

**LIFE CYCLE ASSESSMENT (LCA) ANALYSIS
TOWARDS A SUSTAINABLE CEMENT INDUSTRY
FOR SRI LANKA : AN ANALYSIS OF THREE
PROCESS PATHWAYS**

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(08/8030)

Degree of Master of Science

Department of Chemical and Process Engineering

University of Moratuwa

Sri Lanka

October 2011

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Thesis submitted in partial fulfillment of the requirements for the degree
Master of Science with major component of research

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“Consumers are increasingly interested in the world behind the product they buy. Life cycle thinking implies that everyone in the whole chain of a product’s life cycle, from cradle to grave, has a responsibility and a role to play, taking into account all the relevant external effects. The impacts of all life cycle stages need to be considered comprehensively when taking informed decisions on production and consumption patterns, policies and management strategies.”

Klaus Toepfer, Former Executive Director, UNEP

Declaration of the candidate & supervisor

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Signature of the Supervisor (Prof Ajith de Alwis)

Date

Abstract

Cement has already become an essential commodity which contributes for global development which also contributes globally ~5% of man-made CO₂ as an adverse environmental impact, during its production phase. Cement manufacturers have already implemented programs aiming to reduce their GHG footprint introducing clinker substituted cement types, utilizing alternative fuels and optimizing the cement manufacturing process. LCA is a tool which can be used to quantify & assess the environmental impacts for a selected scope. Study covers a detail LCA study on different cement manufacturing scenarios selecting GHG emission as the main impact category for a local integrated cement manufacturing facility.

As the scope of the LCA 'cradle to gate' approach was selected and functional unit defined as 'one tonne of cementitious material' in order to compare with different clinker percentage cement types. Holcim (Lanka) Ltd – Puttalam Cement Works was selected for the study as the only operating integrated cement manufacturing facility in Sri Lanka. For the scope inland transportation GHG contributions were also included as an extended scope item.

An author designed simple LCA tool 'Cement LCA Calculator' was introduced and used to life cycle inventorying and analyzing process. This tool is compatible with the cement CO₂ protocol published by the WBCSD (World Business Council for Sustainable Development) aligned with GRI (Global Reporting Initiative) & International Panel for Climate Change (IPCC) guidelines.

LCA analysis was categorized into two process units. More than 90% of GHG generated inside the facility due to calcination and kiln fuel combustion in the baseline scenario where no alternative fuels being used. In year 2007 the thermal substitution rate was 19.9% and average overall clinker factor was 76.5%. Also it has been shown the reduction from 913 to 764 net kgCO₂e/tonne of cementitious material from the baseline year – 2001 to 2007. Reported neutral absolute CO₂ volumes were 39,940 tonnes in year 2007. However a small increase shown in the local transporting area from 0.56 to 1.31 net kgCO₂e/tonne of cementitious material due to increasing alternative fuel transporting activities. The net savings of CO₂ by utilizing waste derived fuels were 3,464 tCO₂e in year 2007 as per the 'Cement LCA Calculator'. Research outcomes also opened a number of LCA based research options as future research areas.

The LCA study has clearly shown the GHG benefits a reduction of 16% by using alternative fuels and clinker substituted products. Both these corporate initiatives are way forward actions towards sustainable cement manufacturing process, which Holcim (Lanka) Ltd is committed by its group strategies. Introduced Cement LCA Calculator can also be used on finding CO₂ minimizing strategies in future cement industry focused ecological improvement studies.

Dedication

To my dearest father

Acknowledgement

I am heartily thankful to my supervisor, Prof Ajith de Alwis, whose encouragement, guidance and support from the initial to the final level enabled me to develop an understanding of the subject.

Further I wish to extend my gratitude to Head and the all the academic staff of Department of Chemical & Process Engineering of University of Moratuwa for the given academic support. Special gratitude goes to Dr Manisha Gunasekara for the given guidance and critical commenting during the reviews. Also acknowledge the support given by Post Graduate Institute staff for supporting me to ease the administrative work. During the research period the support given by PG coordinators Irosha Kularatne, Dinuka Prasanga and Chamila Wickramasinghe are highly appreciated

I highly extend my gratitude to my work place Holcim (Lanka) Ltd for the given extensive support to initiate this research and carry out it with required resources. Support given by my former supervisors Mr George Nicole, Mr Rathika de Silva are highly appreciated on this regard.

Life Cycle Assessment is still not a popular subject in Sri Lankan context. In order to overcome the faced technical and theoretical constraints given cross boundary support by Dr Rudiger Stenger (Head of Environment) and Dominique Bouchi from Holcim Group Support, Switzerland, Dr. Fredy Dinkel (Carbotech AG in Zurich), Dr. Ir. Joost G. Vogtländer (Associate Professor at the Delft University of Technology) and Dr Rita Schenck (American Center for Life Cycle Assessment - ACLCA) are also highly appreciated.

I thank for the support given by Prof Katupotha – Department of Archeological Science – University of Sri Jayawardenapua on studying the limestone deposits and its archeological importance and Mr Sena Pieris and senior staff of National Cleaner Production Center for technical facilitations.

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Abbreviations

Abbreviation	Description
%w/w	Percentage by weight
⁰ C	Degrees Celsius
ABC	Application based cement
AF	Alternative fuels
Al ₂ O ₃	Aluminum oxide
BDP	Best demonstrated performance
BSEN	British Standard European Norm
BSI	British Standard Institute
CaO	Calcium oxide
cem	Cementitious material
CEMs	Continuous emission monitoring systems
CER	Certified emission reductions
CKD	Cement kiln dust
cli	Clinker
CO ₂	Carbon dioxide
COD	Chemical Oxygen demand
CSI	Cement sustainability initiative
EH&S	Environmental, health and safety
EIA	Environmental impact assessment
EP	Electrostatic precipitators
EPL	Environmental protection license
ERP	Enterprise resource planning
Fe ₂ O ₃	Ferric oxide
GDP	Gross domestic product
GHG	Greenhouse gas
GRI	Global reporting initiative
Gt	Gigatonnes
HCl	Hydrogen chloride

HFC	Hydrofluorocarbon
HFO	Heavy furnace oil
HLL	Holcim (Lanka) Ltd
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
K ₂ O	Potassium oxide
kg	Kilogram
kgCO ₂ e	Kilogram carbon dioxide equivalent
KPI	Key performance indicators
kWh	Kilowatt hour
LCA	Life cycle assessment
LCI	Life cycle inventory
LCIA	Life cycle impact assessment
mg/Nm ³	milligram per normal meter cube
MgO	Magnesium oxide
mins	Minutes
MJ	Mega joule
mm	Millimeter
Mn ₂ O ₃	Manganese oxide
MSDS	Material safety data sheet
N	Newton
Na ₂ O	Sodium oxide
NIOSH	National institute for occupational health & safety
NO	Nitric oxide
NO ₂	Nitrogen dioxide
NO _x	Gaseous mixture of NO ₂ and NO
OPC	Ordinary Portland cement
P ₂ O ₅	Phosphorus pentoxide
PCW	Puttalam Cement Works
PEP	Plant environmental performance
PFC	Perfluorocarbon
PLC	Portland limestone cement

PM	Particulate matter (dust)
ppm	Parts per million
s	Seconds
SETAC	Society for Environmental Toxicology and Chemistry
SF ₆	Sulfur hexafluoride
SiO ₂	Silicon dioxide
SLSI	Sri Lanka Standards Institute
SO ₂	Sulfur dioxide
t,ton	Metric ton
tCO ₂ e	Metric ton of carbon dioxide equivalent
TEQ	Toxic equivalent quotient
TiO ₂	Titanium oxide
TSP	Total suspended particles
USEPA	United States Environmental Protection Agency
VOC	Volatile organic compounds
WBCSD	World Business Council for Sustainable Development
WRI	World Resource Initiative
wrt	with respect to
YTD	Year to date

Chapter 1 BACKGROUND AND INTRODUCTION

1.1 Background

Global economic development, rapid industrialization and high population growth resulted in increasing infrastructure growth. Urbanization and city development calls for significant infrastructure development. Concrete becomes the essential component in modern infrastructure development where cement is the main bonding component in concrete. As a rapidly developing country Sri Lanka is also in the trend of boosting up the constructional activities. This resulted cement production also in an increasing trend. Holcim (Lanka) Ltd operates Puttalam Cement Works the only operating integrated cement facility in the country.

1.2 Introduction to the study

The cement demand due to the projected economic development will be at least as forecasted and cement already becomes an essential construction commodity which doesn't have a sustainable alternative so far. The GHG emission generated from cement is identified as a key impact to the environment. Identified non GHG emission impacts are NO_x, SO₂, TSP and minute amount of heavy metals. Noise emissions, fugitive dust issues, biodiversity disturbance due to quarrying and high fuel and material consumption are the other environmental impacts common to cement manufacturing process. However other than GHG emissions most of the cement environmental impacts are site specific.

As a developing country sustaining the local cement industry is a key factor for the national economic development. Aligning to sustainable development concepts, environmental management is a key focused area by large scale industries, in order to sustain and grow by optimum usage of natural resources. Hence quantifying the environmental impacts and take precautionary methods to minimize the impacts is a timely requirement.

There are a number of quantification tools and calculation applications available to evaluate the impacts of the product on environment, starting from process steps,

activities involved to related impacts. Life Cycle Assessment (LCA) is one of the most commonly used tool to descriptively evaluate environmental impacts during manufacturing, product use and disposal / recycle phase. LCA is also a well-accepted methodology in creating quantitative environmental inventories and impact assessments by analyzing and researching environmental impacts of a certain process or series of processes for a selected product or service. It mainly supports on producing an 'ecological balance sheet'. End users who are interested in sustainable production and consumption can make their decision lean towards sustainable products by specifically looking at LCA interpretations.

Holcim (Lanka) Ltd also globally aligned on CO₂ reduction action plans by introducing alternative fuels to its kilns and driving the application based cement concept which drive through introducing clinker substituted new cement types. Continual improvement made on plant process conditions, sustain the preventive maintenance schedules are other key factors which supported GHG reduction actions.

LCA methodology is used to quantitatively research the environmental impacts with respect to GHG emission of Holcim (Lanka) Ltd, Puttalam Cement Works (PCW). Covering three major process scenarios which made significant changes to both product portfolio and the kiln fuel type were selected to compile comparative analysis. In this study baseline scenario was selected as traditional cement production mainly Ordinary Portland Cement (OPC) production using heavy furnace oil as the only kiln fuel.

Study objectives were selected to cover the scientific analysis on GHG monitoring, reporting and impacts due to process changes. Research will support corporate on optimize the usage of GHG reporting and its benefits towards corporate reputation appraisal though eco-centric marketing tools.

1.3 Research objectives

Research was performed in order to achieve the following objectives; considering the importance of sustaining integrated cement industry in Sri Lanka as a major economical supporting factor.

- Perform a full LCA for the cement manufacturing process of, Holcim (Lanka) Ltd, Puttalam Cement Works, Palavi, Puttalam which is the only integrated cement manufacturing facility currently in operation in Sri Lanka. The impact category for the study is climate change and a comparative analysis will perform for three manufacturing scenarios as stated in Table 4-5 selecting the scenario 01 as the baseline study.
- Develop a simple LCA software for the quantitative analysis of the selected impacts for LCI & LCIA phase facilitating the comparative analysis between selected scenarios.
- Quantitatively analyze the impacts of the GHG reduction attempts using LCA as the research methodology
- Develop a separate environmental balance sheet using the LCI data base for the current manufacturing scenario of local cement manufacturing facility – HLL PCW.
- Establish a list of recommendations for the facility on improving the reporting and utilizing of the GHG related data and information on environmental management practices and incorporating research findings in green marketing strategies.

1.4 Thesis structure

This thesis consists of six chapters. An abstract is also given as a summary of full study.

First chapter is an introduction to the research and to set up objectives. The content of ‘background’ and ‘introduction to the study’ covers the information which leads for this study.

Chapter two makes a detailed general description on cement and cement manufacturing process linking to Puttalam Cement Works. Also in this chapter, a brief introduction about Sri Lankan cement industry and the Holcim intervention is included. An identified list of environmental impacts related to cement manufacturing process is presented and discussed in the same chapter.

LCA methodology is introduced in the chapter three. The specific areas of the

defined goal and scope, functional unit and unit processes with the importance and relevance of LCA in cement industry were also discussed. Similarly the concept of 'environmental balance sheet' was introduced.

In the chapter four, the selected research methodology – LCA is discussed in detail with related ISO guidelines. Used CO₂ reporting protocols were also introduced and discussed on the relevance and the applicability to the study especially for the Life Cycle Inventory (LCI) phase. The first phase of LCA under LCI – setting the goal and the scope is also discussed in this chapter. System boundaries and exclusions were also defined as a part.

Chapter five covers 'Results and Discussion'. Life cycle inventory analysis is the most important presentation in this chapter. Material flow analysis and process unit wise GHG emission calculation is a part of the study area. Data collection and analysis is discussed in detail based on the LCI calculations performed using the developed simple LCA tool 'Cement LCA Calculator'. Life Cycle Impact Assessment (LCIA) – the third phase of the LCA is also a part of this chapter which leads the study to the final phase of the LCA interpretation. The results are discussed through category indicators as comparative advantage models. The principal of this chapter is aligned to LCI, LCIA and life cycle interpretation ISO guidelines – ISO 14040 to ISO 14043.

Conclusions are described in chapter six along with recommendations and proposed future work.

Chapter 2 CEMENT INDUSTRY AND ENVIRONMENTAL IMPACTS

2.1 Cement history

Cement is one of the essential commodities in today's world. The history of the cement is also so old. The origin of hydraulic cement goes back to Greece and Roman history.

The first materials used to produce cement were lime and volcanic ash that slowly reacted with it in the presence of water to form a hard mass. This formed the cementing material of the Roman mortars and concretes of 2,000 years ago and of subsequent construction work in Western Europe. Volcanic ash mined near the city of Pozzuoli (now Italy) was particularly rich in essential aluminosilicate minerals, giving rise to the classic pozzolana cement of the Roman era. (Encyclopaedia Britannica, 2010)

The Romans found that cement could be made which set under water and this was used for the construction of harbours. The cement was made by adding crushed volcanic ash to lime and was later called 'pozzolanic' cement, named after the village of Pozzuoli near Vesuvius. In places such as Britain, where volcanic ash was scarce, crushed brick or tile was used instead. The Romans were therefore the first to manipulate the properties of cementitious materials for specific applications and situations. (Understanding-cement, 2010)

With base from ancient practices, Ordinary Portland Cement (OPC) was introduced. In 1824, Joseph Aspdin, a British stone mason, obtained a patent for cement he produced in his kitchen. The inventor heated a mixture of finely ground limestone and clay in his kitchen stove and ground the mixture into a powder create a hydraulic cement-one that hardens with the addition of water. Aspdin named the product 'Portland Cement' because it resembled a stone quarried on the Isle of Portland off the British Coast. With this invention, Aspdin laid the foundation for today's Portland Cement industry. (Portland Cement Association, 2010).

The OPC and other cement types are also improved and made a lot of changes during

short history from 1824. After this revolutionary product introduced, ‘cement’ was developed by looking at different needs of the end user. There are new types of cement introduced to fulfill the different constructional (application) requirements. Most commonly used cement types can be categorized as in Table 2-1.

The below categorization is in accordance to the British Standard European Norm (BS EN) standards which is similar to the American Standard Test Methods (ASTM) product types where only the numbering code is different. Types IA, IIA and IIIA are cements used to make air-entrained concrete. They have the same properties as types I, II, and III, except that they have small quantities of air-entrained materials combined with them. (Concrete Network, 2010). Some other cement types are also available focusing geographical and climatic diversification.

Table 2-1: Main cement types

Cement Type	Characteristics
Type 1	Normal Portland cement. Type 1 is general use cement.
Type 2	Used for structures in water or soil containing moderate amounts of sulfate, or when heat build-up is a concern.
Type 3	High early strength. Used when high strength are desired at very early periods.
Type 4	Low heat Portland cement. Used where the amount and rate of heat generation must be kept to a minimum.
Type 5	Sulfate resistant Portland cement. Used where the water or soil is high in alkali.

2.2 Cement demand

Concrete is an essential commodity in built environment especially in infrastructure development. It is the second most consumed material after water and it shapes the built environment (WBCSD, 2009) which resulted concrete as the mostly seen man made material available in the world. Concrete is a material produced by mixing binder - cement, water and aggregate. Average cement content in concrete is about 15% (WBCSD, 2002).

This demand made cement as one of the most wanted materials in current business

context due to the increasing construction activities and no successful alternative found to replace cement yet. Boosting economies demand a lot on higher developments in infrastructure mainly in the constructional field. Both graphs in Figure 2-1 precisely present the relationship of cement demand for the economic development by plotting GDP against cement demand per capita which USA represents the developed region (in left side graph) and India developing economic scenario (in right side graph). It is almost correlating against the GDP and cement demand.

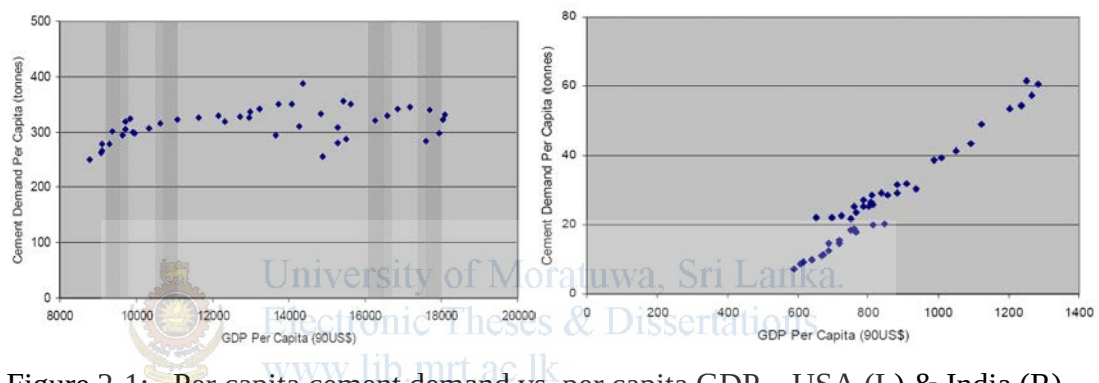


Figure 2-1: Per capita cement demand vs. per capita GDP – USA (L) & India (R)

Source : (WBCSD, 2002)

World demand for cement is forecast to grow 5.3% per year to 3.6 billion metric tonnes in 2012, according to a new study released by ‘The Freedonia Group’ (Cement Americas, 2008). Gains in global cement demand will slow considerably from the 2002-2007 period, which was characterized by double-digit demand increases in China. Since the country accounts for such a large portion of the market — nearly half of global cement demand in 2007 — China is the primary driver of the world cement industry. Product demand in India, the second-largest national market for cement (though far smaller than first-place China), will climb at a increasing rate of any major country. Although comparatively small, cement demand in Indonesia, Malaysia, Nigeria, and Vietnam is expected to record gains of 7% per year or more (Cement Americas, 2008).

