Life Cycle Assessment of the Cement Industry in Zimbabwe

Charles Mbohwa[1], Sibusiso Moyo[2]
[1]University of Johannesburg, Johannesburg, Gauteng, South Africa,
[2]University of Zimbabwe, Harare, Zimbabwe

Abstract

This paper generates data that can be used to quantify total life cycle environmental impacts of cement production in Zimbabwe. Emissions of carbon dioxide, sulphur dioxide, nitrous oxides and solid waste occur. These have adverse effects on climate, global warming flora, fauna, water bodies and humans. Quantifying these within a life cycle assessment framework at a local level provides data that can be used in other environmental impact assessment activities, where cement industries operate. A number of environmental metrics were obtained for the cement factories in Zimbabwe and form a basis for future work covering all cement plants.

Key Words:

Life Cycle Inventory; cement industry; LCA.

1 INTRODUCTION

There has been a lot of interest shown by manufacturing companies, organisations and individuals in protecting the environment as evidenced by the number of environmental management systems and techniques that have been developed. The cement industry contributes to environmental degradation, especially during manufacture where a lot of harmful gases and dust are discharged to the environment and these discharges have negative impacts on the environment. In addition, there is a depletion of natural resources and use of energy. It is therefore necessary to carry out a study on these impacts and how they affect the environment. There are three cement companies in Zimbabwe and these are; Pretoria Portland Cement Zimbabwe based in Bulawayo, Circle Cement Limited based in Harare and Sino-Zimbabwe Cement Company based in Gweru. The aim of this paper is to discuss the use Life Cycle Assessment (LCA) to analyse the environmental impacts associated with the Cement industry in Zimbabwe, with Circle Cement Limited as the main case study. Other aims were to:

- Identify the environmental impacts associated with the production of cement and bring them into perspective.
- Provide information that will assist in defining key environmental issues throughout the life cycle of cement.
- Provide information on the wastes produced by the cement industry in Zimbabwe and energy expended in the process.
- Analyse the contribution of each stage of production to the total environmental load.

The reason for preferring LCA to other forms of environmental management systems and techniques is the fact that LCA considers environmental impacts from all possible sources at all stages of production, that is from the extraction of raw materials, manufacture, service life and demolition and brings the different environmental impacts into perspective. Information on how to conduct LCA studies is widely available. [1], [2], [3], [4]. The process starts with a goal and scope definition, which indicates the objectives of the study and sets the system boundaries. This is followed by inventory analysis, which involves data collection, analysis and quantification of system inputs and outputs. The next phase, life cycle inventory analysis evaluates the environmental impacts associated with the inputs and outputs and finally life cycle interpretation and improvement analysis to consider the soundness and robustness of the analysis done. Such LCA studies and equivalent environmental impacts assessments have been done in the cement industry in Japan, [5], Europe [6], in the Americas and in Africa. These provided useful information on identifying opportunities for improvement based on these experiences. It helped to make decisions on system boundary, environmental improvement alternatives and for benchmarking purposes.

2 METHOD

The five steps, stages or phases involved in LCA discussed above were used. These were used as follows:

2.1 Goal and scope definition

The study was based on the production of one tonne of cement as the functional unit. The system boundary, which defines the limits of the product system by defining the unit process to be included, covered the stages from the extraction of raw materials up to the production of the cement powder which is ready for packaging or for bulk transportation.

2.2 Life Cycle Inventory Analysis, Life Cycle Impact Assessment, Interpretation and Improvement Analysis

The Life Cycle Inventory was concerned with data collection and calculation procedures to quantify relative inputs and outputs of a cement product system. A systems inventory of inputs and outputs of energy, materials and emissions directly attributable to the manufacturing and functioning cement throughout its life cycle was considered. [2], [7] Life cycle interpretation considered, the appropriateness of the functional unit, examined the system boundaries chosen and looked at the data quality and system analysis. The study focused on four unit processes, which are Raw Milling, Raw meal blending, Pyroprocessing and Cement Milling. The diagram of the System Boundary is as follows:

