# Green Cement Manufacturing in South Africa through Utilization of Supplementary Cementitious Materials-Market Assessment

**Asser Letsatsi Tau, Emmanuel Innocents Edoun, Charles Mbohwa and Anup Pradhan**
Faculty of Engineering and the Built Environment,
School of Mechanical Engineering and Industrial Engineering
Department of Quality and Operations Management
University of Johannesburg, 55 Beit St, Doornfontein, Johannesburg, 2028, South Africa
gobetse.t@gmail.com, edounsen@hotmail.com, anupp@uj.ac.za and cmbohwa@yahoo.com

## Abstract

The continued increase in economies in most developing countries is associated with the requirements for construction materials such as cement and concrete. Globally, cement production continues to increase further into year 2030 with expected increase to level that is 5 times year 1990, which is close to about 5 billion tones. Manufacturing of cement is associated with emission of carbon dioxide ($CO_2$) during the clinker production process stage. There is further expectation that the cement industry is most probable to exceed the total amount of emissions of $CO_2$ of the emission standards. The industry in then under pressure to deploy strategies aimed at reduction of carbon dioxide and South African cannot afford to be left behind in reducing the $CO_2$ emission levels. Utilization of Supplementary Cementitious Materials (SCMs) (fly ash, Ground Granulated Blast Furnace Slag and limestone) has been proven as one of strategic levers in manufacturing of cement at lower $CO_2$ emissions. To assess the South African industry's implementation of this strategy, the types of cements being manufactured as guided by SANS 5097-1 2013 and with respect to product offering to the market in terms of the formulation using raw materials in the manufacturing process were used for the evaluation purpose. The South African cement industry indicated to have 7 manufacturers that have integrated plants for producing cement thus associated with clinker production and 10 cement producers who manufacture cement by commencing the manufacturing process at the blending process stage. Based on the market survey for the cement types being supplied in the market, the product offering ranged from CEM I, CEM IV and CEM V which made use of fly ash, GGBFS and limestone for reduction of clinker factor. The percentage clinker substitution was as high in the range of 6 to 62. This indicated a potential $CO_2$ reduction of between 0.054 ton and 0.558 ton per 0.94 ton and 0.38 ton of clinker utilized in producing the cement respectively. Although utilization of SCMs alone cannot be enough to reduce the emissions to 100% acceptable limits, the manufacturers were advised adopt additional potential decarbonization options such as decarbonization of the heat of burning through and Carbon capture, utilization, and storage as additional $CO_2$ reduction strategies.

## Keywords

SANS 5097-1 2013, $CO_2$, clinker, and formulation

## 1. Introduction

As the economies grow and get wealthier, cement and concrete as construction materials increase in demand and this is particularly evident in emerging economies. Globally, the cement industry in facing challenges in business sustainability while reducing its carbon intensity from processes of production, uses of fuel and its end use of product. The world must reduce the greenhouse emissions by 80% below the 1990 levels.

Utilization of waste process streams from other industries such coal fired Power Stations which releases fly ash, steel industry which releases Ground Granulated Blast Furnace Slag (GGBFS) from and Limestone from quarry have been used as Supplementary Cementitious Materials (SCMs) mainly as the "*nice to have*" raw materials for producing cement. Their use has been to reduce the cost of manufacturing cement and for enhancement of properties of cement for suitability in different applications.

However, the call for Sustainable development goals (SDG), 7 and 8 calls for climate change and responsible production has propelled manufacturers of cement in South Africa to be more innovative in reducing emissions of $CO_2$. Over the years, this has been striven to be achieved through efficiency improvements on rotary kiln operations and through utilization of SCMs as strategic achievements. Typically, the production of 1 ton of clinker is associated with emission of 0.9 ton of $CO_2$.

As the production of cement is expected to increase until the year 2050 for developing countries (Scrivener 2014).
The need for continuous cement production indicated that annually, every individual requires about 1 ton of cement (Cembureau 2012). The South African cement industry cannot afford to be left behind in contributing to the Paris Agreement commitment target where reduction of emissions of greenhouse gas to about 1.7Gt by year 2050 by the cement sector is required globally.

This is because the cement industrial sector contributes 12% to 16% on average of the energy within the industrial sector and $CO_2$ emissions of 6% to 8% globally (Fry 2013). In addition to the environmental crisis that are associated with emission of $CO_2$, the energy requirements and consumption to produce cement is critical in a country such as South Africa where load shedding is a continuous challenge.

About 1.5t of limestone is needed to produce 1 ton of cement with thermal energy requirement of between 2.93GJ and 6.28GJ, and electrical energy requirement of between 65kWh and 141 kWh (Huntzinger and Eatmon 2009; Madlool et al. 2011; Valderrama et al. 2012). Energy security is a critical issue to various stakeholders, including policy makers, businesses which are particularly consumers and the community in general whose life quality depends on supply of energy which is uninterrupted (Ang et al. 2015). The South African industry consists of cement suppliers ranging from manufactures having integrated plants, that is, from limestone quarrying, pyro-processing in rotary kilns up until finishing milling and dispatch as shown on Figure 1.

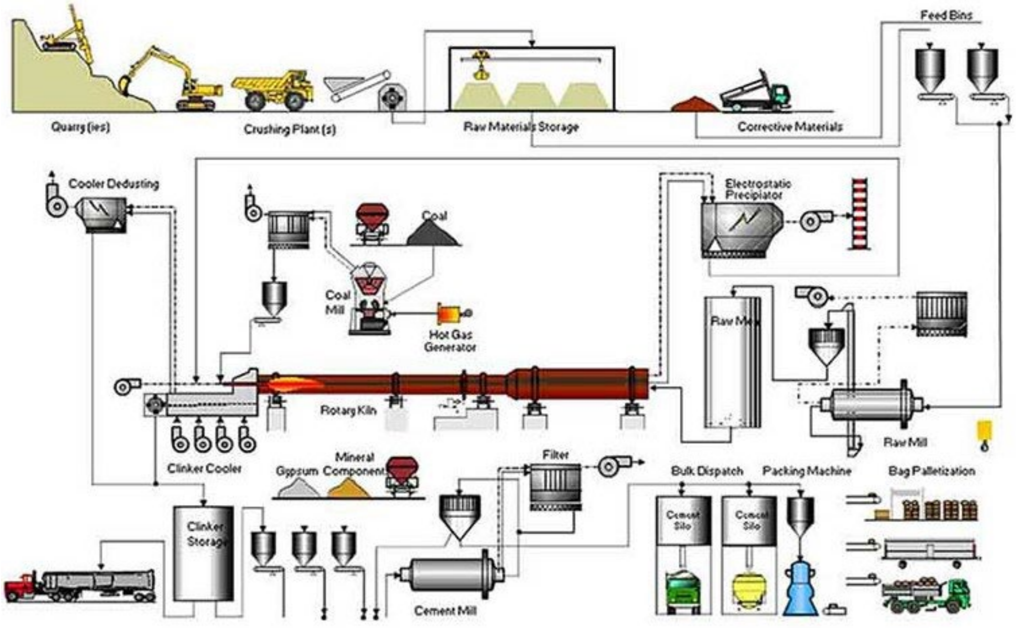


Figure 1. Cement manufacturing by dry method
Source: Mohsen and Al-Farayh (2015)

Other cement suppliers start the cement manufacturing process from the blending operations.
In South Africa, there are seven cement manufacturers with integrated plants and ten cement suppliers that start cement manufacturing from the blending operations process stage. There is a forecast of about less than five cement manufacturers to enter the market within the cement blending operations in the next coming five years.