Figure 2-2 shows the above relationship and the cement production growth pattern for developed and developing economies separately. Also it indicates the CO₂ release from the cement production. Increasing cement growth in developing

countries significantly contributed to the increased CO₂ volumes. However the cement related CO₂ generated from developed countries had remained at a constant level over the years.

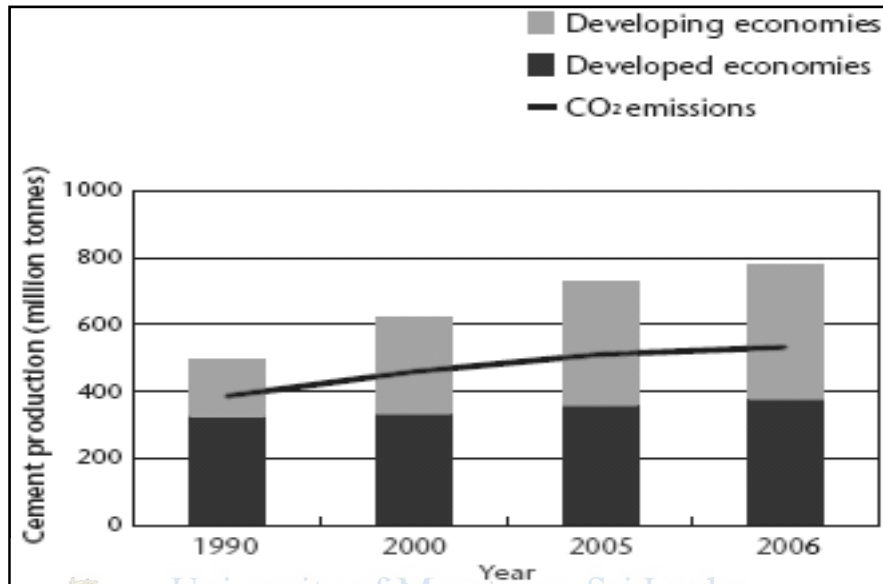


Figure 2-2: Cement production and accompanying CO₂ emissions

Source : (WBCSD, 2008)

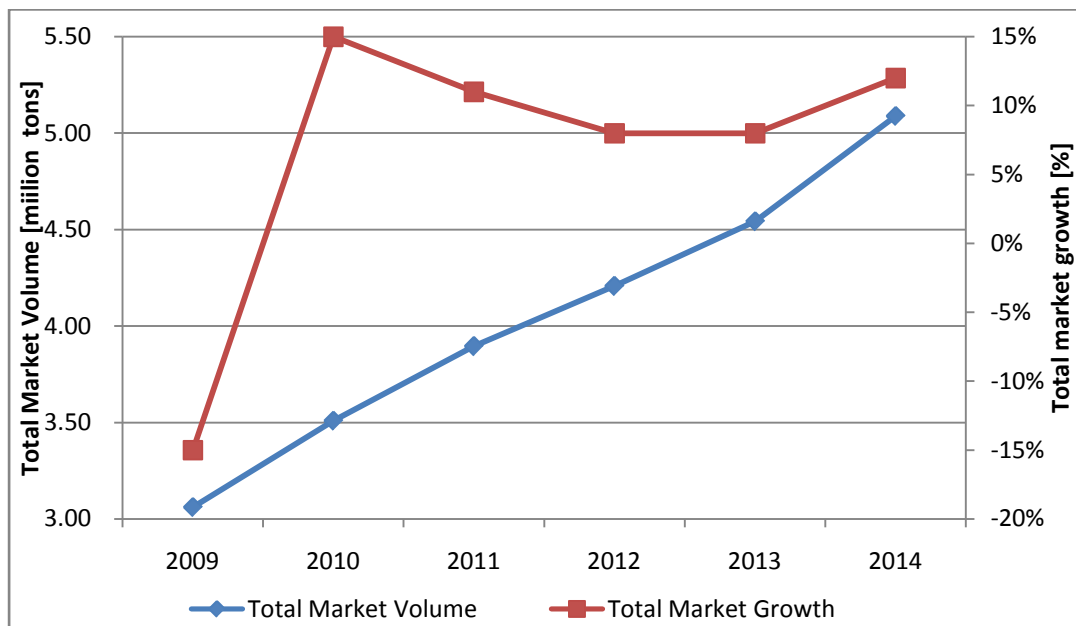


Figure 2-3: Sri Lankan cement demand -market growth & volumes

Source: (HLL internal sources, 2010)

With the post war developments and the rapid construction growth, Sri Lankan

cement demand also in the rapid increasing trend as shown in the Figure 2-3.

Holcim (Lanka) Limited – HLL owns and manages Puttalam Cement Works - PCW in Palavi, Puttalam the only integrated cement manufacturing facility which currently operates in Sri Lanka.

2.3 Cement chemistry

Cement is a hydraulic powder material, which reacts with water to produce strength-bearing lattices. The mixture of aggregates, cement and water is concrete. The strength and durability of concrete makes it one of the most useful materials developed by man.

The chemistry and mineralogy of cement is complex. In simple terms, cement is a manmade mineral structure created at high temperatures, mainly comprising lime (CaO), silica (SiO₂) and oxides of aluminium - Al₂O₃ and oxides of iron - Fe₂O₃. (WBCSD-CSI, 2010)

Cement clinker the intermediate product of cement is defined as ‘a hydraulic material which shall consist of at least two-thirds by mass of calcium silicates (3CaO.SiO₂ and 2CaO.SiO₂), the remainder consisting of aluminium- and iron-containing clinker phases and other compounds. The ratio of CaO to SiO₂ shall not be less than 2.0. The magnesium content (MgO) shall not exceed 5.0% by mass’ (European Committee for Standardization, 2000).

Main clinker minerals are alite, belite, aluminate and ferrite. Proportions vary depending on ‘raw meal’ composition and firing and contribute to defining the hydration and strength development properties of the cement product.

Table 2-2: Main clinker minerals and chemistry

Mineral	Main constituent	Minor constituent
Alite	C ₃ S - 3CaO.SiO ₂	Al ₂ O ₃ , MgO, P ₂ O ₅ , Fe ₂ O ₃ , Na ₂ O, K ₂ O
Belite	C ₂ S - 2CaO.SiO ₂	MgO, P ₂ O ₅ , Fe ₂ O ₃ , Na ₂ O, K ₂ O, Al ₂ O ₃
Aluminate	C ₃ A - 3CaO.Al ₂ O ₃	Fe ₂ O ₃ , SiO ₂ , MgO, Na ₂ O, K ₂ O
Ferrite	C ₄ AF- 4CaO.Al ₂ O ₃ .Fe ₂ O ₃	SiO ₂ , MgO, TiO ₂ , Mn ₂ O ₃ .

The hydraulic property of cement originates from its cement minerals (calcium silicates). The major components in terms of metal oxides are CaO , SiO_2 , Al_2O_3 , and Fe_2O_3 . In order to provide a suitable chemical composition for sintering, raw materials are either quarried or collected from other industrial processes for the cement manufacturing process. Typically, Calcium (Ca) is provided from limestone, Silicon (Si) from sand or flyash, Aluminum (Al) from flyash or clay, and Iron (Fe) from iron ore, laterite or slag.

2.3.1 Cement kilns

There are two major cement (clinker) kiln types which are known as wet and dry kilns. Dry kilns are further categorized as long dry, preheater, or precalciner kilns. On the whole, wet kilns tend to produce more tons of cement (or clinker) but also require more energy than dry process kilns. (Battye, Hou, & Nelson, 2009)

There is a clear shift of dry, preheater kiln technology replacing less efficient wet kilns over the past 16 years so that today more than half of the clinker from Cement Sustainability Initiative (CSI) members is made with this modern technology considering the fuel efficiency and emission related issues. Annexure II describes the two types of kilns in more detail manner. The selected cement plant for this study – HLL – PCW operates two pre-heater type dry kilns which was installed and commissioned in early 1970's.

2.4 Sri Lankan cement industry

The beginning of Sri Lankan cement industry runs to early 1950's and the establishment of Kankasanthurai Cement Factory in 1950 is the first cement factory which started operation in Sri Lanka. Ceylon Cement Corporation formed in 1959 and there onwards it took the ownership of managing, expanding and developing Sri Lankan cement industry. The expansions of this factory were completed in 1960 after commissioning the stage 2. Ruhunu Cement Plant – a grinding and packing terminal been in commercial production since 1967 and clinker was supplied by Kankasanthurai plant via rail transport.

Puttalam Cement Plant (PCW) was established and commissioned in 1971 with two

short kilns with pre-heater type in 1971 and at that time the annual cement production capacity was 725,000 tons. PCW operated its limestone quarry at: Aruwakkalu, near Wanathawilluwa (47 kilometers away from the PCW) and explores limestone 15 to 18m from earth surface. In mid 1993 with the government decision of privatizing, PCW was firstly taken by a Pakistanian firm which was not financially succeeded. By the end of 1990's Switzerland based Holcim Group (Holderbank on those days) acquired the PCW with all the staff and continuing the management.

Holcim is the world largest cement manufacturer present in 82 countries and produces 150 million t of cement annually. (Holcim, 2008). Being the market leader in the cement industry, HLL focuses on economic, social and environmental performance along the triple bottom line of sustainable development. The company currently operates one fully integrated cement plant in Puttalam, while also operating a grinding plant in Galle. A new packing unit is planned for Trincomalee, for better customer focus and coverage (HLL, 2009).

Holcim Lanka sold approximately 1.23 million tonnes of cement in year 2008. The company operates in all 9 regions of Sri Lanka with cement & services, creating approximately 15,000 (direct & indirect) employment opportunities. Holcim Lanka generated annual revenues of approximately LKR 14.9 billion (137 million USD) in 2008 (HLL, 2009).

HLL is also committed to implement solutions to reduce its GHG footprint and other environmental impacts aligning with the Holcim Group strategies. HLL also started using AF (alternative fuels) in its cement kilns with a national level solution for industrial waste. Initiatives were also taken to introduce clinker substituted material by promoting the application based cement concept to Sri Lanka for the first time. Both these initiatives supported the company strategies on reducing the GHG footprint and conservation of natural resources.

2.4.1 Sri Lankan limestone deposits

Sri Lankan limestone deposits are well spread from Puttalam, Jafna to Mulathivu cities over the coastal belt. This limestone region is commonly named as Jafna

limestone region in most of the research publications.

- Structure

The Jafna Limestone is flat-bedded over nearly all the area in which it occurs but in places a slight dip to the West may be observed. It is generally on surface level or a little below it. Kolonkanatte (6 miles South of Kudiramalai) it forms cliffs about 50 feet high (Cooray, 1984). Aruwakkalu limestone quarry which is the primary raw material sources for Sri Lankan cement industry (for Puttalam Cement Works) is also a part of the above area.

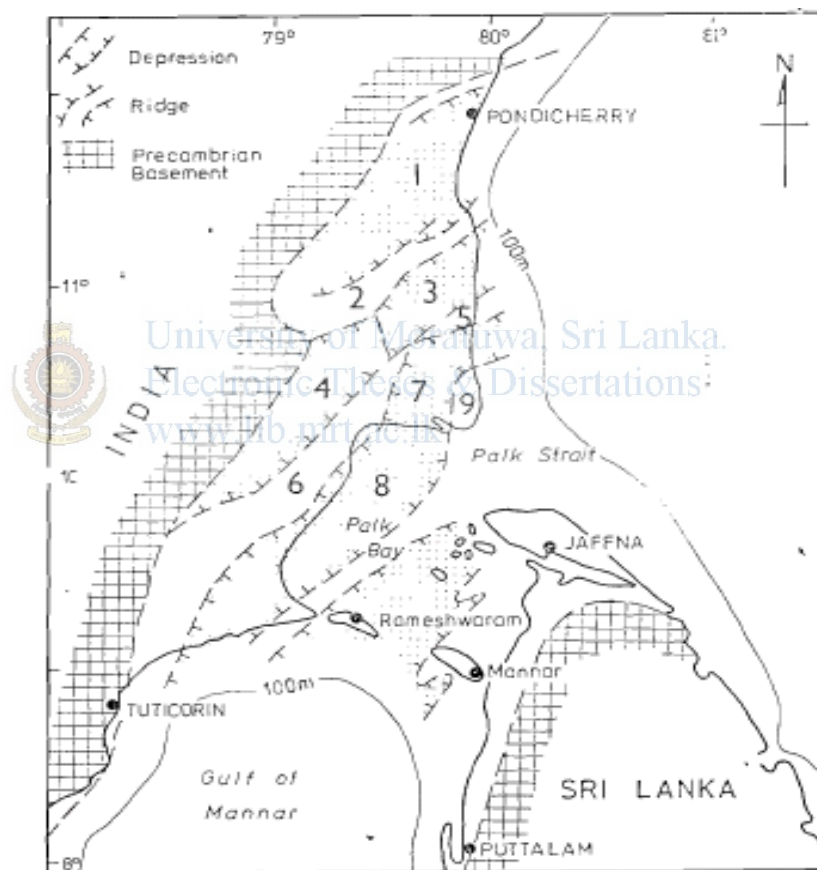


Figure 2-4: Sketch map of the Carvery basin

Source: (Cooray, 1984)

- Lithology

The typical Jafna Limestone is hard, partly crystalline, compact, indistinctly bedded creamy colour. It is massive in parts but some layers are richly fossiliferous and weather into a honey-combed mass. At Aruwakalu (Aruwakkalu) hill for example, soft powdery limestone and calcareous (or marl) overlie the hard typical limestone, and calcareous sand-stones and siliceous limestones are present in addition to the hard,

pure limestone. (Cooray, 1984)

▪ Fossils

A varied assembling of fossils is found in the Jafna limestone and it includes foraminifera, lamellibranchs, gastropods, echinoids, corals, calcareous algae and anthozoa. The foraminifera (or 'forams') are important microfossils by which the territory system has been subdivided into a number of 'stages', thus enabling formations in one part of the world to be correlated with those in another. The characteristic foraminifer in the Jafna limestone is 'Taberina Malabarica' which, together with the association of other forms, dates the Jafna Limestone as belonging to the upper part of the Lower Miocene. (Cooray, 1984) The largest deposits of Miocene limestone are found in the north western coastal belt near Puttalam. The limestone is used for cement manufacturing.

2.5 Types of cement used in Sri Lanka

Table 2-3: Cement types available in Sri Lanka and their applications

Cement type		SLS standard		Specific application(s)
Ordinary Portland Cement – OPC		SLS 107 (2008)		Ready mix concrete Structural concrete with that needs high strength Infrastructure projects those need high strength and durability
Portland Limestone Cement – PLC		SLS 1253 (2008)		Structural elements in normal concrete such as foundations columns, beams & slabs where workability and 28 day strength are the key parameters. Other possible uses are as mortar for brick and block walls
Masonry Cement MC	-	SLS 515 (2003)		Brick laying and block work. Internal and external plastering.
Blended Hydraulic Cement – Portland Pozzolana or Slag		SLS 1247 (2008)		Cement applications specially resistance to aggressive environments.

Ordinary Portland cement commonly known as OPC was the firstly introduced cement to local market and which remained as the only available cement type for few decades. With the constructional developments, for different cement application requirements a new set of cement types were introduced to local market in 2003. In the Sri Lanka Cement Corporation history, there were some attempts taken to promote masonry cement in their product portfolio however it did not succeed. The resistance to change from OPC to introduced ‘application based cement’ types still exist in the local market mainly due to the lack of technical know-how. The main cement types available in Sri Lanka are shown in Table 2-3 with specific application and the local product quality standards. The material composition requirements as per the local standard are mentioned in Table 2-4.

Table 2-4: Material composition of available cement types in Sri Lanka

Cement type	Material composition (mass/mass)			
	Clinker	Minor additional constituents	Other materials	
OPC		<5%	<1%	Additives (where appropriate)
PLC	80-94%	0-5%	6-20%	Limestone
MC	>40%		<1%	Organic material (where appropriate)
				Balance inorganic material
Blended Hydraulic : Type 1 Portland Pozzolana cement	65-94%	0-5%	6-35%	Pozzolanic material
Blended Hydraulic Cement : Type 2 Portland Slag cement	65-94%	0-5%	6-35%	Blastfurnace slag

Sources: (SLS, 2008), (SLS , 2008), (SLS , 2008), (SLS , 2008)

The parameter mentioned as ‘minor additional constituents’ is generally defined as ‘specially selected inorganic material used in a proportion not exceeding a total of 5% by mass related to the sum of all main and minor additional constituents’. However to have a specific idea on this parameter referring the specific SLS standard is required.

2.5.1 Cement product standards

Sri Lanka Standard institute (SLSI) has set up the cement quality standards for each cement type of cement available in Sri Lanka and it is mandated to comply with SLS standard requirements. These requirements are frequently audited by the SLSI.

British Standard European Norm (BSEN) and American Stranded (ASTM) are mostly accepted throughout the world. Responsible cement manufactures adopt one of these standards, not as a mandate standard however as a marketing & internal control tool. Complying with BSEN and ASTM create a value for the cement which manufactures focusing export process. Selected cement types which are certified under BSEN has to undergo a series of initial and surveillance audit cycles to sustain the certification.

2.6 Cement manufacturing process

Cement is the end product of a number of complex process steps which may take place in different locations. In HLL case Aruwakkalu quarry site is forty seven kilometers away from the main plant. In order to understand the full LCA process, it was divided in to two main process units.

The main steps of cement manufacturing process is graphically presented in Figure 2-5 and described their onwards. The full process is discussed stepwise from section 2.6.1 to 2.6.12.

