMEGA 136 (ml)<br>CHRYSO SA | 2220 | 2430 | 2790 | | | | |
| TARGET SLUMP (mm) | 75 | 75 | 75 | | | | |
| CEMENT/WATER RATIO | 1.50 | 1.65 | 1.85 | | | | |
| WATER/CEMENT RATIO | 0.67 | 0.61 | 0.54 | | | | |
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Adjustments must be made on site to take into account moisture in the aggregates.