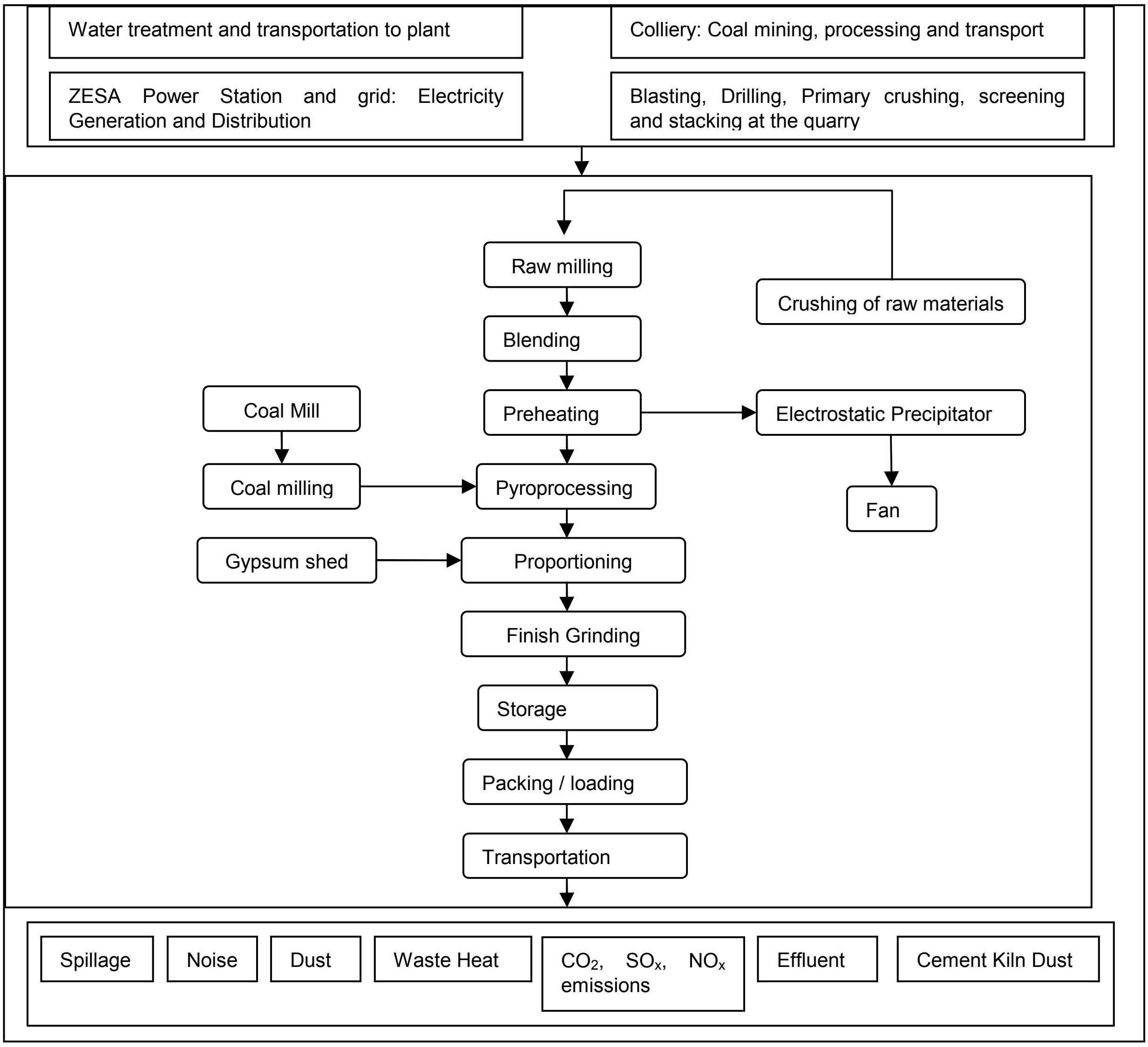


Figure 1: The system boundary chosen for the cement industry

Planned visits were made to the cement plant in Harare to collect primary data from the company's records. Structured and semi-structured interviews were conducted. The data collected were analysed separately and then fed as required into the SIMAPRO 7.0 software for a more structured assessment.

3 FINDINGS AND RESULTS

Cement production starts off with raw material and acquisition. Limestone is mined in a quarry where explosives, drilling machines, crushers and transporting dump trucks. At the plant, Limestone (75%-80%), Silica <23%, Iron ore <5% and Alumina <5% are mixed and crushed, stacked and stockpiled ready for use. It was observed that while all the three cement producers in Zimbabwe had managed to implement environmental management systems according to ISO 14001 requirements, a life cycle perspective and environmental data collection systems were not very strong. The data and information from this study has therefore provided useful management decision making tools.

3.1 Inventory Analysis

The electricity use was considered in various operations within the cement plant and the percentage of power used in the different parts of the plant is shown in Table 1. Finish grinding, raw milling and grinding and pyroprocessing were identified as the major consumers of electricity. Many other processes which consumed much less were not considered for this paper. The material inputs, energy outputs and emissions to air and water per tonne of raw meal produced are as indicated in Table 2. The same data was difficult to obtain for raw meal blending. The inventories for pyroprocessing, which involves precalcination and clinker production are shown in Table 3. Clinker is a compound composed of 50-70% tricalcium silicate, 15-30% dicalcium silicate, 5-10% tricalcium aluminate and 5-15% tetracalcium aluminoferrite.