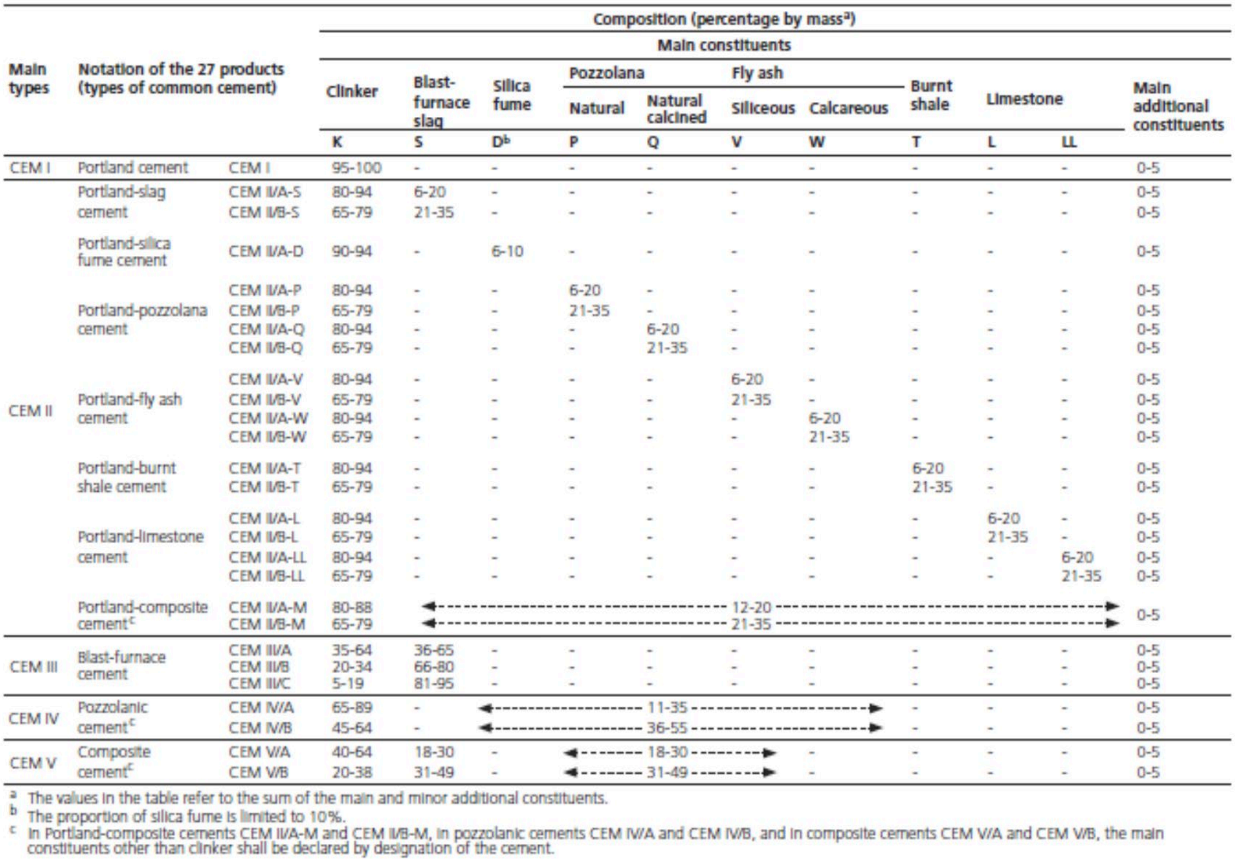
The cement supplier market assessment in terms of product offerings at the perspective of cement product formulations for the contribution to reduction of $CO_2$ is required to be conducted. This is to further evaluate the carbon neutrality transition by each cement supplier in South Africa as part of their strategic green manufacturing for striving to meet the $CO_2$ emissions target by year 2050.

### 1.1 Objective

The objective of the study was to investigate types of cement being manufactured in South Africa in accordance to SANS 50197-1 2013 in response to reduction of carbon dioxide emissions.

## 2. Literature Review

The South African National Standards (SANS) 50197-1 (2013) guides the cement manufacturing processes with respect to composition, specifications and conformity of cement being produced. The specification with respect to the quality performance of cement is also outlined which aids with enforcement of compliance to manufacturers based on the standard. Figure 2 shows a section within the SANS 50197-1 standard that indicates 27 cement types 27 available in the family of common cements.



| Main types | Notation of the 27 products (types of common cement) | | Composition (percentage by mass[a]) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Main constituents | | | | | | | | | | Main additional constituents |
| | | | Clinker | Blast-furnace slag | Silica fume | Pozzolana | | Fly ash | | Burnt shale | Limestone | | |
| | | | | | | Natural | Natural calcined | Siliceous | Calcareous | | | | |
| | | | K | S | D[b] | P | Q | V | W | T | L | LL | |
| CEM I | Portland cement | CEM I | 95-100 | - | - | - | - | - | - | - | - | - | 0-5 |
| CEM II | Portland-slag cement | CEM II/A-S | 80-94 | 6-20 | - | - | - | - | - | - | - | - | 0-5 |
| | | CEM II/B-S | 65-79 | 21-35 | - | - | - | - | - | - | - | - | 0-5 |
| | Portland-silica fume cement | CEM II/A-D | 90-94 | - | 6-10 | - | - | - | - | - | - | - | 0-5 |
| | Portland-pozzolana cement | CEM II/A-P | 80-94 | - | - | 6-20 | - | - | - | - | - | - | 0-5 |
| | | CEM II/B-P | 65-79 | - | - | 21-35 | - | - | - | - | - | - | 0-5 |
| | | CEM II/A-Q | 80-94 | - | - | - | 6-20 | - | - | - | - | - | 0-5 |
| | | CEM II/B-Q | 65-79 | - | - | - | 21-35 | - | - | - | - | - | 0-5 |
| | Portland-fly ash cement | CEM II/A-V | 80-94 | - | - | - | - | 6-20 | - | - | - | - | 0-5 |
| | | CEM II/B-V | 65-79 | - | - | - | - | 21-35 | - | - | - | - | 0-5 |
| | | CEM II/A-W | 80-94 | - | - | - | - | - | 6-20 | - | - | - | 0-5 |
| | | CEM II/B-W | 65-79 | - | - | - | - | - | 21-35 | - | - | - | 0-5 |
| | Portland-burnt shale cement | CEM II/A-T | 80-94 | - | - | - | - | - | - | 6-20 | - | - | 0-5 |
| | | CEM II/B-T | 65-79 | - | - | - | - | - | - | 21-35 | - | - | 0-5 |
| | Portland-limestone cement | CEM II/A-L | 80-94 | - | - | - | - | - | - | - | 6-20 | - | 0-5 |
| | | CEM II/B-L | 65-79 | - | - | - | - | - | - | - | 21-35 | - | 0-5 |
| | | CEM II/A-LL | 80-94 | - | - | - | - | - | - | - | - | 6-20 | 0-5 |
| | | CEM II/B-LL | 65-79 | - | - | - | - | - | - | - | - | 21-35 | 0-5 |
| | Portland-composite cement[c] | CEM II/A-M | 80-88 | ◄---------- 12-20 ----------► | | | | | | | | | 0-5 |
| | | CEM II/B-M | 65-79 | ◄---------- 21-35 ----------► | | | | | | | | | |
| CEM III | Blast-furnace cement | CEM III/A | 35-64 | 36-65 | - | - | - | - | - | - | - | - | 0-5 |
| | | CEM III/B | 20-34 | 66-80 | - | - | - | - | - | - | - | - | 0-5 |
| | | CEM III/C | 5-19 | 81-95 | - | - | - | - | - | - | - | - | 0-5 |
| CEM IV | Pozzolanic cement[c] | CEM IV/A | 65-89 | - | ◄------ 11-35 ------► | | | | | - | - | - | 0-5 |
| | | CEM IV/B | 45-64 | - | ◄------ 36-55 ------► | | | | | - | - | - | 0-5 |
| CEM V | Composite cement[c] | CEM V/A | 40-64 | 18-30 | - | ◄--- 18-30 ---► | | | - | - | - | - | 0-5 |
| | | CEM V/B | 20-38 | 31-49 | - | ◄--- 31-49 ---► | | | - | - | - | - | 0-5 |