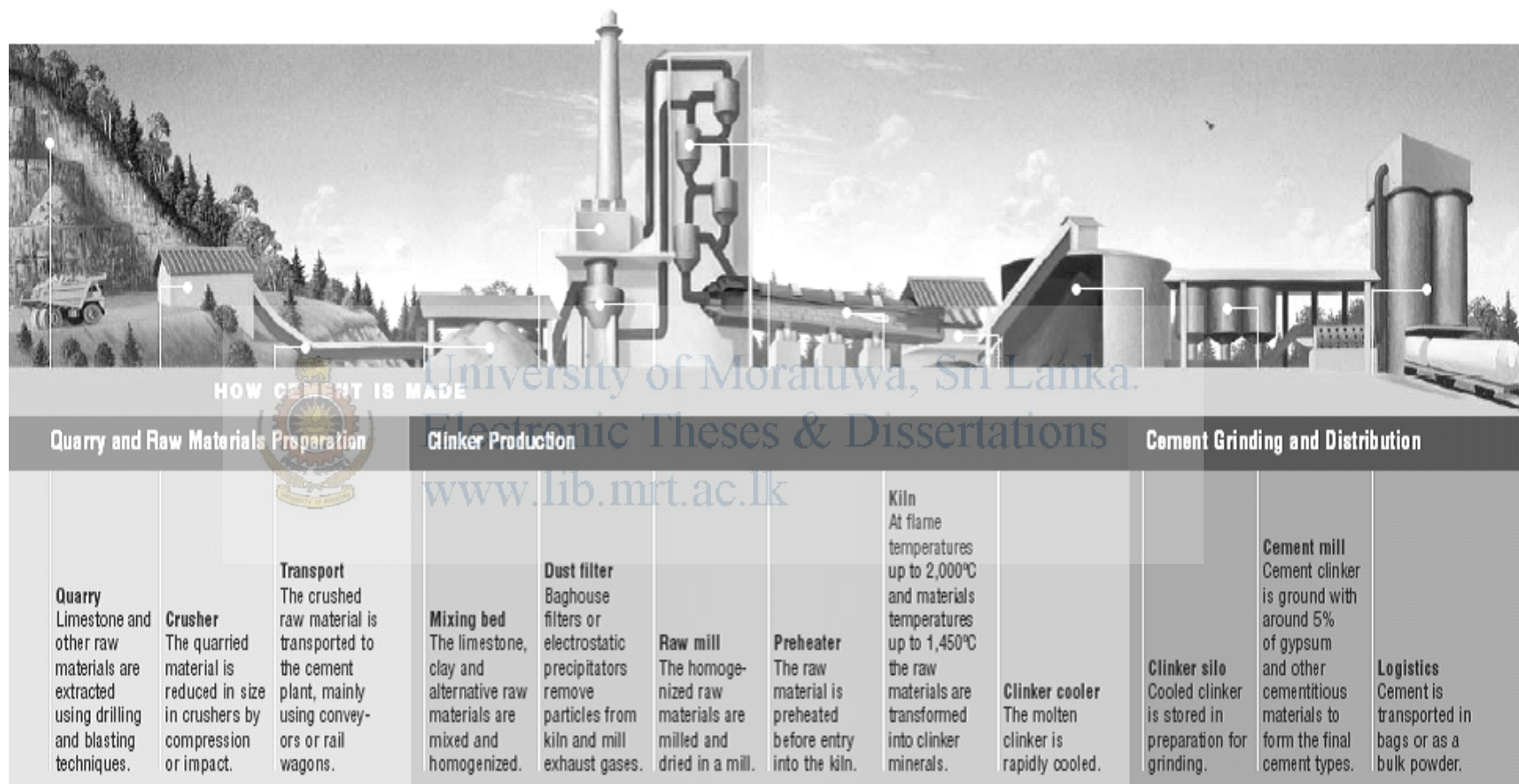


Figure 2-5: Integrated cement manufacturing process

Source: (Holcim , 2005)

Table 2-5: Identified unit processes

Unit process	Details
One (raw material to clinker)	Process until producing clinker, the main component of cement. Clinker is produced from raw materials, such as limestone and clay, which are crushed, homogenized and fed into a rotary kiln.
Two (clinker to cement)	The next phase is handled in a cement grinding mill. Gypsum and other additional materials (such as blast furnace slag, coal fly ash, natural pozzolanas, limestone, etc.) are added to the clinker and ground leading to a fine and homogenous powder: cement. (CEMBUREAU , 2009). End product cement either packed or filled to bulk tankers

2.6.1 Material Extraction & Quarrying

Limestone the main raw material is extracted through mining and excavation. Geographically limestone available locations are scientifically explored to mine. For this purpose modern software's are used to model the deposits by the core-drilling data inputs. Some most common software are listed below

QSO expert	Holcim software expanded by Colenco. QSO
CADE	
Quarry Master	Software standard for aggregates and extraction
QVis	

Different mining methods are used depending on the specific surrounding and material demand. In Aruwakkalu (Ref chapter 2.4.1) quarry site overburden removal and extraction is practiced. There are a lot of environmental aspects involved during mining and material extraction process which causes environmental impacts in different magnitudes. These are highly depended on the source and the surrounding ecology.



Figure 2-6: Quarrying & mining at HLL Aruwakkalu quarry site

2.6.2 Raw material transportation

Limestone, the extracted main raw material is transported using company owned locomotives. The distance between plant and the quarry is forty seven kilometers. Usually the crusher is located at the quarry, however in the HLL case it is at the cement manufacturing facility.

Other raw materials are transported using out sourced vehicle fleets. Mainly dolomite is from Kandy and Matale area and laterite is sourced from Andigama, in Anamaduwa electorate. Gypsum is received at Colombo ports and it is transported using outsourced vehicle fleets.

2.6.3 Raw material crushing

Material transported from the quarry site is fed into hammer type two raw material crushers with 160t/hour capacity and crushed into fine stage. Materials are poured to the crusher chute using a mechanical installation call ‘tippler’ which rotate the rail wagon full with material 180°. The crushed material either fed directly to raw mills or stored in ‘open yard’ area. Storing and feeding needed to be done accordingly by taking precautionary measures to divide and homogenize high quality & low quality limestone in the given ratios to support the burning process.



Figure 2-7: Hammer type raw material crusher at HLL - PCW

2.6.4 Raw milling

The dosed, crushed raw materials are dried and finely ground in the raw mill to form an intermediate product, called “raw meal”. The grinding provides an increased surface area to enhance heat exchange in the downstream heating process. In PCW there are two horizontal ball mills installed for raw milling. The BDP of those is 60 t/hour.



Figure 2-8: Raw mill at HLL – PCW

2.6.5 Homogenizing

The “raw meal” is then stored in homogenizing silos in which the chemical variation is reduced.



Figure 2-9: Homogenizing silos (blending silos) at PCW

This homogenizing process is important to stabilize the downstream sintering process as well as to produce a uniform quality product. The “raw meal” is then transferred to the preheater tower. Normally homogenizing silos are with the blending function and separate de-dusting systems are established to minimize the fugitive dust from silos.

2.6.6 Preheating

In the preheater tower, the raw meal undergoes a series of concurrent heat exchanges using the hot exhaust gas from the kiln system. The gas and material stream are separated by cyclones after each heat exchange process. In PCW a four stage preheater system was installed. The raw meal (input material) temperature increases from 80°C to 1000°C within 40 seconds in between these four stages in the preheater tower. This is shown in the below temperature phase diagram in Figure 2-11.

The first chemical reaction is taken place in the precalciner stage in the cement plants with the secondary firing system. Mostly the AF's are fired through precalciner unit. Precalciner stage is not installed in the PCW set up. In the precalciner CaCO_3 in limestone is decomposed into lime – Calcium oxide (CaO) and CO_2 .

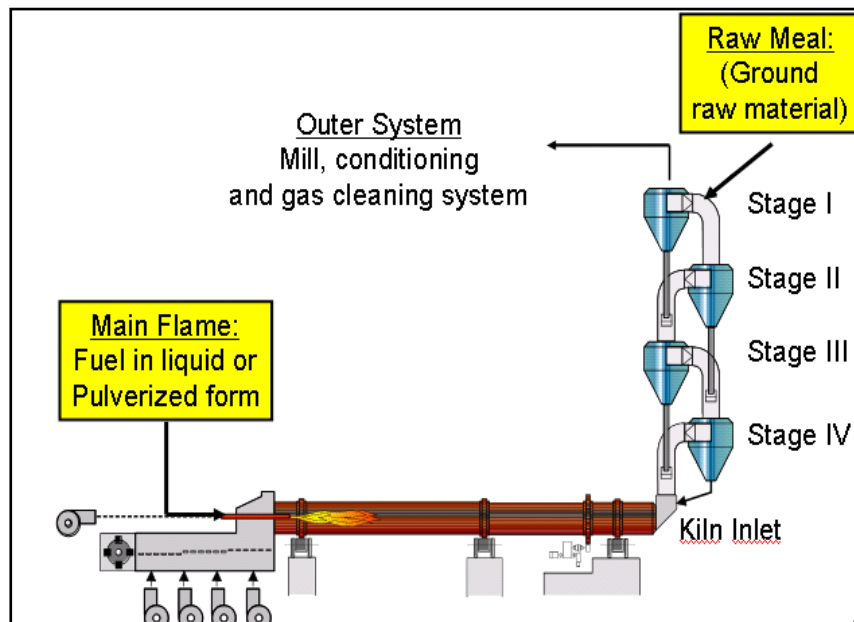


Figure 2-10: Four stages preheater structure

Generally material is transported within ten seconds in preheater area. The following temperature phase diagram shows the heat exchange in between waste heat and material in preheater stage.

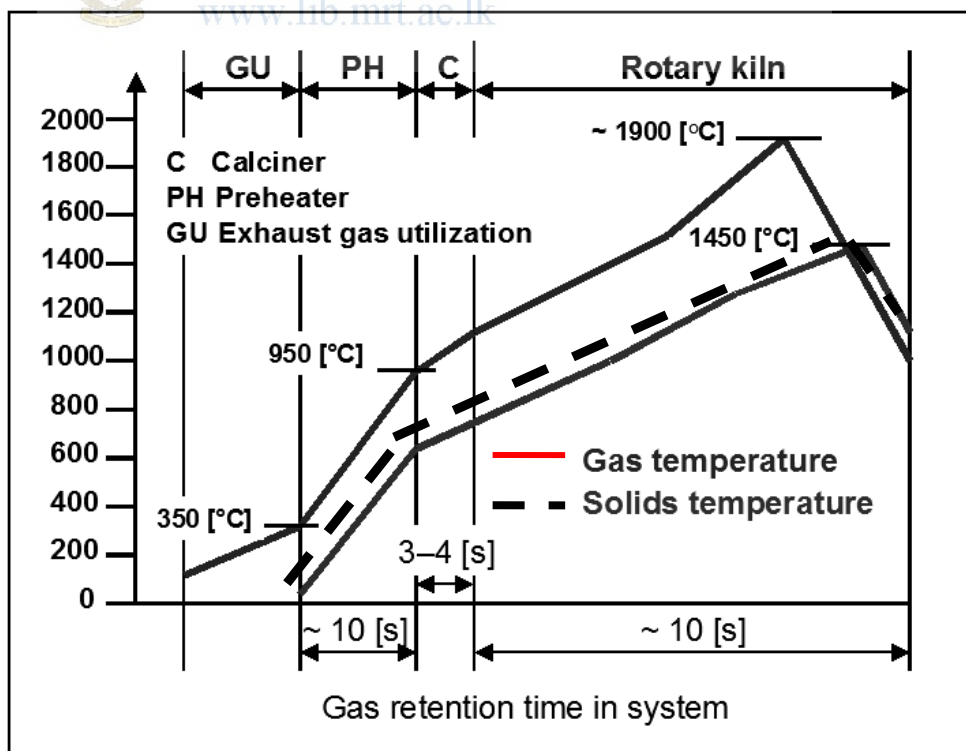


Figure 2-11: Temperature phase diagram - preheater to kiln



Figure 2-12: Clinker kilns & pre-heater tower at HLL - PCW

2.6.7 Fuel Preparation Process

Cement kiln fuels can be categorized into two main streams. Coal, heavy furnace oil (HFO) type traditional fuels which are nonrenewable and alternative fuels (AF's) like biomass and other industrial wastes are the two common cement kiln fuels. Both these categories can again split into two streams considering their physical status as liquid and solid fuel.

Fuels are pre-processed before fed to the kilns and these pre-processing methods are based on the fuel characteristics. Common pre-processing methods used in PCW case is shown in below Table 2-6. This is mainly to increase the feeding and burning efficiency and achieve the maximum heat input from the fuel. The pre-processing step helps to keep the constant fuel feeding which supports to maintain consistent product quality and manage emissions.

Main fuel source - coal is received at Trincomalee port and there to PCW it is transported by lorries. Alternative fuel - biomass supply is scattered over North Western, Central & North Central provinces. However the industrial wastes which are used as alternative fuels are mostly sourced from the Western province.

Preprocessed fuel sources are then mixed into a fuel ratio considering clinker quality parameters, fuel optimizing parameters and kiln stack emissions. This is carried out using the internally developed MS Excel based software 'Fuel Mix Optimizer'.

Table 2-6: Fuel preprocessing methods used at PCW

Fuel type	Preprocessing type	Description
Coal	Milling	Vertical ball mill with BDP 16 t/hour at PCW.
Waste oil (AF)	Pre-heating	Using electrical heaters the waste oil is heated in to an optimum temperature (average 90 ⁰ C)
	Agitating	Increase the homogenize status of the fuel using the installed agitators in the temporary feeding stock tanks
Biomass (AF)	Homogenizing	Saw dust and paddy husk mixed into an optimal ratio to enhance clinker quality and thermal heat.
Industrial waste – Garment waste (AF)	Shredding	Using two ‘single shaft’ shredders driven by a single geared motor (90 kW) & the larger one driven by 2 similar geared motors (110 kW each). Output particle size is 30 mm
Industrial non-biodegradable waste – plastics, polythene (AF)	Granulating (3-D items) and shredding	
Pharmaceutical waste (AF)	Appropriate preprocessing as per the MSDS’s.	Feeding through kiln back end chute (from kiln inlet side) and solvents after impregnating with biomass.
Scheduled waste (AF)	Appropriate preprocessing as per the MSDS, EIA and EPL conditions	Industrial sludge – impregnation with saw dust Liquid waste – direct feeding and homogenizing to match with material quality Solid waste – feeding through kiln back end chute



Figure 2-13: Coal mill at PCW



Figure 2-14: AF - Industrial shredder (R), homogenized bio mass stock (R)

2.6.8 Burning process / co-processing (AF's) in the kiln

The calcinated material entering the kiln through it back-end undergoes a long heating process. The material temperature rises from 800°C to 1400°C. The material retention time in the kiln is 40-45 mins (Figure 2-11).

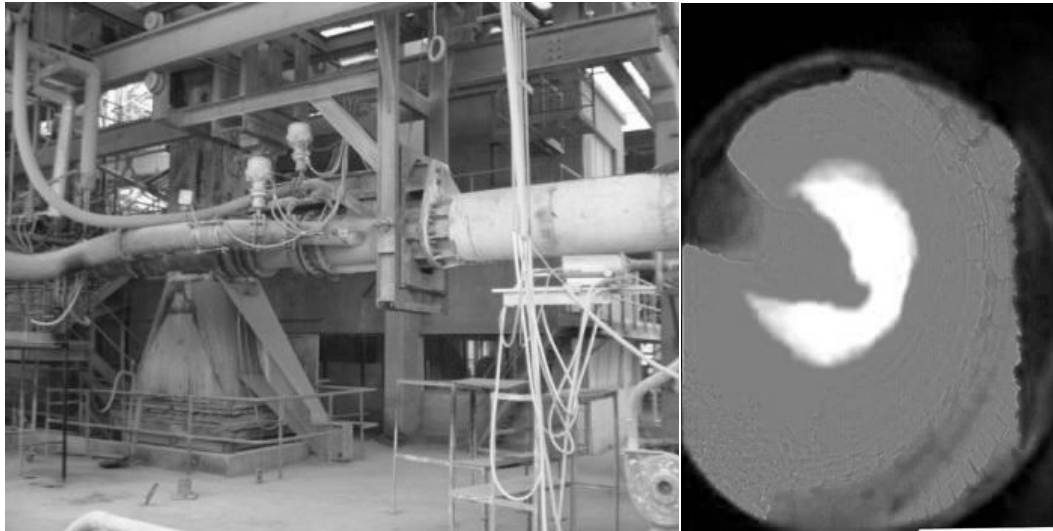


Figure 2-15: Multichannel main burner (L), burner flame HLL – PCW (R)

In the kiln, mineral matrices of raw material are totally destroyed and cement minerals formed at the sintering temperatures. A semi-product called “clinker” is formed. Coal and other alternative fuels are used as the energy sources for this process. The ash from fuels is absorbed into the clinker matrix.

Pre-processed fuels are fed in the same rotating kiln (normally a cement kiln is having an inclination around $2.5^{\circ} - 3^{\circ}$ to 4°). Material retention time inside the kiln is 40-45 minutes; however this parameter depends on the rotation speed of the kiln and the production rates. Average temperature at the back end of the kilns is 1050°C and at the front end is 1450°C . HLL – PCW kiln burner was replaced with a new multichannel burner in recent years to support different type AF feeding.

2.6.9 Clinker cooling process

The residual heat from the clinker leaving the kiln, is recovered by a grate cooler (consisting of rows of grates). Cooling air is injected from the bottom of the grate, and is forced into the clinker which is traveling slowly on the grate. The heated air is then recycled as secondary air for combustion in the kiln, or in the precalciner.

Normally grate coolers are used as clinker cooling apparatus. Sudden quenching is needed to produce good clinker and it reduces temperature of clinker (just exit from kiln) 1450°C to 150°C within 45mins. The residual heat from the clinker leaving the kiln is recovered by a grate cooler to reduce the energy requirement.

2.6.10 Main de-dusting systems

There are two commonly used de-dusting technologies in cement manufacturing. They are bag filter systems and electrostatic precipitators (EP's). EP's were used in the older generation plant designing and the current trend is towards bag filter systems, mainly due to energy efficiency and ease of maintenance. However the initial cost for installing bag filters are much higher than EP's.

New cement installations are always commissioned with bag filter system than EP's. Bag filters are being used to reduce dust in the plumes. PCW has also converted its main de-dusting system to bag filter from EP's in year 2004 under the project 'Blue Sky'.