Phase or stage	% of Total
Raw milling/grinding	24
Pyroprocessing	22
Finish grinding	38
Homogenisation	6
Packaging,	5
Crushing and preheating	5

Table 1: Electricity use in cement plant

Material Inputs		**Energy Inputs**	
Limestone	800kg	Electricity	25680kWh
Silica	100kg	Coal	500kg
Alumina	50kg		
Ferric oxide	50kg		
Emission to air		**Emission to water**	
Noise	95dB	Phosphate	3g
Waste heat	100KJ	Oils	7.5g
NO_2	150g	Solids	100g
CO_2	100g	Grease	7.5g
SO_2	30g	Chloride	400g
Methane	50mg	BOD	150g
Waste/Spills	500kg	COD	100g
		Ammonia	1.5mg

Table 2: Inputs and outputs for one tonne of raw meal

Material Inputs		**Energy Inputs**	
Raw Meal	1500kg	Electricity	23540kWh
		Coal	500kg
Emission to air		**Emission to water**	
Noise	90dB	Phosphate	3mg
Waste heat	100KJ	Oils	7.5g
NO_2	180g	Solids	2g
CO_2	130g	Grease	7.5mg
SO_x	40g	Chloride	400mg
Methane	300mg	BOD	200g
Coal dust	120g	COD	400g
Dust	120mg	Ammonia	1.5mg
Chloride	400g	Sulphate	100mg
CO	300mg	Fecal	1500mg

Table 3: Inputs and outputs for one tonne of clinker

The cement milling using ball mills processes well proportioned and mixed clinker and gypsum to produce the final product. The inputs and outputs for the production of one tonne of cement were found to be as shown in Table 4.

Material Inputs		**Energy Inputs**	
Clinker	1425kg	Electricity	40660 kWh
Gypsum	75kg		
Emission to air		**Emission to water**	
Noise	90dB	Phosphate	5g
Waste heat	10KJ	Oils	5g
NO_x	100g	Sulphate	70g
CO_2	90g	Chloride	400g
SO_x	30g	BOD	100g
Dust	120g	COD	100g
		Ammonia	100g

Table 4: Inputs and outputs for one tonne of cement

After these cleaner production assessment types of results, data was input into SIMAPRO software using Eco-indicator 99 to obtain the inventory results shown in Table 5. These compare well with the cleaner production assessment results in the earlier tables.

Substance	Area	Unit	Total	Cem.	Clk.
Coal	Raw	kg	855	X	855
Diesel	Air	l	285	X	285
Electricity	Air	GJ	12.7	X	12.7
CO_2	Air	kg	446	90	356
CO		kg	88.4	20	68.4
Coal dust		kg	171	X	171
Dust	Air	kg	321	150	171
Heat waste	Air	kJ	153	10	143
Methane	Air	kg	513	X	513
NO_2	Air	kg	673	160	513
Noise	Air	dB	362	80	282
SO_2	Air	kg	138	30	108
Ammonia	Water	kg	6.42	1	5.42
BOD	Water	kg	143	X	143
Chloride	Water	kg	992	302	690
COD	Water	cm3	570	X	570
Fecal	Water	l	2.14	X	2.14
Grease	Water	kg	23.5	X	23.5
Oils	Water	kg	28.5	5	23.5
Phosphate	Water	kg	14.4	5	9.4
Solids	Water	kg	3.42	X	3.42
Sulphate	Water	kg	213	70	143
Suspended	Water	kg	143	X	143

Key: Cem.- Cement; Clk.- Clinker

Table 5: SIMAPRO results for one tonne of product

3.2 Life Cycle Impact Assessment

This involved characterisation, classification and assessment of the potential environmental impacts of the different categories like energy use, resource depletion and pollution of soils, water and air. It also involves normalization, ranking, grouping and weighting. [8] This study used SimaPro Version 7.0 for the analysis of the results. The characterisation results show that the important categories in the cement industry are respiratory organics and inorganics, climate change, acidification/ eutrophication and the use of fossil fuels.