[a] The values in the table refer to the sum of the main and minor additional constituents.

[b] The proportion of silica fume is limited to 10%.

[c] In Portland-composite cements CEM II/A-M and CEM II/B-M, in pozzolanic cements CEM IV/A and CEM IV/B, and in composite cements CEM V/A and CEM V/B, the main constituents other than clinker shall be declared by designation of the cement.

Figure 2. Cement types available in SANS 50197-1 2013 for manufacturing
Source: South African National Standards ( 2013)

The production of cement is associated with emissions of greenhouse gasses that are high. Cement can contain numerous constituents including clinker, gypsum, supplementary cementitious materials (SCMs) such as fly ash , blast-furnace slag and other materials that occur naturally such as limestone and clay which can be converted to metakaolin. Out of these constituents, about 65% to 85% contribution of the global cement mass is by clinker and 90% to 98% of cement Greenhouse gas (GHG) emissions. The clinker manufacturing through calcination process produces calcium oxide (CaO) and $CO_2$. The further heating process of raw materials to a temperature of about 1400 °C for the formation of chemical clinker species such as calcium silicates requires this high level of energy inputs and further results with additional emissions of GHG (Miller et al. 2016). The calcination chemical reaction process is represented by the following reaction equation where calcium carbonate ($CaCO_3$) and silicon oxides (i.e. $SiO_2$) are heated on high temperature scale thereby releasing $CO_2$.

Clinker formation reaction equation: $3CaCO_{3\,(s)} + SiO_{2\,(s)} \rightarrow Ca_3SiO_{5\,(s)} + 3CO_{2\,(g)}$

The emissions of GHG associated with the calcination process can be in the range of 45% to 60% of the total cement being produced depending on the efficiency, fuel being used in the kiln, mixes of energy, and other materials being used in the production process (Miller et al. 2016). Imbabi et al. (2013) indicated that in a typical Portland cement manufacturing process, the emissions of $CO_2$ contributed from process of grinding, quarrying and transportation which makes 15%, meanwhile 85% is resulted from pyro-processing. Figure 3 further indicates $CO_2$ total share across production lines in cement manufacturing.

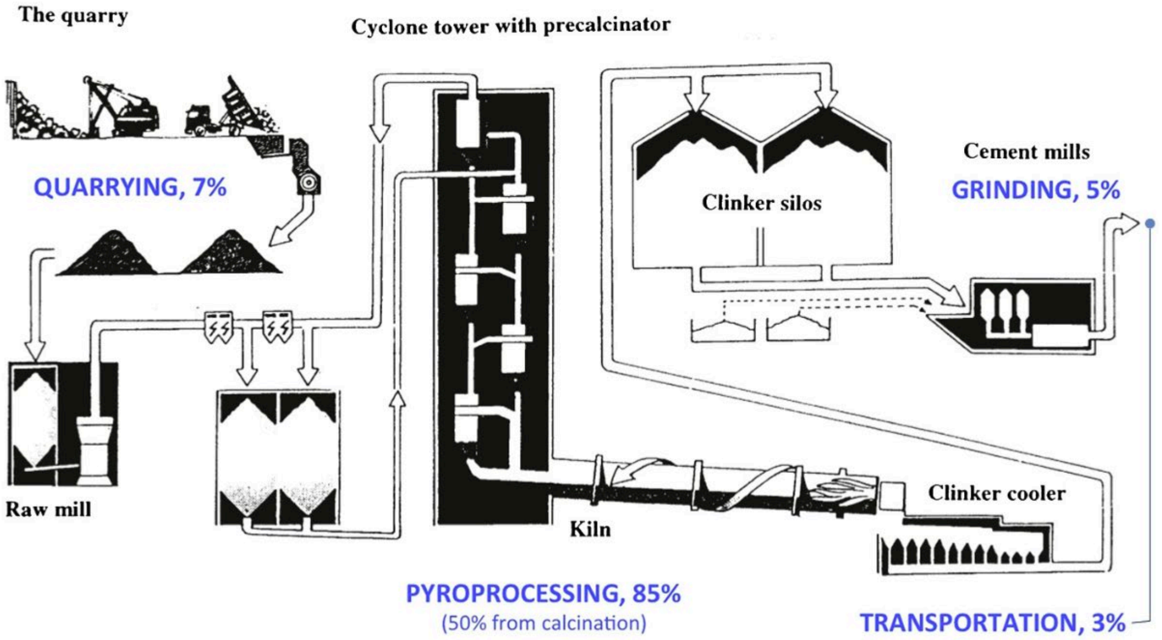


Figure 3. Total share of $CO_2$ emission in Portland cement production process
Source: Imbabi et al. (2013)

There most common strategies for reduction of GHG emissions in manufacturing of cement include (i) substitution of raw materials in cement (ii) utilization of alternative fuels during manufacturing (iii) improvement on the efficiency of kiln and utilization of electricity, and (iv) development of carbon capture and storage (Muller and Harnisch 2008; Sakai and Buffenbarger 2014). Every ton of Ordinary Portland cement produced clinker contributes to about 0.9 tons of $CO_2$ (Benhelal et al. 2012).

Furthermore, Pade and Guimaraes (2007) explained that the manufacturing of cement is associated with 50% emission of $CO_2$ being from burning of calcium carbonate meanwhile the other 50% emission is associated with fuels combustion process steps with one ton of cement being produced releasing one tone of $CO_2$ (Hannawi et al. 2010). WBCSD-CSI (2009) also indicated that $CO_2$ emission during limestone calcination is about 0.87ton for every 1 ton of Portland cement clinker to environment. This emission quantity ranges between 0.77 tons for Japan as high performers to 0.99 tons for China as poor performers. $CO_2$ emission associated with cement is also dependent on the region and process of manufacturing and infrastructure (Lowitt 2020).