Figure 2-16: 'Blue sky' filter bag unit (L), main stacks (R) at HLL – PCW



Figure 2-17: Mini dust bag system on blending silos at HLL – PCW

2.6.11 Cement Milling

The final process of cement making is called finish grinding. Clinker dosed with controlled amount of gypsum is fed into a finish mill which is a horizontal steel tube filled with steel balls. As the tube rotates, the steel balls are lifted, tumble and crush the clinker into a super-fine powder. The particle size is controlled by a high efficiency air separator. Other additives may be added during the finish grinding process to produce specially formulated cement.

There are two horizontal cement grinding mills in PCW with average capacity of 120 t/hour. Capacities of the mills are related with the milling cement type. PCW has also commissioned a roller press installation in year 2004 and increased the cement grinding capacity with energy efficient technology. The roller press (semi and finish grinding) crushes cement clinker prior to the material being sent to the cement mills for finish grinding. The new circuit consumes less specific power than the old installation. Also it increases the production rates by pre-milling the material. Following figure shows the both installations in HLL – PCW.

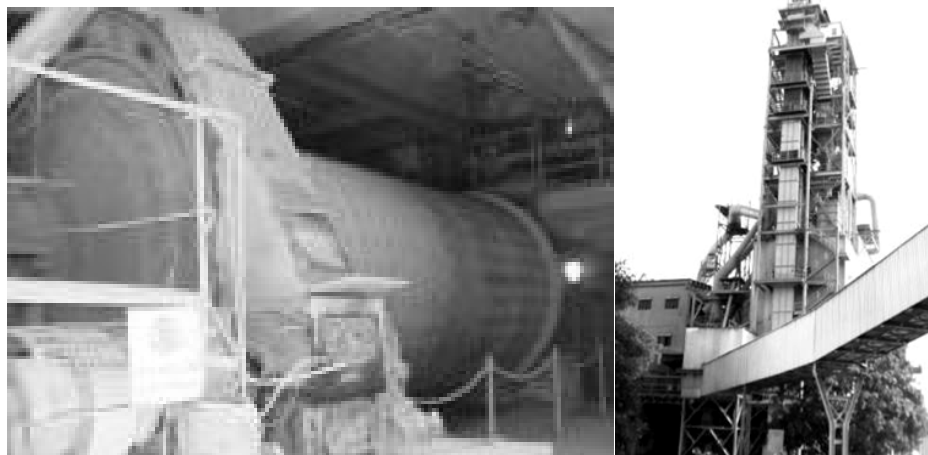


Figure 2-18: Cement mill (L), Roller press installation (R) at HLL – PCW

2.6.12 Packing Plant

Final stage of the cement manufacturing process is cement bagging or feeding to the tankers at packing plant. Cement is dispatched in two forms upon the customer requirement; in bags for domestic usage and bulk form in tankers for industrial

usage. Two new packers were commissioned in PCW in 2008 and bulk cement dispatch facilities have the packing capacity of 4,000 – 4,500 t/day.



Figure 2-19: Dispatching: bulk tankers for industrial use (L), packer (R)

2.7 Cement manufacturing related environmental impact management

From material excavation at the quarry until bagged cement loading process there are number of activities and processes which contributes to the environment either in a positive or negative manner. Resulted un-productive waste streams are the most commonly occurred and observed environmental impacts. They can be categorized to gaseous, solid and liquid (very rare in dry kiln used cement industry) or energy (electrical and thermal) waste streams.

In most of the cases identifying, assessing, implementing mitigate programs and monitoring of these impacts are carried out as per the ISO 14001: 2006 standards. ISO 14001 standard has more emphasis on quantified evaluation schemes which make the findings more rational and justifiable. Structured environmental management system practices supports a lot on minimizing environmental impacts. Most of the cement manufacturing facilities have now certified their process under ISO 14001 environmental management system. Management commitment and the following of Plan-Do-Check-Act (PDCA) cycle enhance the environmental commitments towards sustainable environmental performance.

The process of identifying environmental aspects and impacts is described more

precisely in the standards ISO 14001:2006 as, 'The organization shall establish, implement and maintain a procedure(s) - a) to identify the environmental aspects of its activities, products and services within the defined scope of the environmental management system that it can control and those that it can influence taking into account planned or new developments, or new or modified activities, products and services and b) to determine those aspects that have or can have significant impact(s) on the environment (i.e. significant environmental aspects). The organization shall document this information and keep it up to date. The organization shall ensure that the significant environmental aspects are taken into account in establishing, implementing and maintaining its environmental management system'. (ISO, 2004)

Initially a detailed environmental aspect and impact registry has developed. These are respectively presented in the below Table 2-7 and Table 2-8 representing unit process one and two separately. The primary documents used to prepare these table are sourced from HLL – environmental management system (EMS) databases. Assessing the significance is based on two axis quantification matrix representing the likelihood of occurrence of an impact versus consequence of an incident. There are some deviated incidents like spills which are emergencies and abnormal conditions like over spilling. All these aspects and impacts are listed as per the ISO requirements. The aspect and impact registry is updated regularly and in HLL case annually.

Table 2-7: Significant environmental impacts – unit process 01

Sub Process(es)	Input(s)	Output(s)	Significant Env Impacts
Raw material extraction, and quarrying of limestone (Indirect : dolomite, laterite)	Explosives (gelignite, ammonium nitrate), fuel (diesel), electricity	Extracted material, GHG emission, SO ₂ , NO _x , fugitive dust, noise and vibration due to explosions, cut down trees, removed top soil	Biodiversity disturbance (deforestation, habitat disturbance), air pollution, global warming, noise and vibration, fossil loss
Raw material transportation and fleets and locomotives material handling	Fuel (diesel) for lorry and (limestone transportation),	Transported materials, vehicle emissions, noise emission, fugitive dust	Air pollution, global warming, noise and vibration
Raw material / additives crushing	Limestone, additives (laterite), electrical energy	Crushed material, vibration, noise, indirect GHG - due to electricity use, direct GHG - vehicle emissions, fugitive dust	Air pollution, noise and vibration, global warming
Raw material / additives milling	Crushed limestone / additives (laterite), electrical energy, tear and wear (Grinding aids)	Crushed material, vibration, noise, indirect GHG emissions due to electricity use, fugitive dust	Air pollution, noise and vibration, global warming
Homogenizing	Milled material, electrical energy, compressed air	Indirect GHG emissions due to electricity use, fugitive dust, noise	Air pollution, noise and vibration, global warming

Preheating	Homogenized materials, waste heat from kiln, electrical energy, compressed air	Indirect GHG emissions due to electricity use, fugitive dust, noise, waste heat	Air pollution, noise and vibration, global warming
Fuel preparation – coal	Coal, electrical energy, waste heat from kiln	Ready to feed (fined) coal, fugitive dust, noise, vibration, waste heat, indirect GHG emissions due to electricity use	Air pollution, noise and vibration, global warming, water and soil pollution - coal storing
Fuel preparation – HFO, waste oil and other liquid AF	HFO, waste oil, liquid AF, electrical energy	Transferred fuel to burner tip, indirect GHG emissions due to electricity use	Air pollution, global warming
Fuel preparation – solid AF	Biomass (saw dust, paddy husk), industrial waste, electrical energy	Transferred fuel to burner tip, indirect GHG emissions due to electricity use, odor, noise, vibration	Air pollution, noise and vibration, global warming
Burning process & co-processing (with respect to AF)	Kiln fuels, electrical energy, raw meal mixture, tear and wear (refractory items - fire bricks)	Clinker, waste heat, CO ₂ from calcination, direct GHG emission from fuel burning, indirect GHG emissions due to electricity use, other gaseous emissions (SO ₂ , NO _x , VOC, HCl, PM), noise, vibration, reject materials – CKD and bypass dust	Air pollution, noise and vibration, global warming, water / soil pollution

Clinker cooling	Hot clinker, electrical energy	Cooled clinker (170 ⁰ C to 180 ⁰ C), waste heat, other gaseous emissions (HCl, PM), noise, vibration, reject materials, indirect GHG emissions due to electricity use	Air pollution, soil pollution (reject material storing), global warming
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Table 2-8: Significant environmental impacts – unit process 02

Sub Process(es)	Input(s)	Output(s)	Potential Significant Env Impacts
Cement milling (roller press & mills)	Clinker, setting regulators (gypsum), cement strengtheners (enhancers), clinker substitutions, (mineral components), electrical energy	Different cement types, fugitive dust, used chemical containers, indirect GHG emissions due to electricity use, noise, vibration	Air pollution, noise and vibration, global warming
Cement packing and dispatch	Cement, paper bags, electrical energy	Packed or loaded cement, reject material, damaged cement bags, vehicle emissions, fugitive dust, noise	Air pollution, noise and vibration, global warming

Cement industry related environmental impacts can be further listed as in Table 2-9, with general mitigation practices. However there may be number of less significant impacts associated with cement manufacturing related activities. However most of them are not generic but more location and process oriented.

GHG (mainly CO₂) emission, other gaseous emissions like SO₂, NO_x & dust, ecological disturbances, noise & vibration issues and accidental spillages (not in normal scenario) are the most generic and relatively significant impacts which are identified during environmental aspect & impact identification process.

Majority of the cement manufacturers have already made lot of effort to minimize these identified significant environmental impacts by integrating preventive action plans in to their corporate strategic action plans. Most of the responsible entities have identified these environmental impacts as their business risks and started looking at them in the view of sustainable environmental performance angle. The increased environmental pressure from the legal and statutory regulators is also pushed a lot towards these environmental friendly process changing steps and the aggressive focus given by environmental lobby groups attributed a lot.

Table 2-9: Cement manufacturing environmental impact mitigation

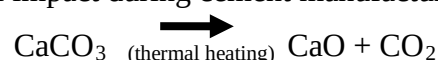
Impact		Global best practices
Global warming due to GHG (CO ₂) emission		Promote application base cement – with more clinker substituted product scheme complying to specific quality standards
		Increase trend on alternative fuel usage
		Improve process technology
Other gaseous emissions		High NO _x emitting plants : Applying SNCR (selective non catalytic reduction) technology
		High SO ₂ , HCl emitting plants : Applying scrubber technology
		High dust emitting plants : Installing efficient dust captive systems (bag filter systems)
		For high VOC and Mercury emitting plants : applying

	specific high-end technology to reduce the harmful emissions
Biodiversity disturbances and deforestation during mining activities	Through scientific biodiversity assessments & surveys and implementing the ecological enhancing programs - re-vegetation programs, species recovery activities and establishing proper monitoring systems
Noise and Vibration	Implement continuous condition based monitoring in regular intervals and focus on specific preventive and corrective actions
Chemical/solvent spillages and particle mixed water runoff	Operational control measures Upon significance : proper engineered solutions

Above Table 2-7 to Table 2-9 support on rationalizing the selected LCA scope. ‘Global warming due to GHG emissions’ (which is mainly CO₂) is the most common cement related environmental impact in each process step. This finding justifies selecting ‘climate change’ as the impact category and ‘kgCO₂e’ as the category indicator.

2.8 GHG emission and cement industry

Limestone which contains Calcium carbonate (CaCO₃) as the main chemical component is the principal raw material of cement which converts to clinker an intermediate compound in cement production. During the calcination process of CaCO₃ emission of CO₂ (the most common GHG source) is identified as a significant environmental impact during cement manufacturing process.



Cement industry is also identified as a higher energy intensive industry with respect to other manufacturing processes. It consumes thermal energy an average of 3,702 MJ/t cli as per the EN3 GRI guidelines (Holcim, 2008). Global figures which are shown in the Figure 2-20, were collected by ‘GNR – Getting Number Right Project’ which conducted by CSI - a working group under WBCSD.

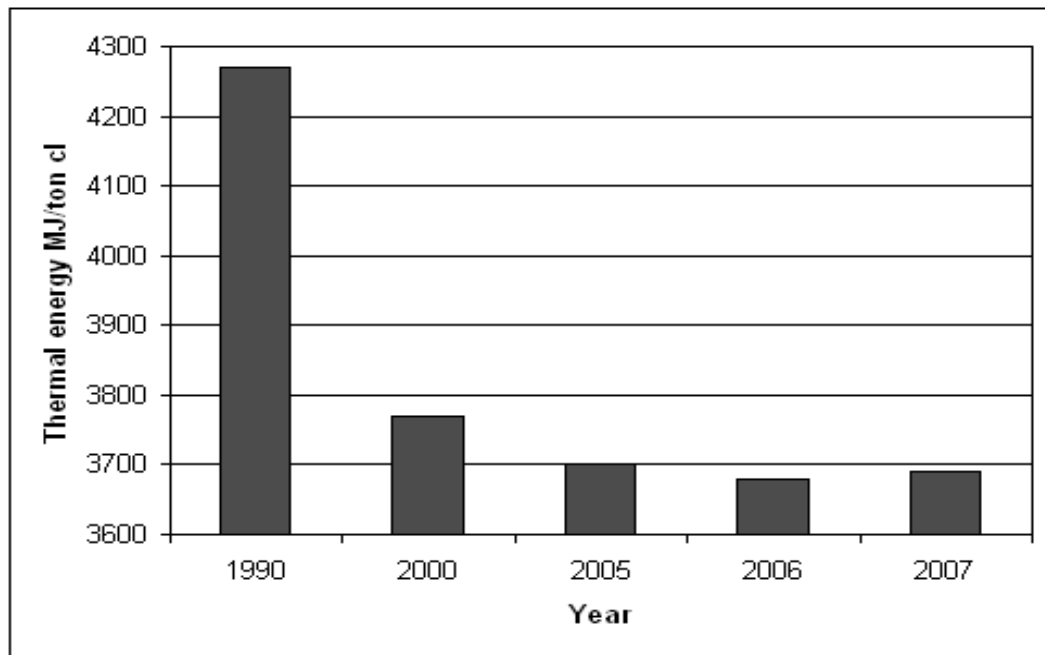


Figure 2-20: Specific heat consumption over time – CSI members

Source: (WBCSD - CSI, 2008)

It shows an increasing efficiency in thermal power utilization in cement kilns which has decreased from 4,270 MJ/t cli(1990) to 3,690 MJ/t cli (2007). (WBCSD - CSI, 2008)

Average Electrical energy requirement to produce one tonne of cement is 105kWh (Holcim, 2008). Both thermal & electrical energy consumption also significantly contribute on cement related GHG emissions. The burning of fossil fuels such as coal, gas, and oil as well as deforestation adds additional GHG's to the natural GHG level that persists in the atmosphere. For example, anthropogenic CO₂ accounts already for 12% of total CO₂ emissions (Holcim, 2009). As a consequence, the CO₂ concentration level has increased from 280 ppm in pre industrialized (Holcim, 2009) times to about 392 ppm today (www.350.org, 2010).

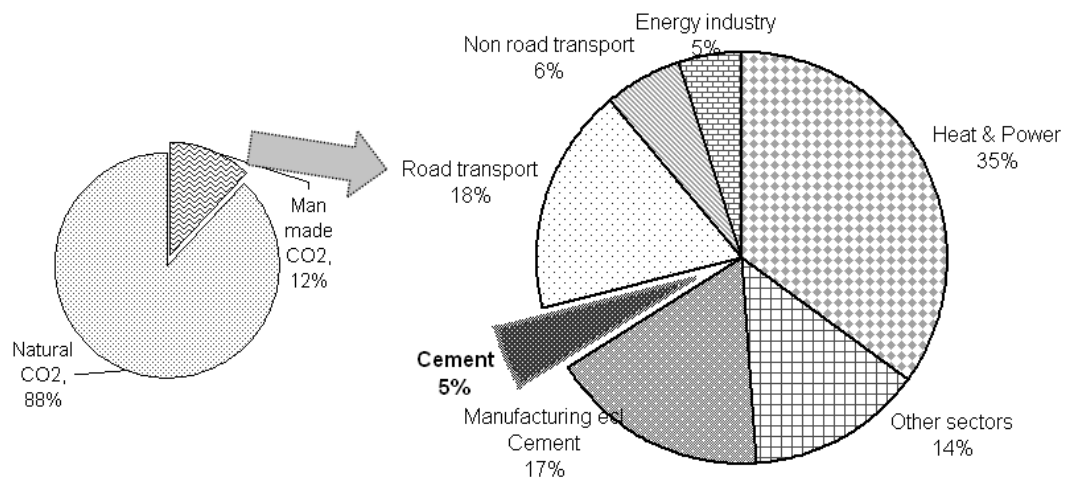


Figure 2-21: Global anthropogenic CO₂ production

Out of approximately 30 GtCO₂e man made CO₂ emission, 5% contribution is from cement industry which is nearly 1.5 GtCO₂e per annum (WBSCD, 2005). GHG emission, typically CO₂ emissions in cement industry is identified as the most related and significant environmental impact during the cement manufacturing process.

Major responsible cement manufactures continuously carry out research on reducing individual GHG footprint during cement manufacturing process. (WBCSD - CSI, 2008). The GHG calculation tools under chapter 4.1.1 describe the GHG calculations and protocols used. Cement manufactures focuses GHG reduction in three major areas.

2.8.1 Co-processing alternative fuels (AF's) in cement kilns

Research work has proven cement kilns can be used successfully as an incinerator to dispose waste material which is a material and energy recovery process which is one step higher than an incinerator. This process is industrially known as 'co-processing technology'. Alternative fuels are now no more a new fuel source for cement kilns.

- Advantages of co-processing

Co-processing in the cement industry is the optimum way of recovering energy and material from waste. It offers a safe and sound solution for society, the environment

and the cement industry, by substituting nonrenewable resources with societal waste under strictly controlled conditions. The co-processing of alternative fuels provides a solution in terms of reducing fossil fuel dependency as well as a contribution towards the lowering of emissions. The use of alternative raw materials also has numerous benefits, including a reduced need for quarrying and an improved environmental footprint of such activities.(CEMBUREAU , 2009).

With the opening of alternative fuels to cement kilns, the increased use of biomass instead of traditional fuel sources, supported on neutralizing GHG in cement manufacturing process. Most of the industrial waste which is generated having nowhere to disposing also an AF for cement kilns which finally add GHG credits.

There are several advantages of co-processing in cement kilns while comparing with other incinerator methods. Recoveries of material and emission control are significant benefits of co-processing.