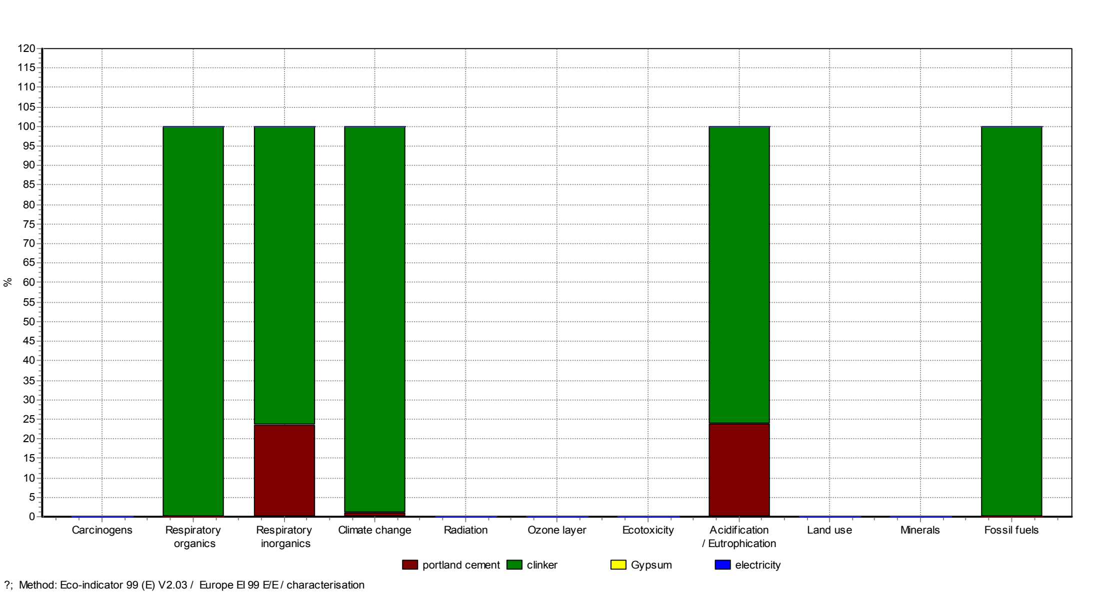


Figure 2: The characterisation of the environmental impacts using SIMAPRO Eco-indicator 99

Abiotic resource depletion included the use of fuel during transportation of raw meal and consumption of limestone and clay during preparation of raw meal. Energy depletion is mainly from electricity and coal used during the cement production processes. Emission from energy production and use contributes to global warming particularly from carbon dioxide.

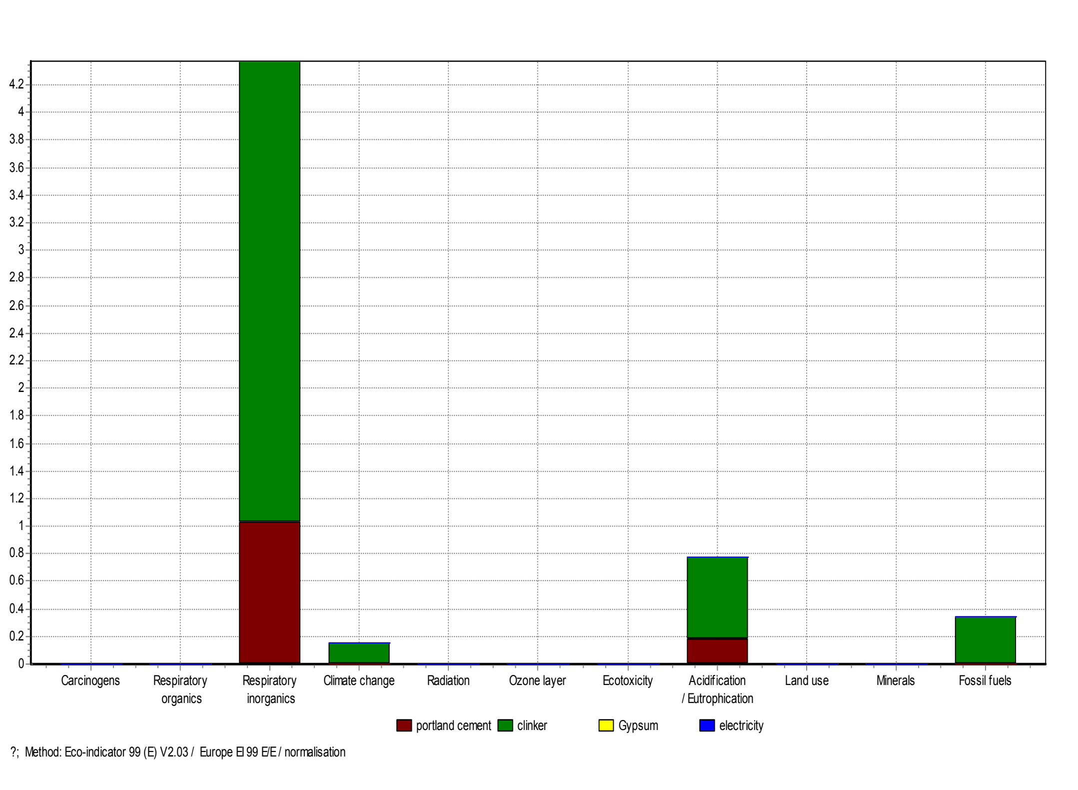
The cement kiln dust produced is harmful to humans and causes respiratory problems and diseases. Dust from the coal mill and the raw meal silos are equally liable. The cement kiln dust is also harmful to plants. Once it settles on the leaves, it deprives them of photosynthesis. Spillage from the cement mill, the kiln and from the raw mill and raw mill silos cover the land and when it comes into contact with water hardens, preventing vegetation and disturbing the ecosystem.