WWF business case (2018) indicated that there are four available options to mitigate the emissions of $CO_2$ in the cement industry. These include adoption of new technologies such as carbon capture and storage (CSS), alternative binders such geopolymers and limestone calcined clay cements ($LC^3$), energy efficiency improvement, utilization of alternative fuels in the kiln during pyro-processing and increase of substitution of clinker through utilization of SCMs in Portland cement traditional mixes to produce eco-blended cements.

Blended cements are deemed to provide means that are attainable and effective whereby emissions of carbon can be reduced (Lowitt 2020) and it is suggested that about 37% of reduction of carbon can be reduced by 2050 through blended cements, meanwhile Leanne and Preston (2018) further indicated that blended cements can reduce emissions by 70% theoretically.

Figure 4 further highlights some of sources of potential methods of reducing $CO_2$ emissions thereby product slightly green cement.

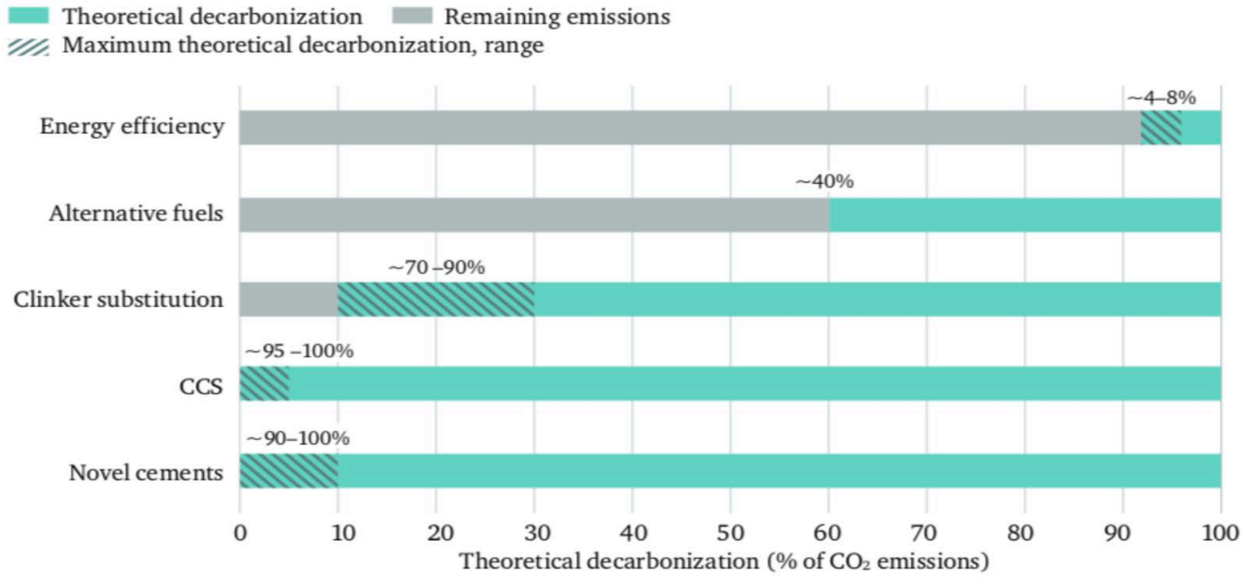


Figure 4. Potential sources of reduction of $CO_2$ emissions in cement production

Source: Leanne and Preston (2018)

The negative effect associated with $CO_2$ emissions when manufacturing of cement is taking place continuously lead to more research for materials that are available locally from both natural occurrence and recycles, also from material waste streams from other industrial processes for incorporation as cement raw materials inputs. This calls for development of clinker by utilisation of minerals alternatives, low carbon cements and fuels that are less carbon intensive. There are several methods that has been brought forward by many researchers on $CO_2$ reduction in the industry of manufacturing cement. These methods include carbon capture and storage which is associated with capturing and storage of emissions from kiln operations, use of geopolymers which are produced at temperatures which are low and obtained from wastes from other industries that are treated with heat (Shapakidze et al. 2019). Introduction of alternative clinker free cements is also one of the methods that are still under research and development.

The use of SCMs as alternative method are ideal as fly ash and slag has proven to be a good partial replacement of cement yield acceptable results. This is one of the alternative methods to reduce high emission levels of $CO_2$ (Onyenokporo 2021). SCMs are materials that are inorganic and contribute to cementitious mixture properties for instance, in paste, mortar, concrete and grout through hydraulic reactivity or pozzolanic reactivity or combination of both (ASTM C125-19 2019). (Celik et al. 2014) further indicated that elimination of 1 billion tons of $CO_2$ would require about 1.58 billion tons of SCMs during the processing of cement.

Onyenokporo (2021) studied the usage of SCMs for suitability as replacement of cement partially within the building industry through critical review of literature. The findings that were concluded indicated that use of SCMs provided solutions to avoid landfilling of SCMs as some of them are waste from other industrial processes which subsequently results with environmental pollution due to disposal. Furthermore, it was found that benefits within the cement sector is energy consumption reduction and reduction emissions of carbon as less clinker is utilised thereby reducing environmental impact and foster sustainability.

Celik et al. (2014) indicated that conventional ordinary Portland cement is manufactured by inter-grinding Portland clinker and gypsum at 95% and 5% composition by weight respectively. The clinker factor thereof equates to 0.95. In comparison to utilisation of 30% basaltic ash that is finely grounded from Saudi Arabia and 15% powdered limestone for Portland clinker replacement, the clinker factor within the ternary blended Portland cement equated to 0.52 thus avoiding 48% $CO_2$ emission. This replacements with SCMs were further associated with enhancement on development of strength and durability in the case of self-compacting concrete (SCC) where the cement is used.

Furthermore, the conventional SCMs such as fly ash and slag from blast furnace has been studied and empirical experience provide confident for low-clinker cements production consisting of these materials (Juenger et al. 2019). Similarly these materials are used to produce concrete that have improved physical properties and subsequently lowering cement clinker usage thereby reducing $CO_2$ as concrete is one of the largest consumed construction material.

The assessment of SCMs to mitigate the anthropogenic greenhouse gas emissions from concrete production which contributes between 8% and 9% emissions on global scale has been studied by (Miller 2018). Utilisation of SCMs in concrete production assist in offsetting cement clinker demand therefore leading to reduction of anthropogenic greenhouse gas emissions. (Miller 2018) used quantitative analysis by utilizing environmental impact assessments and comparison was drawn as a function of variation in emission of anthropogenic greenhouse gases for concrete production. However, the type of SCMs and usage allocation, variation in transportation, and high levels of replacement by SCMs in concrete does not always consequently reduce the emissions of concrete produced per unit of strength achieved. Furthermore, the availability of these materials limits the full utilization of them in some countries.

Similarly, the South African cement and concrete market is concerned about the future availability of coal fly ash due to the call for green energy production and consistent loadshedding. These threatens availability of coal fly ash from power stations due to potential reduction of coal usage for power generation because of its carbon and sulphur oxide emission intensities. Although the power producer in South Africa have built state of the art power stations such as Kusile and Medupi which incorporate flue gas desulphurisation technologies for sulphur oxides emission reduction, lifespan would not sustain the South African market's fly ash requirement even when each is operating at its 4800 MW installed power generation capacity. Also the interrupted steel manufacturing industry from production perspective in South Africa due to influx of steel import from other countries threatens the availability of GGBFS. The ripple effect of the steel import is potential GGBFS import also which has potential high costs than local GGBFS.