Table 2-10: The advantages of co-processing

Characteristics	Temperature & time
Temperature at main burner	>1,450°C material >1,800°C flame temperature
Residence time at main burner	>12-15 sec and >1,200°C > 5-6 sec and > 1,800°C
Temperature at precalciner	>850°C: material >1,000°C: flame temperature
Residence time at precalciner (not related to HLL case)	> 2-6 sec and >800°C

Source: (CEMBUREAU , 2009)

2.8.2 Promote more clinker substituted cement products

The average carbon footprint of manufacturing clinker tonne is 862 kgCO₂e (WBCSD - CSI, 2005) and responsible for nearly 60% of the CO₂ emission from cement manufacturing process. Substitution of clinker in cement is an example of the positive contribution of the European cement industry to resource management.

(CEMBUREAU , 2009). Below Figure 2-22 shows the global trend of clinker substitution materials, which is commonly known by cement to clinker factor ratio (clinker factor).

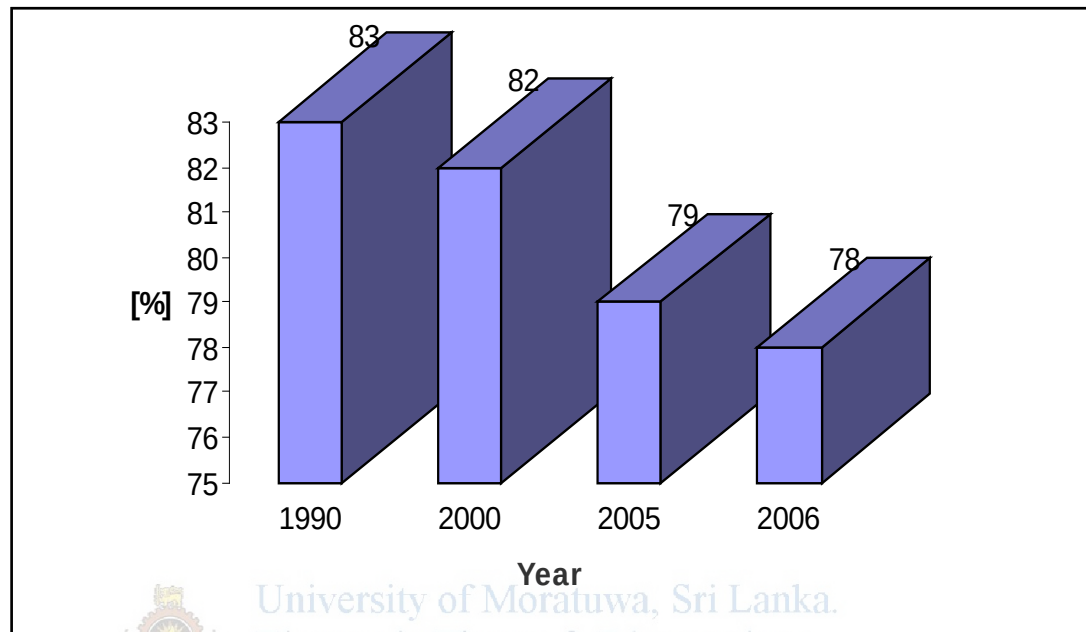


Figure 2-22: Clinker to cement ratio

Source: (WBCSD, 2008)

HLL also aligned to the global trend in developing more clinker substituted cement types with the intervention of product portfolio as mentioned in the chapter 2.5. It clearly shows the revolutionary and evolutionary steps of introducing application based cements and its classes. It is a proven way which brings down the specific CO₂ emission in cement.

2.8.3 Improving the process technology

Cement industrial processes and knowledge are frequently upgraded due to the given higher interest in research and development focus. Introducing thermal & electrical energy efficient technologies are some of the identified key priorities in cement industry in aiming get down the energy related environmental impacts. The efficient thermal improvements always resulted in lowering the GHG emissions by bringing down the specific thermal energy requirement. One example for such changes is shifting from ESP's to bag filter systems. The changes made for fuel pre-processing

and channeling also saved a lot of thermal & electrical power which resulted in reduction of GHG emission.

2.9 HLL process changes supporting better GHG management

Holcim Group always aligns with the responsible environmental mitigation actions introduced by WBCSD and CSI, where climate change is identified as a top priority. As a result HLL is also kept GHG mitigation in its corporate strategies which is driven through its organizational road map.

The contribution the group can make to climate protection and energy security focuses on promoting sustainable building practices and cutting-edge approaches to reducing CO₂ emissions in cement production. This includes optimizing products and processes, investing in research and development of new kinds of cement, as well as using alternative fuels (Holcim, 2010). HLL has also taken several step changing decisions on promoting GHG reduction within its production facilities.

2.9.1 Introducing new cement types (other than OPC) to Sri Lanka

From the day of introducing OPC as the main cement type, there were number of initiatives and changes made for the cement types considering the specific application requirements. However until early 2000's OPC was the only cement type which used in Sri Lanka. The concept of introducing right application cement is more specifically branded by HLL as 'Application Based Cement - ABC'. Cement is no more a commodity which supplies a general need. For each constructional activity, specific cement can be used. This concept promotes using right cement in right application without depending only on OPC.

- **HLL product portfolio**

HLL cement range meets customer requirements with the application based sub-brands *Supiri* (concrete applications), *Pedereru* (masonry applications) and *Ready-Flow* (quick hardening). Holcim Lanka also manufactures special cements for large scale infrastructure projects (HLL, 2009). These products were briefly described in the following Table 2-11.

Table 2-11: HLL product portfolio

Product	Detail	Recommended applications
Holcim Supiri: the all-purpose cement ideal for concrete – available in 50kg bags	Holcim Supiri is a Portland limestone cement manufactured in compliance with Sri Lankan Standard SLS 1253:2008 and British standard CEM II/A-LL42.5N of BS EN 197-1:2000.	Structural elements in normal concrete such as foundations, columns, beams & slabs where workability and 28 day strength are the key parameters. Used As mortar for brick and block walls.
Holcim Pedereru: the masonry cement - available in 50 kg bags.	Holcim Pedereru is a masonry cement manufactured in compliance with SLS 515:2008 and British Standard MC 22.5X of BS EN 413-1:2004 which is ideal for masonry wall construction and for plastering.	Brick laying and block working. Internal and external plastering.
Holcim 'Ready Flow' available in bags and bulk form (Project purposes)	Holcim Ready Flow is an ordinary Portland cement manufactured in compliance with Sri Lankan standard SLS 107:2008 and British Standard CEM I 42.5N of BS EN 197-1:2000	Ready mix concrete, Structural concrete with that needs high strength Infrastructure projects those need high strength and durability.

Source: (HLL, 2009)

Chapter 3 LIFE CYCLE ASSESSMENT (LCA)

The interest of knowing and taking necessary precautionary actions to reduce product (both products and services) related environmental impacts is significantly increased among interested parties. However assessing environmental impacts of the full life stretch of a product or service was an identified gap. LCA was introduced and developed as a structured tool to fill this gap.

3.1 History of LCA

LCA concept started with first multi criteria study for Coca-Cola led by Harry E. and Teastley Junior. This study was carried out with its objectives: choice between glass and plastic for the product bottling, choice between internal or external bottle productions, end of life options (recycling or one-way) for the chosen bottle type. They researched taking into account of the whole environmental impacts, from the raw material extraction to the waste disposal (what is called from the cradle to the grave approach) in 1969.

The study revealed the plastic bottle as the best choice, contrary to all expectations. The study has never been published in its complete version. Only a summary was published in April 1976 in 'Science Magazine'. First discussions on validity of comparisons appeared with the first study results. This led the scientific community to go into a standardization process (Ecobilan, 2008).

Early forms of LCA were used in the United States in the late 1960s for defining corporate environmental strategy, and later in the 1970s by government agencies as an aid for developing public policy. In the late 1990s, LCA emerged as a worldwide environmental management tool in the form of the ISO 14040 series. (Tan, Raymond R; Culaba, Alvin B., 2002) Life Cycle Assessment methodology was developed thereafter by looking at the new mechanism of environmental impact evaluation. History of LCA is in detail described in Annexure III.

'Publishing Ecological' report of packaging material in 1984 and initiatives taken by Society for Environmental Toxicology and Chemistry (SETAC) 1991 onwards has remarkably supported on developing a structured LCA methodology. The

developments of ISO 14040, 14041, 14042 and 14043 international series of standards defining the different stages of the LCA methodology from 1997 to 2000 established the acceptable base for LCA (Ecobilan, 2008).

3.2 The LCA Concept

The process of LCA is defined and described in different ways in different sources. However the mostly accepted two definitions are from ISO and SETAC which described in below two paragraphs.

LCA is defined by ISO as : ‘LCA is a technique for assessing the environmental aspects and potential impacts associated with a product by: compiling an inventory of relevant inputs and outputs of a product system; evaluating the potential environmental impacts associated with those inputs and outputs; interpreting the results of the inventory analysis and impact assessment phases in relation to the objectives of the study’ (ISO, 2006). Further it is mentioned as ‘LCA studies the environmental aspects and potential impacts throughout the product’s life (i.e. cradle to grave) from raw materials acquisition through production, use and disposal. The general categories of environmental impacts needing consideration include resource use, human health, and ecological consequences’ (ISO, 2006).

LCA is defined by SETAC as ‘Life Cycle Assessment is a process to evaluate the environmental burdens associated with a product, process, or activity by identifying and quantifying energy and materials used and wastes released to the environment; to assess the impact of those energy and materials used and releases to the environment; and to identify and evaluate opportunities to affect environmental improvements. The assessment includes the entire life cycle of the product, process or activity, encompassing, extracting and processing raw materials; manufacturing, transportation and distribution; use, re-use, maintenance; recycling, and final disposal’ (SETAC, 1993).

In most of the cases, LCA concept is used to evaluate environmental footprint of a product or a service. LCA typically does not address the economic or social aspects of a product. The specialty of LCA study is together it evaluates inputs and outputs. Upon the significance of the impact categories the scope can be defined. A LCA

study follows a very clear structured analysis which consists of four phases as shown in Table 3-1. Study shall cover from defining the scope to final communication.

Table 3-1: Four different LCA phases

Phase	What covers in brief
Goal& Definition	The product or service to be analyzed is defined with a functional unit. Also clearly define the required level of details
Inventory Analysis (LCI):	Input (energy and material) flows , emissions to : air, water, soil and different land used patterns are mapped and quantified.
Impact Assessment (LCIA):	The effects of the resource use and emissions generated are grouped and quantified into a limited number of impact categories which may then be weighted for importance.
Interpretation:	The results are reported in most informative way to reduce ecological impacts. This is the phase which more focuses on the communication part of the LCA studies.

The respective ISO guidelines are discussed in Table 4-1. Below Figure 3-1 describes the interaction & relationship in-between four LCA phases which also shown the importance of ‘interpretation’ phase, not highlighted in most LCA studies.

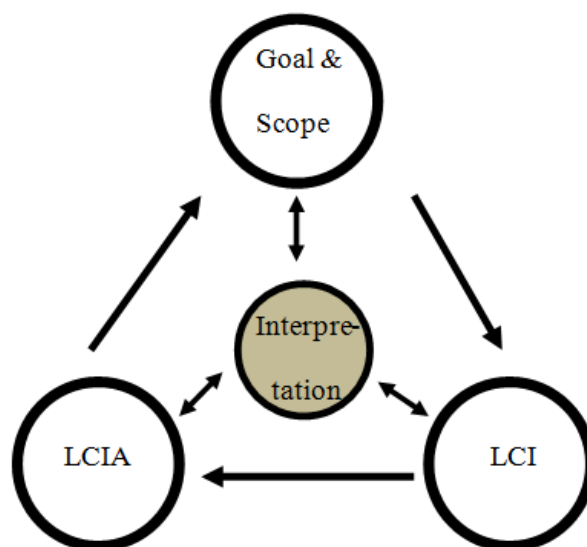


Figure 3-1: Four LCA phases and their relationship

3.3 LCA scope

A comprehensive LCA study shall focus from raw material extraction, manufacturing process, distribution, use phase and disposal or recycling. However limitations may occur due to accessibility or availability of relevant data sourcing, representative gaps due to diversified usage / disposing or recycling practices, geographically difference data availability and due to downstream data sourcing / calculation constraints.

The scope, boundaries and level of detail of an LCA study are depended on the subject and intended use of the study. The depth and breadth of LCA studies may differ considerably depending on the goal of a particular LCA study (ISO, 2006).

There are two common scopes which are defined in literature and accepted in LCA studies. However the LCA practitioner has the full flexibility to define the scope without limiting to these common scopes depend on the objectives of the study which covers under the ‘Goal of the study’. These two common scopes are further described as in Figure 3-2.

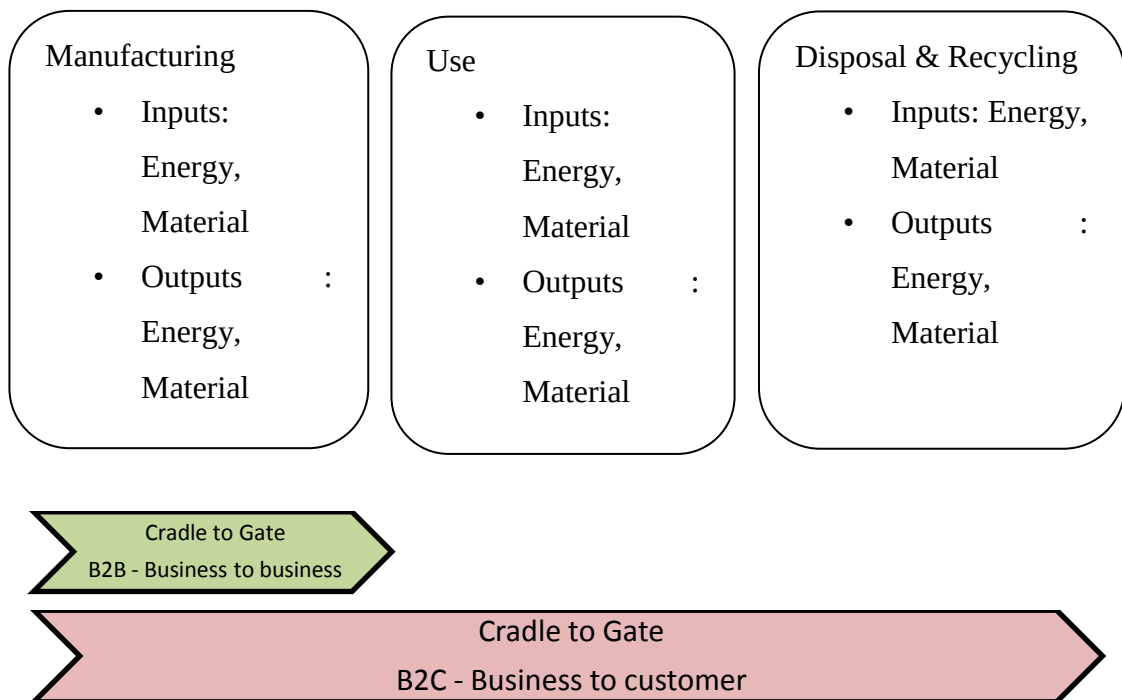


Figure 3-2: Two common LCA scopes

3.3.1 Cradle to gate approach -Business to business scenario (B2B)

Business to business is provision of inputs, including products, to another party that is not the end user (BSI, 2008). This scope covers from raw material extraction to dispatch to the next business layer: distributor, retailer or converter. Common functional phases within this scope are: raw material extraction, production process and starting point of dispatch from the facility to the next business party.

3.3.2 Cradle to grave approach - Business to consumer scenario (B2C)

Business to consumer scenario is provision of inputs, including products, to the end user (BSI, 2008). LCA cases which study the environmental aspects and potential impacts throughout the product's life from raw material acquisition through production, use and disposal. A LCA study with this scope for cement may face number of constraints due to data accessibility in downstream after the production phase.



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3.4 LCA and cement

With the increasing material need for infrastructure, cement is already become an essential and demanded commodity. Being an industry which uses intensive natural resources and energy (both electrical and thermal), focusing on environmental footprint will make a definite value addition. Since LCA is a quantitative method to evaluate the environmental impacts involved with a certain product over its whole life cycle by calculating the inputs and outputs of the system (Lei, Zhifeng, & Fung, 2003), using LCA the tool to assess environmental impact of full life cycle of cement is ideal.

Importance of a LCA study for cement industry is specifically studied and presented by an independent study 'What LCA can tell us about the cement industry' commissioned by World Business Council for Sustainable Development (WBCSD) in March 2002. Research in this project unearthed about 80 publications related to LCA of cement. Some of these addressed cement and / or alternative materials; others used the method for a variety of purposes. Many of the available references are academic reports, which focus on the method and application of LCA to cement

and other building materials (WBCSD, 2002). The following Table 3-2 shows the ten uses of LCA for the cement industry, including existing and potential applications with a rating according to their value to the cement industry. Criteria for the ranking (value) of each use is based on its prior use by cement industry, proven value to the industry, ease of application, and whether it is an area of importance to the industry. The scale (rate – value) is from High – for mostly used aspects to Low – leastly used.

Table 3-2: LCA value to the cement industry

General use	Industry related area(s)	Rate (value)
Generic data sets	The availability of LCA information on cement, and competing with products like steel, wood and asphalt, a market expectation in many regions.	High
Environmental performance improvement	For intra-company benchmarking, identification of opportunities, support of EH&S, setting up KPI's	Mid
Industry benchmarking on environmental performance	Company-to-company or/and industry to industry performance comparison and benchmarking best practices.	Mid
Technology assessment and business planning	Can be used to assess new technologies for their environmental performance, contributing to other sources of information on business, regulatory, technology, legal, etc	Mid-High
Industrial Ecology Assessment	LCA can potentially help to evaluate the efficiency in industrial ecology efforts. This use is largely unproven; it is the reason to rank as low.	Low
GHG Measurement	Measurement of CO ₂ and other emissions, including direct and indirect inventories, baseline establishment and scenario models	Mid

Environmental Reporting	LCA can be useful to generate and structure public information about company products, including communication of case studies and reporting of product performance indicators.	Low-Mid
Environmental Labeling	Product information generated through LCA for environmental reporting to a more target audience, ISO for Type III environmental labeling.	Mid
Marketing	More specific than using LCA to provide generic data sets, marketing implies active communication of the life-cycle benefits of cement into specific applications or market regions	Mid-High
Sales Support	LCA serves a close and immediate use, the value of which needs to be determined on a case-by-case basis.	Mid

This study precisely covers the LCA case studies in cement segment which its listed more than eighty cement related LCA's under the following sub categories.