Summer smog can be caused by volatile organic compounds and nitrogen oxides from the diesel trucks transporting raw meal, inputs and outputs in cement production. Winter smog can be caused by sulphur oxides and particulate matter (dust) from fuels such as diesel and from coal used for firing the kiln.

The water for cooling the mills is contaminated by oils and spills are common contaminating the water systems. The effluent from the plant is discharged into aquatic bodies, causing aquatic acidification, caused mainly by the nitrate and sulphate compounds. Air acidification also results from nitrogen oxides and sulphur oxides emitted during the transportation of raw meal to the kiln and from burning coal in the kiln. The effluent created from cooling water also contributes to eutrophication due to the phosphate and nitrate compounds present in the effluent.

Noise is generated by the heavy diesel trucks that carry raw materials and products, by the cement mill during finish grinding, by the raw mill during raw grinding and by the kiln during pyroprocessing of raw meal to produce clinker. A lot of noise is also generated during the blending of raw meal.

The normalisation results are presented in Figure 3, to enable comparisons across the different impact categories. Clinkering is found to contribute most of the respiratory inorganics as well as the cement production process. Respiratory inorganics dominate the environmental impacts followed by acidification and eutrophication. The other significant impacts are from the use of fossil fuels that contribute to climate change.



4 INTEPRETAION AND CONCLUSIONS

The results of the study revealed that the production of raw meal and Pyroprocessing produce the most impacts due to significant inventories of cement kiln dust and electricity used in different stages of cement production. The finish grinding section consumed more electrical energy than all the other stages. Respiratory inorganics produced mainly from cement kiln dust were found to have the highest potential damage to health.

This study has confirmed cleaner production assessment results which were presented in the paper showing that clinker production has the most impact on the environment followed by the cement milling, the final stage of cement production. Environmental improvements can be focused in these two areas to get the most benefit. More studies need to be carried out and more work needs to be done if the cement industry is to benefit fully from LCA. Some data not yet available was replaced by assumed values in the software used. The LCA methodology was found to offer useful results for management decision making in environmental management and cleaner production. In future it may be of benefit to include Life Cycle Costing to evaluate the financial burdens associated with damage to the environment and social auditing in order to address the full spectrum of sustainability issues and graduate to life cycle management.

5 REFERNCES

[1] ISO (1997), Environmental Management – Life Cycle Assessment – Principles and Framework, ISO 14040, International Organisation for Standardisation, Geneva

[2] ISO (1998), Environmental Management – Life Cycle Assessment – Goal and Scope Definition and Inventory Analysis, ISO 14041, International Organisation for Standardisation, Geneva

[3] ISO (2000a), Environmental Management – Life Cycle Assessment – Life Cycle Impact Assessment, ISO 14042, International Organisation for Standardisation, Geneva

[4] ISO (2000b), Environmental Management – Life Cycle Assessment – Life Cycle Interpretation, ISO 14043, International Organisation for Standardisation, Geneva

[5] Taiheiyo Cement, 2007, Corporate Sustainability Report 2007,http://www.taiheiyo-cement.co.jp/english/csr/pdf/2005/csr_english.pdf, last accessed on 14th November 2007.

[6] Cembureau, 1999, Environmental Benefits of Using Alternative Fuels in Cement Production in Cement Production: A Life Cycle Approach.

[7] Nisbet .M and M.van Geem, 1997, Environmental LCI of Portland Cement and Concrete, The Journal of World Cement.

[8] Goedkoop .M and M. Oele, 2000, Sima Pro 6: Introduction to LCA with Sima Pro, PRé Consultants, Holland