The need for SCMs in South Africa is vital in order to sustain the infrastructural development needs which requires cement to achieve some of construction related projects. The South African cement industry was began by Pretoria Portland Cement Company (PPC) in 1892 by producing Ordinary Portland Cement. In 1934, Afrisam, Lafarge and Natal Portland Cement (NPC) formed part of the market. These companies were the only one manufacturing cement until 2006 when Sephaku entered the market, then later in 2016 Chinese cement manufacturer Mamba Cement also entered the market (Lowitt, 2020). In 2016, there six producers of cement in South Africa existed with an assumed worth of R48 billion in year 2014 and had about 7000 employees (Arp et al. 2018). The market share of PPC, NPC, Sephaku, Afrisam, Lafarge and Mamba cement are at 22%, 15%, 12%, 9%, 9% and 5% respectively. The outstanding 29% is being shared at 5% imports and 24% party blenders (Perrie 2014; Arp et al. 2018; Pretoria Portland Cement (PPC) 2018). The local market constitute 91% of ordinary Portland cement. In 2006, about 52% of cement sales was accounted to domestic sales, 15% to ready mix concrete manufacturers, 16% to manufacturers of concrete products. Direct companies civil engineering associated 9% on sales of cement, 6% of cement sales was accounted by third-party blenders and 2% was for others applications (Perrie 2014). However, it was reported that about 70% on estimate was accounted for retail market in 2016 (Brown and Hasson 2016). Table 1 further indicates market share by product where the cement clinkers, white Portland and other white cement has highest share respectively (WWF business case 2018).

Table 1. Product type market share

| Type of product | Share of market (%) |
|---|---|
| Aluminous cement | 1.90 |
| Hydraulic cement | 1.10 |
| Cement clinkers | 6.10 |
| White Portland | 8.50 |
| Other Portland cement | 82.40 |

In comparison to Europe and most parts of Asia, the South Africa' share of market in the bagged cement differs were the ready mix segment is mainly dominant. Meanwhile, in the United States, Australia and South Africa, the segment of ready mix is small on market share and bagged cement dominates the market due to distances that are extensive which impedes the ready mix site deliveries to be feasible (Lowitt 2020). The Concrete Institute indicated South Africa' s actual demand of cement sales and imports as shown on Figure 5 and was noted that cement demand has been increasing year on year on average.

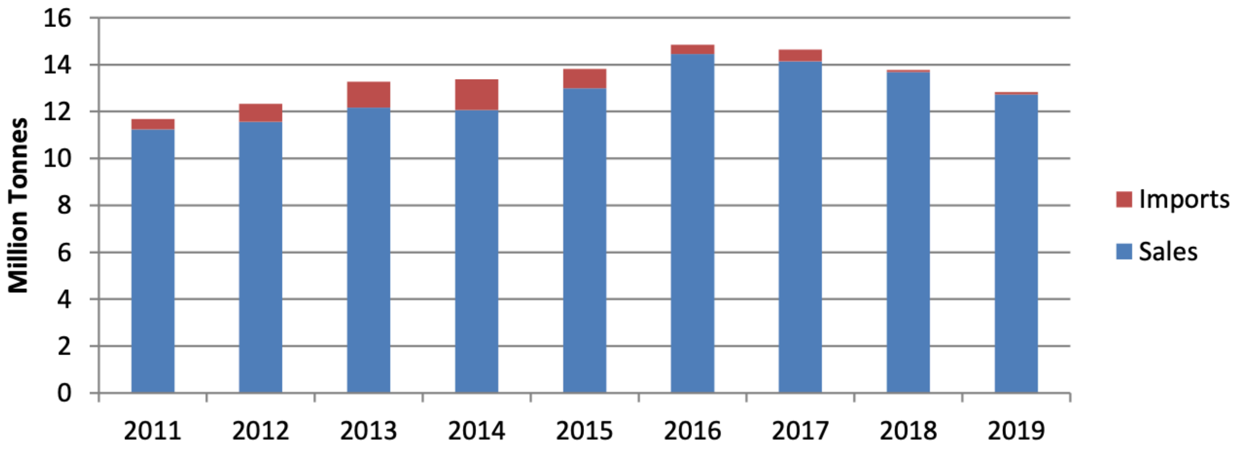


Figure 5. Cement sales and import from year 2011 to 2019
Source: (Lowitt 2020)

The manufacturing of cement in South Africa contributed 1% on country's net emissions from greenhouse gases during year 2010 according to Association of Cementitious Materials Producers (2011). This was an increase of 27% between year 2000 and 2010, from emission of $3.3MtCO_2$ to $4.2MtCO_2$ (Department of Environmental Affairs 2014). However, there have been reduction in emission per ton of cement produced year on year since 2008 due to increased substitution of clinker (Lowitt 2020). The substitution of clinker was 12% in 1990 and increased by 11% in 2000 and to 41% in 2009 (Association of Cementitious Materials Producers 2011), while mitigation potential analysis calls for further substitution increase to 60% by year 2030 (Lowitt 2020) as the cement demand in South Africa is anticipated to increase as illustrated on Figure 6. The figure shows cement demand trend from 1996 to 2022 and this further illustrates the need to subsequently mitigate the carbon dioxide emissions.

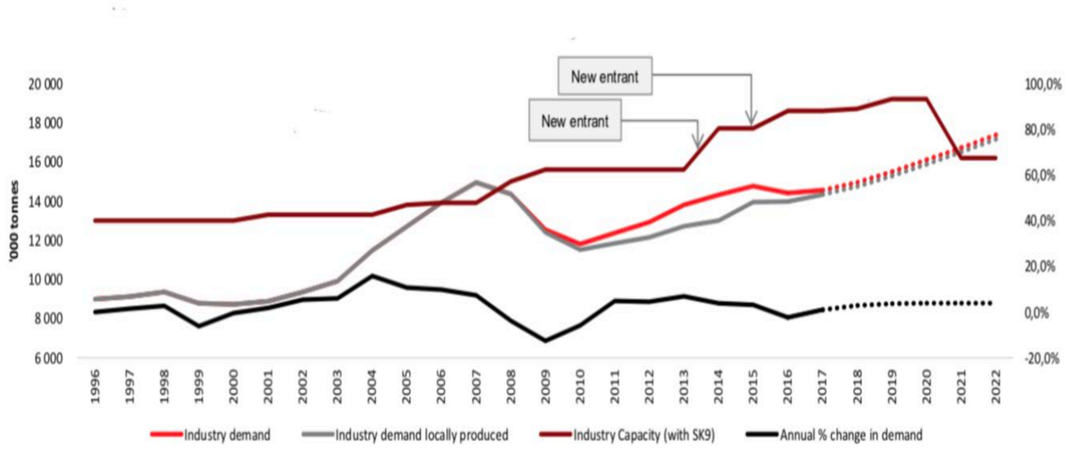


Figure 6. Cement demand trend from 1996 to 2022, modified from PPC (2018) publication
Source: (Lowitt 2020)

## 3. Methods

The Portland cement producers having integrated cement plants and those commencing cement production process from the blending operations (also known as third party cement blenders) have been identified. The suppliers were engaged and feedback with respect to the type of cement classes or types they are producing was supplied to the researcher.