- Corporate Environmental Reports
- Environmental Impacts of Cement and Concrete
- Life Cycle of Cement and Concrete
- Use of Alternative Fuels
- Use of Alternative Raw Materials
- LCA Methodology for Cement and Concrete
- Alternative Production Techniques
- LCA/LCI of Cement
- LCA of Concrete Buildings/Building Components
- LCA of Concrete Roads and Bridges

However most of them were not focused directly the cement industry impact category related studies but spread more towards the cement application related

impacts, such as concrete usage. It has shown some case studies are focused on alternative fuels & raw material side. There are two case studies from Taiheiyo Cement - Japan and Scancem - Sweden which more focused on corporate reporting side.

3.4.1 Cement LCA tools

Numerous tools are available for LCA practitioners (LCA practitioner is defined as 'individual or group that conducts a life cycle assessment' (ISO, 2006).) to apply life cycle methods and undertake life cycle studies. However the developing and utilizing of such modern sophisticated software in developing countries will take more time which is similar in Sri Lankan case.

These include decision support tools both quantitative and qualitative such as software, matrices and checklists. Moreover, one or more methods (e.g., environmental indicators) might be available within a single tool. LCA practitioner is responsible to select the best supportive method to successfully and scientifically complete the LCA study. LCI calculation plays a critical role in fulfilling the above requirement. In most of the LCA studies LCA software are used to implement the data collection and calculation process by using commercially available compatible software packages. There are more than 30 LCA software tools presently available. It was judged that the most useful tools to the cement industry are those with high quality databases, that comply with the ISO 14040 series of LCA standards, and that can be used to fulfill the full LCA methodology (from goal and scope definition, to inventory, to life cycle impact assessment and final interpretation) (WBCSD, 2002).

Most often in order to reduce the difficulties in data gathering and structured data storing, commercially available LCA software are used. Mostly used software which compatible in cement industry relating LCA studies are listed in the Table 3-3. Continuous interest shown in the LCA studies by cement manufacturers is the first motivation reason on developing LCA software's especially for cement industry and its different environmental scenarios.

Table 3-3: Cement industry supporting LCA software

Name	Developer / Research entity	Database	ISO*	DQA**	Impacts***	Stats
GaBi 3	IKP Uni. Stuttgart/PE, Germany	X	X	X	X	X
LCAiT 4.0	Chalmers Ind. (CIT), Sweden	X	X		X	
NIRE LCA 2	NIRE, Japan	X				
SimaPro 4.0	Pre, The Netherlands	X	X		X	X
TEAM 3.0	Ecobilan / Ecobalance Price Waterhouse Coopers, Europe/USA	X	X	X	X	X

ISO* – actively supports studies to comply with the ISO 14040 standards on LCA, DQA** – includes data quality assessment indicators or evaluation, Impacts*** – includes features for Life Cycle Impact Assessment.

Source: (WBCSD, 2002)

The LCA analysis tools which suitable for cement industry are introduced in the above study commissioned by WBCSD are GaBi 3, LCAiT 4.0, NIRE LCA 2, SimaPro 4.0 and TEAM 3.0.

Chapter 4 RESEARCH METHODOLOGY

The research methodology structure was kept aligned with the four LCA phases as published in ISO guidelines. Globally accepted ISO guidelines for LCA were used as the research methodology for this specific study. These guidelines were developed by International Organization for Standardization - ISO, Switzerland involving an expert team consisting industrial, ecological, corporate and other related areas and reviewed by another team of multidisciplinary experts. Below listed guidelines / specifications (in section 4.1 and 4.2) were extensively followed during the study in order to produce an LCA study to match with internationally accepted criteria.

Two GHG reporting guidelines were also used as the GHG reporting and calculation guides while following the LCA – ISO guides as the main framework. The selected GHG guidelines are explained in sub chapter 4.1.1.

4.1 ISO standards & GHG accounting guidelines

There are a set of guidelines already published focusing LCA under the ISO 14000 family and the following guides were specifically used as the methodology for this study.

Table 4-1: ISO guidelines followed as the research methodology

ISO Specification	Guideline /	Scope of the guideline / Specification
ISO 14040:2006, Environmental Management - Life cycle assessment Principles and framework	14040:2006,	ISO 14040:2006 describes the principles and framework for LCA including: definition of the goal and scope of the LCA, the LCI phase, the LCIA phase, the life cycle interpretation phase, reporting and critical review of the LCA, limitations of the LCA, the relationship between the LCA phases, and conditions for use of value choices and optional elements.
ISO 14044:2006, Environmental	14044:2006,	ISO 14040:2006 does not describe the LCA technique in detail, nor does it specify methodologies for the individual

Management cycle	Life assessment	phases of the LCA.
Requirements and guidelines		The intended application of LCA or LCI results is considered during definition of the goal and scope, but the application itself is outside the scope of this International Standard.

Source: (ISO, 2006)

Below guidelines developed and published by ISO, shown in Table 4-2 which were used where appropriate in this study.

Table 4-2: LCA supportive ISO technical guidelines

ISO guidelines	Scope of the guideline / specification
ISO 14047:2000	Examples of application of ISO 14042 to goal and scope definition and inventory analysis
ISO 14049:2000	Examples of application of ISO 14041 to goal and scope definition and inventory analysis

There are LCA technical guidelines other than developed by ISO. They were developed and published by research & development institutions and environmental regulatory bodies. Some of the countries already developed their own national guidelines on LCA studies for several products / services. However for this study those were not used, in order to provide more validated and generally accepted outcome.

4.1.1 Cement GHG reporting and accounting

Internationally accepted GHG reporting and calculating (accounting) guidelines (applicable to cement) were used throughout this study. These guidelines were properly studied prior to set up the LCA tool ‘Cement LCA Calculator’. The tool was formulated compatible to the below GHG reporting protocols.

- Greenhouse Gas Protocol

The ‘Greenhouse Gas Protocol’ initiative is a multi-stakeholder partnership of businesses, non-governmental organizations (NGOs), governments, and others

convened by the World Resources Institute (WRI), a U.S.-based environmental NGO, and the WBCSD, a Geneva-based coalition of 170 international companies. This launched in 1998 and the mission is to develop internationally accepted greenhouse gas accounting and reporting standards.

Many industry, NGO, and government GHG programs used this standard as a basis for their accounting and reporting systems. Industry groups, such as the International Aluminum Institute, the International Council of Forest and Paper Associations, and the WBCSD Cement Sustainability Initiative, partnered with the GHG Protocol Initiative to develop complementary industry-specific calculation tools. (WBCSD, WRI, 2004)

- CO₂ Accounting and Reporting Standard for the Cement Industry

Cement Sustainability Initiative (CSI) of the WBCSD, a number of leading cement companies are collaborating to address issues related to global sustainability. In 2001 the CSI companies agreed on a methodology for calculating and reporting CO₂ emissions 'The Cement CO₂ Protocol'. The second revised edition of the Cement CO₂ Protocol used for this study incorporates changes based on extensive practical application of the protocol by many cement companies worldwide which was published in March 2004. The basic calculation methods used in this protocol are compatible with the latest guidelines for national greenhouse gas inventories issued by the IPCC and with the revised WRI / WBCSD Protocol.

Table 4-3: Direct GHG emission parameters & default values

Emission components	Parameters	Unit	Proposed source of parameters
CO ₂ from raw materials			
Calcination of clinker	Clinker produced	t	Measured at plant
	CaO + MgO in clinker	%	
	CaO + MgO in raw meal	%	
Calcination of dust	Dust leaving the system	t	Measured at plant
	Emission factor clinker	tCO ₂ /t cli	Calculation
	Dust calcinations degree	% calcined	Measured at plant

Organic carbon in raw materials	Clinker	t	Measured at plant
	Raw meal: clinker	t/t cli [ratio]	Default = 1.55
	TOC content of raw meal	%	Default = 0.2%
CO ₂ from fuel combustion			
Conventional (traditional) kiln fuels	Fuel consumption	t	Measured at plant
	Lower heating value	GJ/t fuel	Measured at plant
	Emission factor	tCO ₂ /GJ fuel	IPCC/CSI default
AF (fossils)	Fuel consumption	t	Measured at plant
	Fuel lower heating value	GJ/t fuel	Measured at plant
	Fuel emission factor	tCO ₂ /GJ	IPCC/CSI default
AF (biomass)	Fuel consumption	t	Measured at plant
	Lower heating value	GJ/t fuel	Measured at plant
	Fuel emission factor	tCO ₂ /GJ	IPCC/CSI default
Non kiln fuels	Fuel consumption	t	Measured at plant
	Lower heating value	GJ/t fuel	Measured at plant
	Fuel emission factor	tCO ₂ /GJ	IPCC/CSI default

Source: ((WBCSD - CSI, 2005)

- PAS 2050:2008 Specification for the assessment of the life cycle greenhouse gas emissions of goods and services

Publicly Available Specifications (PAS) 2050 is one of the latest guidelines by BSI which released in October 2008. This guideline only focuses on GHG reporting and accounting part which is related to this research study. This is a revised version of a set of guidelines which was developed earlier. PAS 2050 was collectively developed by: Carbon Trust, UK - Department of Environment, Forestry and Rural Affairs (Defra), BSI - British Standards, PE International and few environmental professional companies and commissioned by BSI.

4.1.2 GHG reporting Scopes

Generally in GHG reporting schemes, emissions are categorized into three major

segments considering their generating points. The above three GHG reporting and accounting protocols are also structured and followed the same structure of scope. They are commonly known as Scope 1, 2 and 3 emissions. Below Table 4-4 shows the different GHG emission sources under said three scopes.

Table 4-4: Overview of scopes and emissions across a value chain

GHG reporting scope	Definition	GHG sources
Scope 1	GHG sources owned or controlled by the organization	Generation of electricity, heat or steam Transportation of materials, products, waste and employees in company owned/controlled vehicles Chemical processing from a manufacturing process
Scope 2	Emissions are a consequence of the production of electricity used by the organization	Electricity purchased by the organization and consumed in its owned or controlled
Scope 3	Optional scope, but provides an opportunity for companies to report on activities those are relevant to their business and goals	Extraction and production of purchased materials and fuels Electricity-related activities Leased assets, franchises and outsourced activities Waste disposal Transportation related activities

Source: (WBCSD, 2004)

4.2 Scope and goal of the LCA study

ISO 14040:2006 has set the guide for the exact requirements of setting up the goals and scope of a LCA. The goal of a LCA study shall unambiguously state the intended

application, the reasons for carrying out the study and the intended audience, i.e. to whom the results of the study are intended to be, communicated (ISO, 1998). Set-up a clear set of goal(s) for an LCA study is extremely important to achieve successful results. ISO14040:2006 5.1 and 5.1.2 describes importance of scoping & goal setting process with special emphasis on the consistency in all the LCA studies.

4.2.1 Goals of the LCA

Following goals were identified to successfully achieve the listed research objectives.

- Identify the cement industry related environmental aspects and impacts for each unit process
- Establish a quantitative database and assess the input material and energy flows in detail manner. Analyze inputs individually align to the scope stated in chapter 4.2.2.
- Evaluate industrial ecological impacts by calculating the specific GHG footprint for the selected functional unit (section 4.5) for the different cement manufacturing process scenarios listed in Table 4-5.
- Establish the Microsoft Excel based software program to study LCA of cement process – “Cement LCA Calculator” (due to lack of availability of LCA software in Sri Lanka)
- Interpret the major advantages and disadvantages due to the changes in the manufacturing process and cement types with respect to selected baseline scenario.
- Establish a set of recommendation to the corporate on improving GHG monitoring, reporting and maximizing the utilization of GHG data in order to improve environmental performance and corporate reputation.

4.2.2 Scope of the LCA

Scoping is an important step in every LCA to establish meaningful and achievable benefits. Defining the scope of an LCA study is clearly described in ISO 14040 guidelines as ‘the functions of the product system, or, in the case of comparative studies, the systems; the functional unit; the product system to be studied; the product

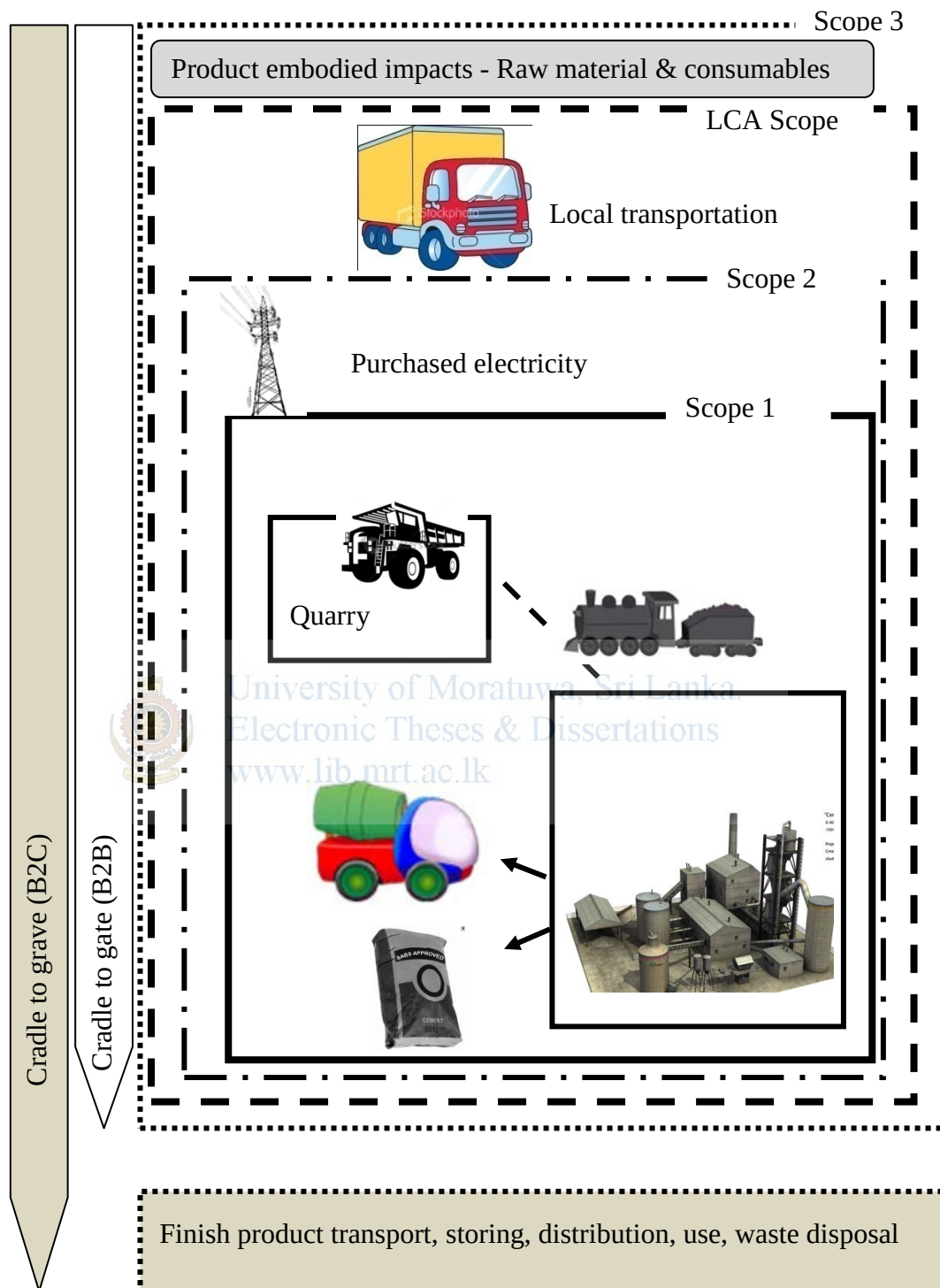
system boundaries; allocation procedures; types of impact and methodology of impact assessment, and subsequent interpretation to be used; data requirements; assumptions; limitations; initial data quality requirements; type of critical review, if any; type and format of the report required for the study' (ISO, 2006).

The scope should be sufficiently well defined to ensure that the breadth, the depth and the detail of the study are compatible and sufficient to address the stated goal (ISO, 1998).

The scope of this study covers from material extraction process to packed cement which dispatches to the lorry at site or bulk cement loaded to the tanker. A comprehensive focus given to greenhouse gas aspect covering the direct and indirect emission extended to local downstream leakage emissions (transport related emissions within the country). This study is a 'cradle to gate' study, which is a 'Business to Business (B2B)' case study. The selected scope is below presented in Figure 4-1. Limitations and functional unit for the selected scope are discussed in sections 4.5.



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LCA scope (including local transporting) — — —

Scope of input / output counting (Physical boundary of cement facility) —

Figure 4-1: System boundary - scope of the Study

Considering the practical data collection constraints and assuming the GHG

contribution to the whole system is negligible following exclusions were made prior to the LCI process.

- Transport related emission for the consumables (not raw material or additives) were not covered other than fire bricks, explosives and cement strengtheners
- Auxiliary energy consumption was not considered because it is not directly effect in the manufacturing process and differs from facility to facility

4.2.3 Rationalizing the selected scope

Cement manufacturing is a complex process. Energy and natural resources are significantly used in cement industry. Input materials are sourced from different geographical locations to comply with the product standard requirements in order to maintain a consistence high quality product and optimize the manufacturing involved cost factors. Most of them are pre-processed at the facility or converted before been used as input materials.

During finish good storing process, there is no significant contribution to environment since the only requirement is a dry place. Since Sri Lanka is a tropical country there is no additional conditioning use at cement warehouses. Current practices have also minimized double handling and there is no significant energy or material been used for storing. Hence the storing phase impacts are not significant with respect to production process related impacts and storing part is not included to the LCA scope. However during the process of logistic, transport related GHG is identified and discussed separately in this study by including it to LCA scope.

Cement in Sri Lanka is mainly used for concrete applications like construction of buildings, bridges, roads, and other infrastructure projects. Also a considerable portion of manufactured cement is used as a raw material for several other industries mainly: producing cement bricks, asbestos industry, constructional pre castings and concrete structures for different purposes. Concrete or cement related product recycling facilities have not been established yet in Sri Lanka. There is a small scale concrete recycling project commissioned at Galle in year 2007. Cement recycling related impacts are not focused due to lack of facilities to re-use or recycle the cement made products and the lack of national interest on such process to be

established in near future.

Accounting of product related GHG increases the value creation of LCA outcomes. However the product embodied GHG data acquisition is less practical without using a commercial LCA software. Even with accessing a commercial LCA software, finding product embodied LCA data customized to local context is a difficult task. A full LCA, with respect to selected category indicator – GHG was prepared for the main input material ‘limestone’. Product GHG related to imported clinker, was separately reported. Above reasons led to finalize the scope, as presented in Figure 4-1.

4.2.4 System boundary exclusions

Few processes and items were excluded from the LCA scope, in order to assure timely completion of the LCA and to improve the quality of the study by minimizing the general data usage which is not specific. The system boundary of the product life cycle excluded the GHG emission associated with below impacts aligning with PAS 2050:2008 guidelines.

- Human energy inputs to processes and/or preprocessing
- Transport of employees to and from their normal place of work
- Animals providing transport services (not related to cement industry)

4.3 LCA Scenarios

The selected three scenarios mentioned in Table 4-5 are studied as LCA scenarios in this specific study. Three different LCI’s were prepared separately using the LCA tool ‘Cement LCA Calculator’. Production of OPC using traditional fuels was identified as the baseline case and year 2001 as the baseline year.

These scenarios were selected to have a comprehensive analysis throughout the changes of the manufacturing processes in Holcim (Lanka) Ltd., Palavi, Puttalam cement factory.

Table 4-5: LCA scenarios (manufacturing scenarios)

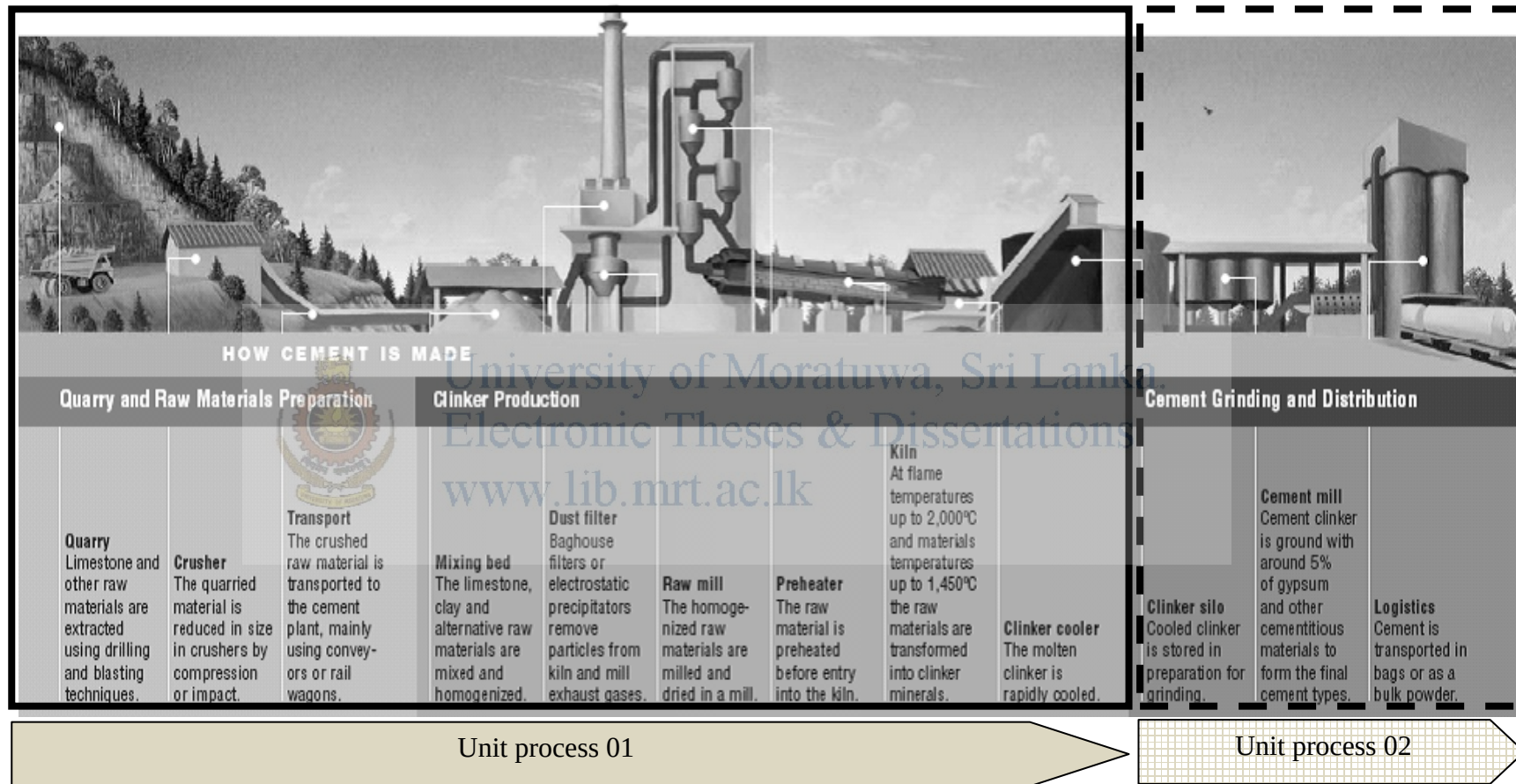
Scenario	Fuel Source	Final Product	Year of Analysis
Scenario 01: Baseline scenario	HFO Type bunker C (1500 , 1800)	OPC only	2001 calendar year
Scenario 02	Coal as the main fuel source	OPC only	2003 calendar year
Scenario 03 : Current scenario	Coal as the main traditional fuel source with AF	Series of application based cement (ABC) products : including PLC, Masonry Cement, and OPC	2007 calendar year

Comparison between several scenarios of a product or a service was provided by the LCA methodology, which supports the selection of ecologically friendly products or services. Comparability of LCA results is particularly critical when different systems are being assessed to ensure that such comparisons are made on a common basis (ISO, 2006). In order to compare the different cement types in a more rational and comparable way functional unit is introduced in section 4.5.

4.4 Unit processes

Unit process is the smallest portion of a life cycle for which data are analyzed when performing a life cycle assessment (ISO, 2006). LCA studies are performed in unit processes in order to study in detail by narrowing the scope. In this study two unit processes were defined considering the goal of the study, scope, data accessing and the extent of the business and presented in Table 2-5. The system boundaries and the material flow for unit process 01 and 02 are defined in section 5.1. Source: (Holcim , 2005)

Figure 4-2 presents the two major unit processes selected in this LCA study. Unit process 01 is shown in the thick color line and Unit process 02 in dashed lines.



Source: (Holcim , 2005)

Figure 4-2 : Two unit processes of the LCA study

4.5 Functional unit

The functional unit defines the quantification of identified function which also consistent with the goal and scope of the study. Having defined the functional unit, the amount of product which is necessary to fulfill the function shall be quantified. The result of this quantification is the reference flow. One of the primary purposes of a functional unit is to provide a reference to which the input and output data are normalized (in a mathematical sense). Therefore the functional unit shall be clearly defined and measurable. (ISO, 1998) This also ensures the characteristic of ‘comparison’ in between different scenarios.

In this study the selected functional unit is: ‘ton of cementitious material’ produced and bagged / loaded to transport fleet. An overview of the selected functional unit with respective to the study is described in the table below.

Table 4-6: Overview of the functional unit of the study

Product	Cement
Functions	Concreting, brick binding, plastering
Relevant function of the particular study	Production (material extraction, clinker production, cement grinding, packing and loading)
Functional Unit	One tonne of cementitious material defined as in above equation (4-1)
Performance of the product	Compliance to locally and globally accepted cement standards
Reference flow	Related cement tonnage derived

Cementitious material is an indicator and not a kind of material physically available which different from cement. It is used as a unique unit to compare in between cement types which as an unbiased measurement of the clinker in cement which is simply the sum of and mineral components. This is defined in ‘The Cement CO₂ Protocol’ as equation (4-1). In this study here onwards abbreviation ‘*cem*’ stands for cementitious material and not cement. All the related inputs (material & energy) and outputs are expressed as specifically referring to the functional unit. Examples: 94kWh/t *cem*, 1200g NO_x/t *cem*

$$\begin{aligned}
\text{Cementitious material} = & \text{Own clinker} + \\
& \text{own clinker sold} + \\
& \text{gypsum, limestone, CKD \& clinker sub. material} + \\
& \text{cement substitutes produced} \quad (4-1)
\end{aligned}$$

Source: (WBCSD, 2005)

4.5.1 Rationalizing the selection of the functional unit

Since the constituent of the cement changes from type to type and from standard to standard it is difficult to compare an impact category by selecting either cement quantity or cement quality related unit as the functional unit. It is mainly because of the change of clinker factor and other clinker substitutions. Change in clinker factor in cement directly (significantly) effect on cement related GHG emissions due to calcination GHG inputs. Cementitious material is like the normalized unit for different cement types. It is used as the functional unit and enable comparing different cement products and it is the mostly used functional unit for cement related quantifying studies.

4.6 Life Cycle Inventory (LCI)

LCI is the next phase, after defining and setting up the LCA scope and the goal which is the data collection process of the LCA study.

Inventorying the environmental inputs and outputs is the second phase of a LCA study. This is one of the significantly important activity throughout the LCA process, since the conclusions and decisions are interpreted on the data / information which gathered and presented in this section in order to properly identify the environmental relevance.

The ISO 14040 (version 2006) ‘International Standard Environmental Management — Life cycle assessment’ was used as the methodology for the LCI phase and ‘Cement LCA Calculator’ was exclusively used as the LCA tool.

An intensive focus was given on each and every set of collected data by following the sequence of activities as recommended in the LCI methodology. Data sourcing is an identified main process constraint for most of the LCA studies mainly due to lack

of data acquisition and difficulties on validating process. Overcoming this common practical constraint was identified as an important area in order to gather accurate data. LCI phase has taken a considerable time portion during the LCA study due to this reason.

Some instances secondary data and estimators were used when primary data is difficult to obtain in order to achieve the project time lines. For some parameters, generic data from reliable data banks like IPCC and WBCSD were used.

Holcim (Lanka) Limited manufacturing data and related official data sources were accessed as primary data to overcome this traditional barrier on data accessibility and accuracy. Globally Holcim practices a unique data reporting protocol which is known as HARP - Holcim Accounting & Reporting Principals. This guides on data collection in a systematic and consistent manner. Data is extracted from continuously updating process records and business enterprise resource planning (ERP) system – SAP. LCI data collection mainly split in to two main processes based on data types and described in sections 4.6.1 and 4.6.2.

The LCI process was started with the material flow analysis which is the core of a LCI inventory covering mass inputs for the processes.

4.6.1 Primary data and sources

Quantitative measurement of an activity from a product's life cycle, when multiplied by an emission factor, determines the GHG emissions arising from a process. Examples of primary activity data include the amount of material and energy used, material produced, service provided or area of land affected. Primary activity data sources are typically preferable relative to secondary data sources as the data will reflect the specific nature / efficiency of the process, and the GHG emissions associated with the process. Primary activity data does not include emission factors. (BSI, 2008)

In this LCA study all the primary activity data is collected by using day to day reporting ERP data source - SAP system. This data acquisition process supported a lot in time efficient data gathering and also increased accurate data selection.

The collected primary data and sources are listed in below Table 4-7 which is

common to selected all manufacturing scenarios. Holcim own annual data reporting file - Annual Technical Report (ATR) was extensively used for annual input and output data collection since it is prepared, validated and approved following the company stringent data management protocols. However it is an annual reflection of the daily collected and derived data from primary sources.

Primary data sourcing is further split into two main streams: consumption and production data. Both data streams are sourced by the annual summary of company ERP data - ATR.

Table 4-7: LCI primary data - inputs

Input segment	Input	Reporting unit	Primary source	Data	Remarks
Raw material	Limestone	[t]	Weighing records through SAP		
	Imported clinker	[t]	Weighing records through SAP		
	Dolomite	[t]	Weighing records through SAP		
	Laterite	[t]	Weighing records through SAP		
Raw material extracting	Explosives	-	[t]	Weighing records through SAP	
supporting material	Gelignite			Weighing records through SAP	
	Explosives	-	[t]	Weighing records through SAP	
	Ammonium nitrate			Weighing records through SAP	
Performance enhancers	Cement	[l]	Number of barrels used (SAP records)	Converted to tons using density 1.12g/ml at 20°C (manufacture specifications)	
	strengtheners				

Clinker substituted material	Limestone Fly ash	[t]	Weighing records through SAP	
Setting regulators	Gypsum	[t]	Weighing records through SAP	
Fuels	Kiln fuel : coal	[t]	Weighing records through SAP	
	Kiln fuel : HFO type bunker C (1500 , 1800)	[m ³]	Flow rate & time data from plant daily records	Converted using specific density as 0.93
	Non kiln fuel sources : Diesel, (type :Super & Auto diesel)	[m ³]	Good issued notes (through SAP)	Converted to mass using specific density as 0.9
	Solid AF: tires, paddy husk, saw dust, mixed industrial waste	[t]	Weighing records (SAP records)	Moisture corrected feed weight
	Liquid AF : waste oil & liquid phase waste	[t]	Flow rate & feeding time data - company SAP records	
Energy	Electrical energy usage from national grid	[kWh]	Daily electricity meter reading (SAP records)	
Consumables	Refractory items (fire bricks using in the kiln), grinding (balls) aids (raw mill & cement mill).	[t]	Goods issued notes during shutdown activities (through SAP)	Considered the items which significantly contributes to GHG

Packaging	Cement bags (converted paper)	[numbers] craft	Issued number of bags (through SAP)	Converted to tonnes using per bag mass equals 200g
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Consumption and output phases data collection made relatively easy due to the HLL practice of systematic data recording in ERP system. Listed data in Table 4-8 below is used as primary outputs of ‘production’.

Table 4-8: LCI primary output data sources

Output segment	Input	Recorded unit	Primary source	Data	Remarks
Unit Process 01 : Material extraction to clinker production	Clinker (intermediate material)	[t]	Weighing records (SAP records)		
	By pass dust leaving the system	[t]	Daily SAP records		Production wastes
	CKD leaving the system	[t]	Daily SAP records		Production wastes
Unit Process 02: Clinker to packed Cement (end product)	Cement	[t]	Weighing records (SAP records)		

From quarry to dispatch all the input and output materials which relates to this LCA study were listed in above two tables. The rest of the used data, listed in Table 4-9 were not acquired from the company’s ERP system. Extra efforts were taken during data validation process with the related senior staff representative of the particular functional area, on below data sources which acquired through company outsourced activities.

Table 4-9: Primary data sources – outsourced activities

Input / output	Parameter	Unit	Primary data source
In-direct GHG calculation	- Transport related GHG emissions - distance one way trip	[km]	
	Transport related GHG emissions – average load per trip	[t/trip]	Registered vendor data from company
	Transport related GHG emissions – fuel consumption loaded trip	[km/l]	procurement and logistics departments
	Transport related GHG emissions – fuel consumption empty trip	[km/l]	

Accessed primary databases for the LCI input phase are listed in Table 4-10. Data sets mentioned in Table 4-7 to Table 4-9 were collected using below primary data reporting sources.

Table 4-10: Databases used for LCI primary data sourcing

Database	Reporting frequency	Description of the records
Annual Technical Report (ATR)	Annually	ATR is a systematic unique questionnaire where Holcim globally use to evaluate its manufacturing performance in every aspect. This is a tool to set the future targets in manufacturing aspects which used globally in every Holcim cement manufacturing facility. Primary data is collected to ATR from company ERP (SAP) system. Filling, validating and verification of ATR are differently responsible tasks and ATR is signed off by the technical director of the company

Plant Environmental Performance (PEP) Report	Annually	Provides comprehensive set of information on cement related environmental components. This includes 17 detail sections which are monitored, reported and quantified globally in a unique manner. PEP is signed off by the CEO of the company
Annual CO ₂ reporting file	Annually (supported by monthly reported figures)	Since Holcim globally committed for CO ₂ reducing efforts, CO ₂ is reported in line with WBCSD –CSI latest protocols. This file contains all the CO ₂ and GHG emission related data.

ATR, PEP and CO₂ reporting files are integrated to each other. All the collected primary data were fed to Cement LCA Calculator and undergone on calculation process keeping the target to deliver the specific LCI outcomes focusing the functional unit & unit processes.

HLL PCW monitors and reports several ecologically sensitive gaseous parameters other than CO₂ (GHG). These gaseous emissions are also reported publically through company ‘Annual Sustainable Development Report’. These parameters and outputs are stated and discussed in the Annexure V. All these data are presented in LCIA profile - environmental balance sheet in section 5.4.

4.6.2 LCI – Secondary data & sources

Secondary data is defined as ‘data obtained from sources other than direct measurement of the processes included in the life cycle of the product’. (BSI, 2008) Secondary data is used when primary activity data is not available or it is impractical to obtain primary activity data. Following data were extensively used throughout the study on calculation purposes as secondary data sources. Maximum precautions were taken to collect the latest available and accurate data with respect to the corresponding time line.

Some secondary data sources are derived from standard protocols and formulae. Data

which are highly scientific and not available due to practical and technical reasons also reported from validated data sources in order to result an accurate LCI process.

Table 4-11: Secondary data sources

Input output	/	Parameter and figure	Data source	Remarks
Direct GHG calculation purpose	-	Default TOC (total organic carbon) content of raw meal: 2 kg/t raw meal (dry weight, corresponding to 0.2%)	The Cement CO ₂ Protocol (WBCSD - CSI, 2005)	Organic CO ₂ calculation
		Clinker factor of Company produced cement [%]	Company data sources – monthly management reviews	Definition: Clinker factor = total clinker volume in cement / total cement volume. Calculated using internal primary data, monthly basis
		Default raw meal to clinker ratio: - 1.55	The Cement CO ₂ Protocol (WBCSD - CSI, 2005)	
		Conversion factor from tonne of Carbon to tonne of CO ₂ - 3.664	The Cement CO ₂ Protocol (WBCSD - CSI, 2005))	Derived from stoichiometric calculations
		Calcination CO ₂	The Cement CO ₂ Protocol and ATR	
		Kiln fuel CO ₂	calculated data	
		Non kiln fuel CO ₂		
Indirect GHG calculation		National grid GHG factor – 426 kgCO ₂ e/MWh	Intergovernmental Panel on Climate Change data base	

Emission factor of The Cement CO ₂ imported clinker : Protocol (WBCSD - default figure 862 CSI, 2005)	
kgCO ₂ e/t cli	
Lower heat Transport GHG consumption of fuel – emission	
diesel : 0.37GJ/l	calculations, WRI &
CO ₂ emission per heat WBCSD developed	
consumed : 74.010	MS Excel workbook
kgCO ₂ e/GJ	‘Emission
	Calculated from Fuel
	Used’

4.6.3 LCI data validation process

Validating of all the collected data is a requirement of LCA methodology. Since HLL data reporting and maintaining procedures are covered under ISO 9001:2000 quality management system, it ensures the accurate data reporting and proper data management. Periodic audits are performed to ensure the accuracy of data monitoring, reporting and storing. Data verification and approval authority is also well defined which enhances the higher data accuracy and accountability. Validating authorities and extended validating steps taken to maintain accuracy is shown in below Table 4-12.