The qualitative information shared on their manufacturing process from the perspective of raw materials was being presented in the form of a rubric. The researcher then conducted data analysis by representing the data in terms of tables and graphs to arrive at an informed cement industry conclusion. This was based on potential reduction of carbon dioxide emission because of types of cement being manufactured.

## 4. Results and Discussion

The available Portland cement types in South Africa as produced by manufacturers with integrated cement plants indicated manufacturers' commitment to reduction of $CO_2$ through the use of SCMs as by products from other industrial processes. The percentage clinker substitution with SCMs was as high as on a range of 36% and 55% as noted on cement type CEM IV/B as shown on Table 2.

Table 2. Cement types supplied by manufacturers with integrated cement plants

| **Integrated cement plant: Manufacturer** | **Cement type being manufactured** | **% Supplementary Cementitious Material on clinker substitution** | | |
|---|---|---|---|---|
| | | **Fly Ash (V)** | **GGBFS (S)** | **Limestone (L)** |
| Manufacturer A | CEM I | 0-5 | | |
| | CEM II/A-L | | | 6 - 20 |
| | CEM II/B-M(V-S) | 21-35 | | |
| | CEM II/A-S | | 6-20 | |
| | CEM II/B-V | 21 - 35 | | |
| Manufacturer B | CEM I | 0-5 | | |
| | CEM II/A-V | 6 - 20 | | |
| Manufacturer C | CEM I | 0-5 | | |
| | CEM II/A-M(V-L) | 12 - 20 | | |
| | CEM II/B-L | 21 - 35 | | |
| | CEM V/A(S-V) | 18 - 30 | | |
| | CEM III | | 66 - 80 | |
| | CEM V/B(V-S) | 36 - 55 | | |
| | CEM II/B-M(L) | | | 21 - 35 |

| | | | | |
|---|---|---|---|---|
| | CEM V/A(S-V) | 18 - 30 | | |
| Manufacturer D | CEM I | 0-5 | | |
| | CEM II/A-V | | | |
| Manufacturer E | CEM I | 0-5 | | |
| | CEM II/B-M | 21 - 35 | | |
| | CEM II/A-L | | | 6 - 20 |
| Manufacturer F | CEM II/A-S | | 6-20 | |
| | CEM II/B-S | | 21 - 35 | |
| | CEM II/A-L | | 6 - 20 | |
| | CEM III/A | 6-20 | | |
| | CEM II/B-L | | | 21 - 35 |
| Manufacturer G | CEM I | 0-5 | | |
| | CEM II/A-V | 6 - 20 | | |
| | CEM IV/B-V | 36 - 55 | | |
| | CEM IV/A-V | 11-35 | | |
| | CEM II/B-L | | | 21 - 35 |
| | CEM II/B-M(V-S) | 21-35 | | |

The manufacturing of Ordinary Portland Cement (OPC), CEM I cannot be completely phased out of production due to its specialized properties for use in construction segment. Although its production is associated with high $CO_2$ emissions, the manufacturers need to find other alternatives to decarbonize the manufacturing processes apart from utilization of SCMs as are not applicable in CEM I production or are in use as < 5%. Table 3 indicates the types of cements as produced by manufacturers on blending operations, meanwhile Table 4 indicates potential $CO_2$ reduction related to cement type based on minimum end of clinker utilization.

Table 3. Cement types supplied by manufacturers of cement from blending operations

| **Integrated cement plant: Manufacturer** | **Cement type being manufactured** | **% Supplementary Cementitious Material on clinker substitution** | |
|---|---|---|---|
| | | **Fly Ash(V)** | **GGBFS (S)** |
| Manufacturer 1 | CEM IV/B-V | 36 - 55 | |
| | CEM IV/A-V | 11-35 | |
| Manufacturer 2 | CEM V /A (S-V) | 18 -35 | |
| | CEM IV/B (V) | 36-55 | |
| Manufacturer 3 | CEM IV/A -V | 11-35 | |
| Manufacturer 4 | CEM V/B (S-V) | 31 - 49 | |

Table 4. Potential $CO_2$ reduction per cement type on the minimum end of clinker utilization as per SANS 50197-1 2013

| **Cement type** | **% clinker composition at minimum level as per SANS 50197-1 2013** | **% SCMs composition as per SANS 50197-1 2013** | **% reduction in $CO_2$ emission** |
|---|---|---|---|
| CEM I | 95.00 | 5.00 | 5.00 |
| CEM II/A | 80.00 | 20.00 | 20.00 |
| CEM II/B | 65.00 | 35.00 | 35.00 |
| CEM III/A | 35.00 | 65.00 | 65.00 |
| CEM IV/A | 65.00 | 35.00 | 35.00 |
| CEM IV/B | 45.00 | 55.00 | 55.00 |
| CEM V/A | 40.00 | 60.00 | 60.00 |
| CEMV/B | 20.00 | 80.00 | 80.00 |

| **Other Statistics** | | | |
|---|---|---|---|
| Average | 55.63 | 44.38 | 44.38 |
| Standard Deviation | 24.99 | 24.99 | 24.99 |

NB: 1 ton of clinker utilization for cement production is associated with 0.9ton $CO_2$ emission
$X_{\text{Amount of CO2 @ \% clinker use}}$ =(% clinker composition0.9 Ton $CO_2$)/1 Ton clinker
$CO_2$ reduction (%) = ((0.9 ton $CO_2$ X)/0.9 ton $CO_2$)100
For CEM I production at 95% clinker and 5% SCMs:
$X_{\text{Amount of CO2 @ \% clinker use}}$ =(0.95 0.9 Ton $CO_2$)/1 Ton clinker
$X_{\text{Amount of CO2 @ \% clinker use}}$ = 0.855ton
$CO_2$ reduction (%)= ((0.9 ton $CO_2$ 0.855)/0.9 ton $CO_2$) 100
$CO_2$ reduction = 5%
Similar procedure was followed for other cement types for calculation of $CO_2$ reduction.

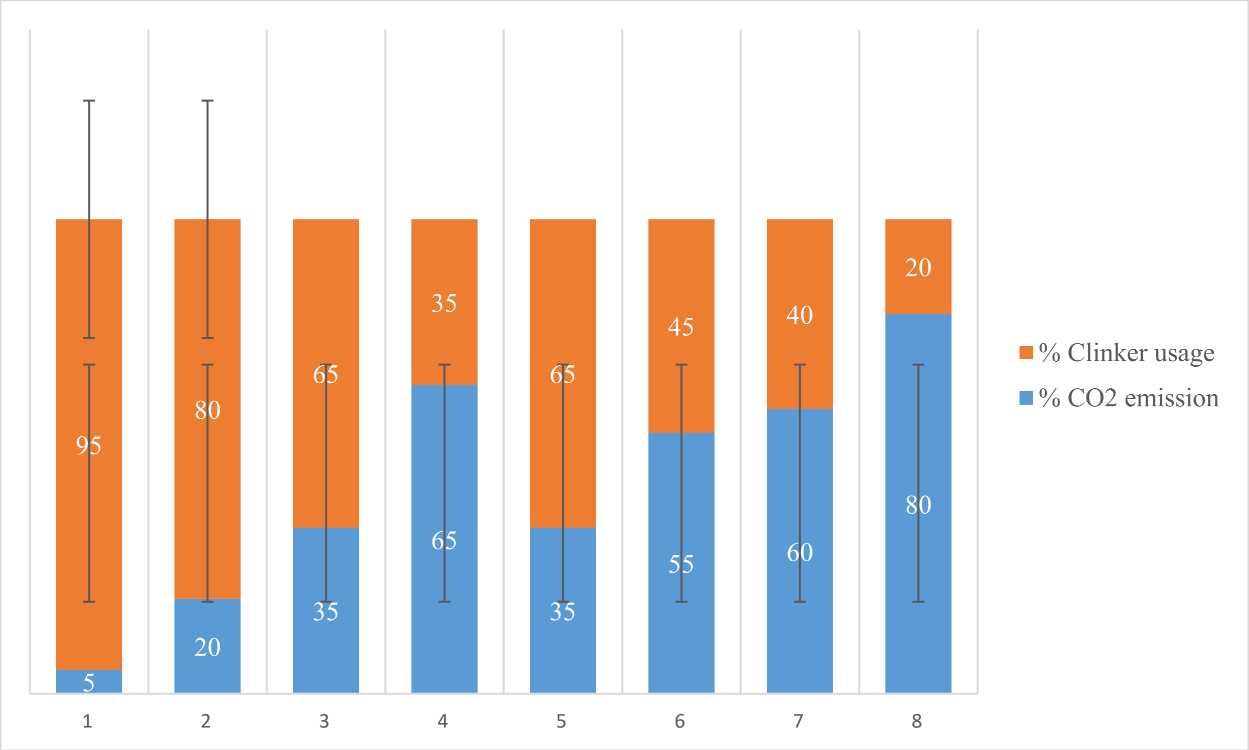


Figure 7. Relationship between minimum clinker substitution with SCM and $CO_2$ emission

Figure 7 graphically represents the findings as outlined on Table 4. It can be noted that the higher percentage substitution of clinker through SCMs during cement manufacturing, was associated with reduction of $CO_2$ and vice versa as shown by Table 5 and Figure 8 which represents the maximum clinker substitution. In the case of lower clinker usage as outlined on Table 4, it was noted that it subsequently resulted with reduced $CO_2$ emission at the same SCMs per-centage utilization. CEM I at clinker usage of 95% only reduces $CO_2$ emission by 5%, whereby the high supplementary cementitious materials extended cement, CEM V/B utilize 20% clinker and reduce $CO_2$ by 80% on the production line.

Table 5. Potential $CO_2$ reduction per cement type on the maximum end of clinker utilization as per SANS 50197-1 2013

| **Cement type** | **% clinker composition at minimum level as per SANS 50197-1 2013** | **% SCMs composition as per SANS 50197-1 2013** | **% reduction in $CO_2$ emission** |
|---|---|---|---|

| | | | |
|---|---|---|---|
| CEM I | 100.00 | 0.00 | 0.00 |
| CEM II/A | 94.00 | 6.00 | 6.00 |
| CEM II/B | 79.00 | 21.00 | 21.00 |
| CEM III/A | 64.00 | 36.00 | 36.00 |
| CEM IV/A | 89.00 | 19.00 | 19.00 |
| CEM IV/B | 64.00 | 36.00 | 36.00 |
| CEM V/A | 64.00 | 36.00 | 36.00 |
| CEMV/B | 38.00 | 62.00 | 62.00 |
| **Other statistics** | | | |
| Average | 74.00 | 27.00 | 27.00 |
| Standard Deviation | 20.43 | 19.78 | 19.78 |

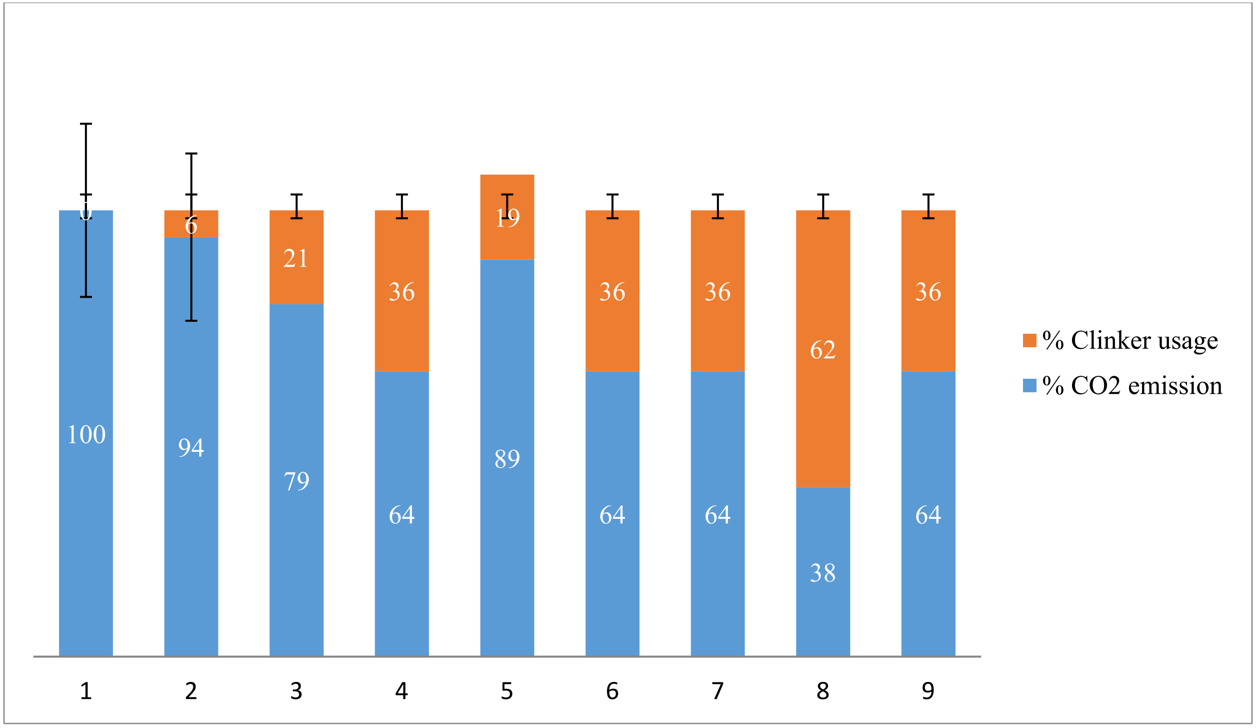


Figure 8. Relationship between maximum clinker substitution with SCM and $CO_2$ emission

Figure 8 and Table 5 represents the maximum utilization of SCMs on the cement types available in South Africa, thus reducing the utilization of clinker which subsequently result with lower $CO_2$ emissions per type of cement being manufactured. Increase in usage of SCMs for cement types being manufactured, from CEM II/A to CEM V/B resulted with reduced $CO_2$ emission in the same quantity. That is, a percentage $CO_2$ emission reduction of 6 and 62 with respect to CEM II/A and CEM V/B cement type at clinker utilization of 94% and 38% respectively. Furthermore, $CO_2$ emissions is reduced by 27.00% on average based on the total cement types being manufactured as less clinker is used, this is further correlated by the achieved standard deviation of 19.78 which indicated less variability of each data point from the mean.

## 6. Recommendations

It was noted that SCMs can be utilized as strategic raw materials for manufacturing of cement, however, they can be used to a certain threshold, leaving behind the need for the cement industry to explore other strategic manufacturing means for $CO_2$ emission reduction. Furthermore, the introduction of South African National Standard (SANS) 50197-5: 2023 for manufacturing of Portland-composite cement CEMII/C-M and composite cement VI can assist with further reduction of $CO_2$ emitted per clinker. This is because SANS 50197-5 2023 further recommends the use of SCMs to produce the composites cement types. The benefits of manufacturing these cement types are due to potentially offer further usage of lowest clinker of 50% and 35% for CEM II/C-M and CEM VI manufacturing respectively.

Evaluation of other cement manufacturing process technologies such as decarbonization of heat required for calcination of limestone and carbon capture storage and utilization are still required to further reduce carbon dioxide emission per ton of clinker produced. Furthermore, Limestone Calcined Clay Cement is a cement type that is gaining traction within South African context due to its potential to offer acceptable performance with respect to quality and reduced $CO_2$ emission. This type of cement has a potential of being produced at lower clinker usage, lower temperature requirement on calcination of limestone which is about 800℃ relative to 1450℃ for clinker production. However, various quality clay deposits need to be identified, evaluated for lifespan so the sustainability of this option can be quantified to attract the investment. The implementation of these strategic projects to re-engineer the existing plants has a potential of improving employment rate in South Africa which was at 32.9% in the fourth quarter of 2023 as reported by Statistics South Africa (2023).

## 7. Conclusion

Based on the conducted cement supplier market assessment in South Africa, the transition of $CO_2$ emission reduction through utilization of Supplementary Cementitious Materials was being fairly achieved. Though the percentage clinker substitution with SCM is of a certain threshold as per SANS 50197-1 as it affects the properties of cement being produced. There was a relationship between per-centage SCM usage for reducing clinker usage and $CO_2$ emission. The relationship was based on what was known that 1 ton clinker production produces 0.9 ton $CO_2$, thus per-centage amount of SCMs composition resulted with the same per-centage in $CO_2$ emission reduction. The percentage clinker substitution with SCMs was as high as within a limit of 36% and 55% which reduced the $CO_2$ emission between 0.576 ton and 0.405 ton respectively. Most manufacturers with integrated plants had cement types ranging from Portland composite cements (CEM II) to composite cements (CEM V), thus indicated the manufacturers' commitment to reduce $CO_2$ emissions. The third party cement blenders are reliant on SCMs in order to manufacture eco-blended cement , thus contributing to lower $CO_2$ emission in the cement value chain.

Conclusion was also drawn that other consumers of cement produced with the supplementary cementitious materials, benefit in their final products quality improvements such as increased durability and strength, reduced alkali-silica reactions and sulfate attack meanwhile reducing $CO_2$ emission during production.

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## Biographies

**Asser L. Tau** is currently a Doctor of Philosophy (PhD) candidate in Operations Management at Department of Quality and Operations Management within the Faculty of Engineering and the Built Environment, University of Johannesburg, South Africa. He earned a Bachelor of Technology (B.Tech) Degree in Chemical Engineering; Advanced Diploma and Postgraduate Diploma in Operations Management with all these qualifications obtained from Vaal University of Technology, South Africa. He also earned a Master’s Degree in Operations Management (Cum laude) from University of Johannesburg and Postgraduate Diploma in Business Administration from Wits Business School. He further obtained a Master of Engineering in Chemical Engineering from Tshwane University of Technology, South Africa. He has over eight years working experience in the Building and Construction materials industry with specific experience in Research & Development, process engineering, and technical sales. He is a registered Candidate Professional Engineering Technologist (Pr Tech Eng) with Engineering Council of South Africa (ECSA). He is also a member for South African Coal Ash Association (SACAA). His research interests include continuous improvement, simulation modeling, energy power generation, industrial solids and liquid waste beneficiation, Life-Cycle Analysis, digitilitization for smart factory design, wastewater treatment and process & environmental engineering.

**Edoun E.I** is an academic, he holds a PhD from the University of Witwatersrand in Johannesburg South Africa. He has travelled widely between different countries in Africa while interacting with academic institutions, policy makers, policy implementers and community members. He is industrious and has good conceptual and organizational skills. He has consulted and spearheaded projects at the African Union, NEPAD , the Pan African Parliament ; AFRODAD.

He has been involved as an academic at various University is South Africa and abroad. He has supervised more than 20 PhD Students, 30 full master's and 100 MBAs students . He has attended many conferences, locally and abroad, and has published many articles in the International accredited Journals.

**Charles Mbohwa** Professor Charles Mbohwa is a Senior Research Associate at the University of Johannesburg. He was, previously the University of Zimbabwe Pro-Vice Chancellor responsible for Strategic Partnerships and Industrialisation from 1st July 2019 up to 30th June 2022. Before that he was a professor of sustainability engineering in the Faculty of Engineering and the Built Environment at the University of Johannesburg. He was a mechanical engineer in the National Railways of Zimbabwe from 1986 to 1991, and lecturer and senior lecturer at the University of Zimbabwe. He was Senior Lecturer, Associate Professor and Full Professor at the University of Johannesburg. He was Chairman and Head of Department of Mechanical Engineering at the University of Zimbabwe from 1994 to 1997; Vice-Dean of Postgraduate Studies Research and Innovation in the Faculty of Engineering and the Built Environment at the University of Johannesburg from July 2014 to June 2017 and Acting Executive Dean in the Faculty of Engineering and the Built Environment from November 2017 to July 2018. He has published very widely. He holds a BSc Honours in Mechanical Engineering from the University of Zimbabwe in 1986; Master of Science in Operations Management and Manufacturing Systems from University of Nottingham; and a Doctor of Engineering from the Tokyo Metropolitan Institute of Technology.

**Anup Pradhan** is an Associate Professor in the Department of Quality and Operations Management at the University of Johannesburg, South Africa. He received BSc in Agricultural Engineering from Bangladesh Agricultural University, Bangladesh, ME in Agricultural Engineering and Systems from Asian Institute of Technology, Thailand, and PhD in Biological and Agricultural Engineering from University of Idaho, USA. His research interests include life cycle assessment, renewable energy, farm mechanization, smart factory, smart grid management, applied research and optimization, organizational productivity, knowledge management. He has published several journal and conference papers. He is a NRF rated researcher in South Africa and a registered engineer with Nepal Engineering Council (NEC). He is a member of American Society of Agricultural and Biological Engineers (ASABE), Engineering Council of South Africa (ECSA), Nepal Engineer's Association (NEA), Gamma Sigma Delta, Golden Key International Honor Society.