Table 4-12: LCI data validating / verification process

Name of the data source	Data validating authority	Data approving authority	Validating steps
ATR	Plant management level	Top management	Each section audited and cross-checked with previous year data. Primary data source is business ERP system and related other official data.

				Data entered as year to date (YTD) base only to represent the cumulative effect during the respective year.
Business ERP (SAP) system	Business process owners	Department heads	Checking process are established in specific intervals and weekly, monthly basis	
PEP	Environmental Management	Top management	Year end reporting, supported with estimated monthly reporting	
			Primary data sources are ERP, ATR and Emission reports from third party accredited laboratories	
Annual CO ₂ file	Plant management, environmental management	Top management, Holcim (Group) Switzerland	CO ₂ file itself have validating steps	
			Formulae are not validated since the file is generated fully aligned to the CSI - GHG protocol.	

4.7 Life Cycle Impact Assessment - LCIA

Collected and analyzed environmental inputs and outputs in the earlier LCI phase is evaluated under LCIA phase. LCIA is the phase that also analyses encompasses numerous environmental impacts. ISO 14042 was the followed methodology for the LCIA phase. There are several mandatory elements which known as 'LCIA elements' which described in the methodology. These LCIA components are enabled to simplify the findings of LCI phase. The main LCIA elements are shown in Figure 4-3 below.

A comparative assertion can be only undergone by fulfilling the requirements for LCI in an understandable and detailed manner. In the case of comparative assertions

disclosed to the public, this evaluation shall be conducted in accordance with the critical review process of ISO 14042 - 2000 as stated in section 7.3.3. Another requirement for comparative assertions disclosed to the public is that an impact assessment shall be performed (ISO, 2006). This is an important component when only a public disclosure is required. Producing ‘category indicator results (LCIA Profile)’ was kept as the objective of LCIA phase by delivering results and presented using ‘Environmental Balance Sheet’ concept in chapter 5.4.

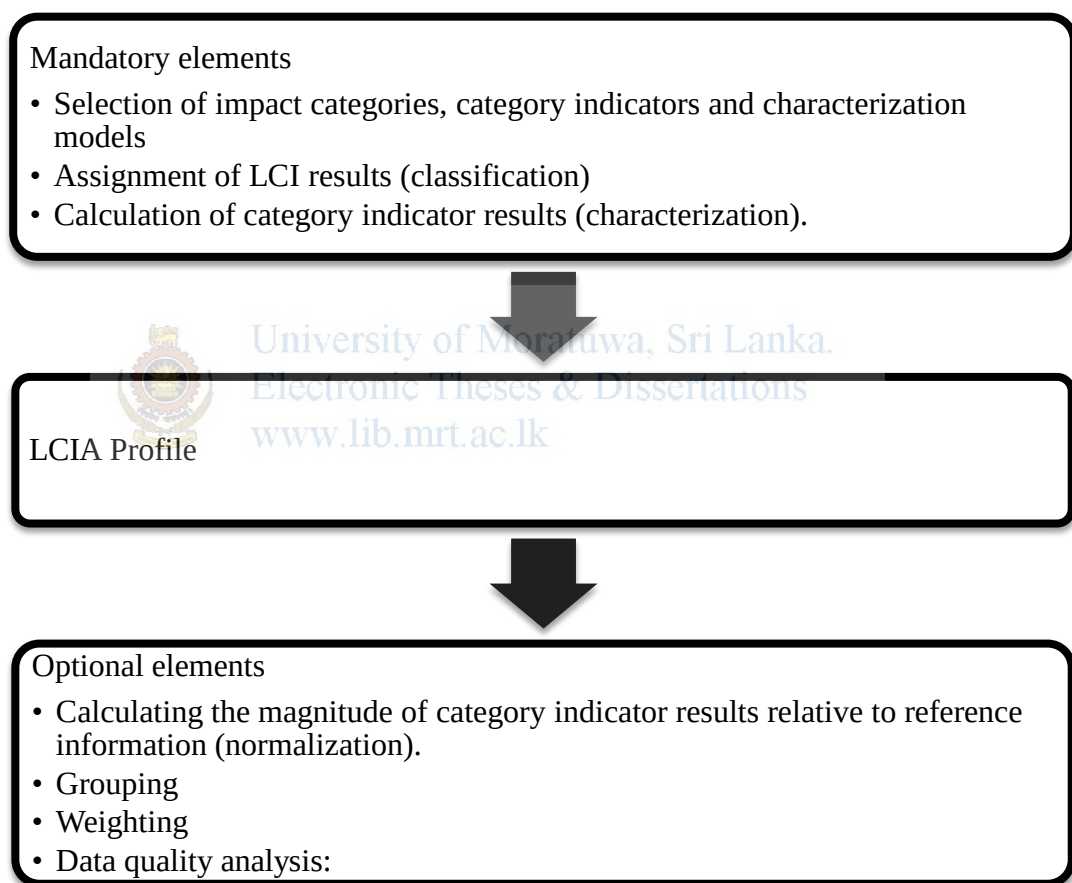


Figure 4-3: Elements of the LCIA phase

The selection of impact categories, category indicators and characterization models shall be consistent with the goal and scope of the LCA study (ISO, 2006). The goal and scope of this LCA study is fully focused on environmental impacts related to climate change, made by GHG emissions. The LCIA definition and category results are tabled below.

Table 4-13: LCIA definitions and parameters specific for this study

Parameter	Definition (as per ISO 14042)	Parameter related to this LCA study
Impact category	Class representing environmental issues of concern to which LCI results may be assigned	Climate change
Life cycle impact category indicator (category indicator)	Quantifiable representation of an impact category	Emitted absolute GHG in tCO ₂ e equivalent and normalized to functional unit as kgCO ₂ e/t cem
Category endpoint	Attribute or aspect of natural environment, human health or resources, identifying an environmental issue of concern	Coral reefs, forest, crops, ecological systems, vulnerable species, human adaptations, water bodies, and land usage
Characterization factor	Factor derived from a characterization model which is applied to convert the assigned LCI results to the common unit of the category indicator	Global warming potential for each greenhouse gas (kgCO ₂ e/kg gas) In this study it was focused CO ₂ as the only GHG. Conversion been made by characterizing the emissions to 'per tonne of cementitious material'
Environmental mechanism	System of physical, chemical and biological processes for a given impact category, linking the LCI results to category indicators and to category endpoints	

- Assignment of LCIA results – classification

In this specific study it was defined in the scope ‘climate change’ only consider as the impact category in order to carry out the in a detail manner while achieving the time commitments. This also supports on studying the cement related major environmental impact – GHG emissions which is common to each cement company.

- Calculation of character indicator results – characterization

The calculation involves the conversion of LCI results to common units and the aggregation of the converted results within the impact category. This conversion uses characterization factors. The outcome of the calculation is a numerical indicator result. (ISO, 2006) The characterization phase of LCIA was aligned to the LCA goal & scope.

All the calculations were performed through the ‘Cement LCA Calculator’. The character indicator results were presented as emitted GHG in kgCO₂e and normalized to functional unit as kgCO₂e/t cem. Throughout the LCIA phase and in the interpretation phase kgCO₂e/t cem was used as the characterization factor which is same to the functional unit this case.

- Grouping & weighting of impacts

LCA methodology was established with the provision of comparing different product (or services) types by assessing all the related ecological impacts. LCI indicators and definitions were set up aligning to the set goal & scope.

This reference is necessary to ensure comparability of LCA results. (ISO, 2006). Compare two different cement manufacturing scenarios is one of the identified key objectives of this research. Cement LCA Calculator the LCI tool which used in this study was specifically considered on introducing parameters to relate with functional unit by following the above structure.

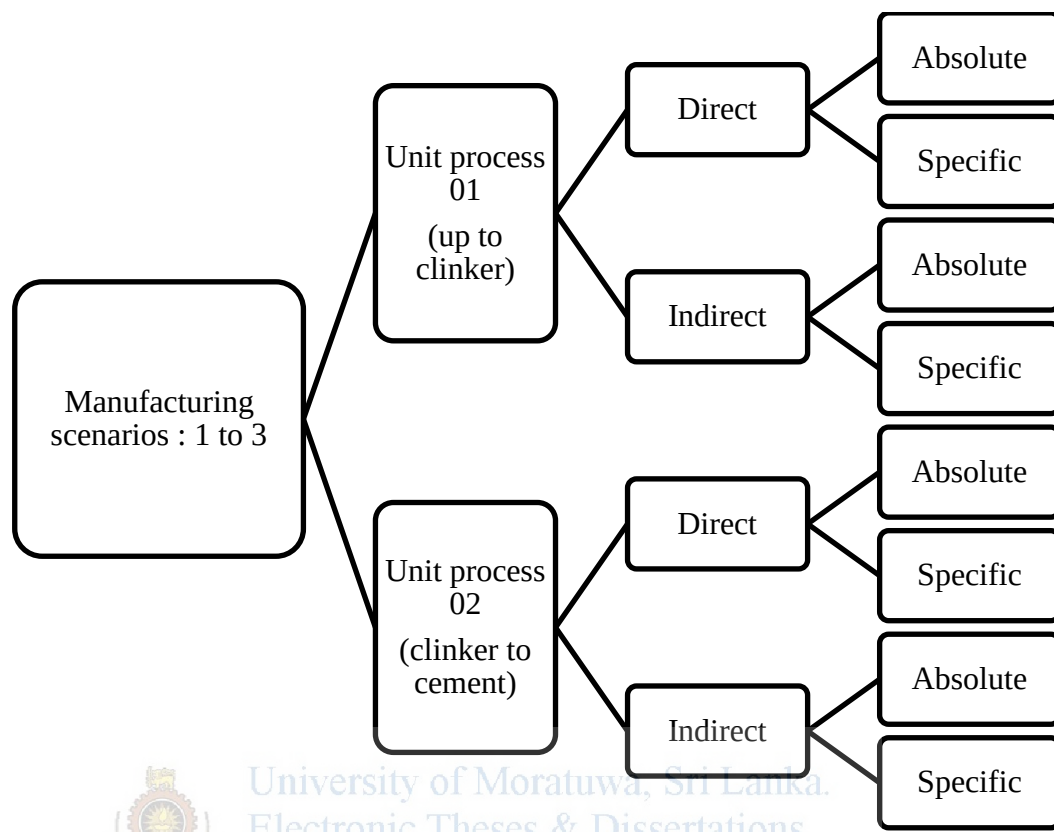


Figure 4-4: LCI data grouping structure in 'Cement LCA Calculator'

The defined LCI data grouping structure in Figure 4-4 was used in Cement LCA Calculator and presented using below set of indicators. These parameters can be further elaborated as 'final indicators' of this study and used to present the related findings in the LCIA phase and interpretation phase.

Table 4-14: Indicators defined related to functional unit

Parameter	Description
Absolute emissions	GHG Summation of GHG emissions in CO ₂ equivalent and presented as tCO ₂ e/year covering scope 01, 02 and selected scope 03 items
Specific emissions	GHG GHG emissions in CO ₂ equivalent presented as specific CO ₂ e/t cem covering scope 01, 02 and selected scope 03 items

There are two types of specific GHG indicators; specific gross emissions and specific net emissions. Specific gross indicators are similar to the calculated specific GHG emissions with respect to the scope. Net emission is an indicator for a company's net carbon footprint. They reflect a company's direct emissions as well as indirect emission reductions achieved, for example, by purchasing emissions allowances in the market (WBCSD, 2005). Net GHG calculation is defined as below equation which relates to both absolute and specific emission.

$$\text{Net CO}_2 \text{ emissions} = \text{Gross CO}_2 \text{ emissions} - \text{Acquired emissions rights} \quad (4-2)$$

Where,

$$\begin{aligned} \text{Acquired emission} &= \text{Allowance ((+) bought (-) sold) +} \\ \text{rights} &\text{ CER's ((+) bought (-) sold)} \end{aligned} \quad (4-3)$$

Source: (WBCSD, 2005)

Since Sri Lanka being an annex B country (as per the Kyoto protocol country categorization) GHG allowances are not relevant and for HLL case there is no relevance to CER's availability due to no Cleaner Development Mechanism (CDM) project realized or planned.

The combination of direct emission impacts, indirect emission reductions, and resource efficiency makes the substitution of AF for conventional fossil fuels an effective way to reduce global GHG emissions (WBCSD, 2004).

The requirements regarding the reporting of CO₂ emissions from fossil fuel-based AF (also called "fossil AF" or "alternative fossil fuels") widely vary between different schemes. The balance sheet approach provides a flexible frame-work for reporting under different schemes while ensuring completeness, rigor and transparency of reporting. Following reporting guidelines from 'Cement GHG Protocol' were adopted and aligned to the primary data source – ATR reporting practices.

- Direct CO₂ emissions resulting from the combustion of fossil AF must always be included in the company's gross emissions, in accordance with section "CO₂ from alternative kiln fuels".

- Credits for indirect emission reductions can be reported under “Acquired Emission Rights”, depending on and in compliance with the rules of the scheme under which the reporting is taking place.
- The resulting net emissions, being the gross emissions minus the acquired emission rights, reflect the emissions according to the rules of the reporting scheme under consideration.

Below two new parameters were introduced for the successful data representation of the study. ‘Net GHG’ calculations were performed by subtracting the fossil AF base GHG emissions from gross emissions. This can be again split in to two indicators considering the interest of interpretation as absolute and specific. Absolute and specific net CO₂ emissions are defined in below two equations.

$$\text{Absolute Net CO}_2 = \text{Gross absolute emissions [tCO}_2\text{e/y]} - \text{gross absolute emissions from fossil AF [tCO}_2\text{e/y]} \quad (4-4)$$

$$\text{Specific Net CO}_2 = \frac{\text{Absolute net CO}_2 \text{ emissions [tCO}_2\text{e/y]}}{\text{annual cementitious material production [t cem/y]}} \quad (4-5)$$

Specific mass input was also introduced in order to study the material consumption patterns and its related GHG impacts, though it has no direct relationship with the selected category indicators. However it provides an understanding on the specific material contribution. The frequently used two indicators were defined as below.

$$\text{Total mass input} = \sum (\text{inputs}), [\text{t/y}] \quad (4-6)$$

Above absolute parameter represents materials which contribute to manufacture cement (raw materials, fuel mass, tare & ware parts, packaging and additives) and below parameter presents the specific material contribution.

$$\text{Specific mass factor of material}_i = \frac{\text{Mass input of material}_i}{\text{total mass input}} \quad (4-7)$$

4.8 LCA software - ‘Cement LCA Calculator’

The overall objective of the collecting of data for LCA study is to establish the specific values with respect to unit processes and functional unit. This process is started from LCI. Data gathering and tabulating is an important process which is also complex in cement LCA studies. In order to compare the selected three scenarios LCI data collection require three separate efforts.

There are more than 30 LCA software tools presently available compatible with cement LCA studies. However these software are not financially affordable for a single LCA research. There is no commercially registered LCA software package found in Sri Lanka. Above reasons led to identify developing in-house LCA software as a research objective.

‘Cement LCA Calculator’ is introduced as the LCA tool for cement related GHG calculations and it covers from GHG reporting scopes from 1 to 3. The developed software requires only feeding of primary and some selected secondary data and it calculates the absolute GHG emission and then converts to product specific functional unit and unit processes. Program is fully supported in using the ‘Cement GHG Protocol’ introduced by CSI and WBCSD which is the mostly internationally used GHG protocol in cement industry. CSI - GHG tool was validated by the WBCSD and WRI. Hence using input data as secondary data from a validated GHG tool further increases the accuracy of the input data. Some of the calculated figures in CSI - GHG tool are directly fed such as calcination CO₂, total organic CO₂ and CKD and by pass dust related to CO₂.

Cement LCA Calculator is fully supported and aligned with most of the PAS 2050 guidelines for the selected cement manufacturing scope (cradle to gate). Tool can be used as a mini software for cement industry and researches focusing on category end point - climate change.

Final results of the LCI needed to lean towards the LCI expectations satisfying the goal & scope of the LCA study and all the indicators are linked to the selected two unit processes. Collected data which fed to LCI tool were thoroughly analyzed. The

outputs supported in, studying the impacts in different process steps and functional units to compare the three scenarios.

This software contains two main components; mainly input sheets and output sheets. Through input sheets the collected LCI data is fed to the program and the output are retrieved through output sheets. There are three main input sheets for the selected three manufacturing scenarios (shown in Table 4-15) and the appropriate scenario can be selected from the sheet menu. In each input sheet the data collection structure and the formulae are formatted uniquely in order to optimize the comparing ability in between different scenarios. There are few options to select accessing the output sheets (shown in Table 4-15) which customized to provide required data fields for the LCIA component.

Table 4-15: Input sheets and output sheets in mini LCA tool

Input sheets	Output sheets
HFO,OPC_01	Summary Mass&GHG
Coal,OPC_03	Sector Summary
Cpal+AFR,ABC_07	Env Balance Sheet Energy
	Env Balance Sheet Mass

The main data input area is used to feed all the primary data and selected data from Cement GHG Protocol which shown in below Figure 4-5. The program is consisted of three sets of these data selected for each scenario and calculations are processed separately.

Clinker Consumption [tcl/y]	471,236.0	Non Kilns Fuel (Diesel)consumed for Limestone Extract + Transport [%]	95.0
Cement Production [t cem/y]	509,168.0	Total CO2 from Non Kiln fuel - Vehicles On site Instruments [t CO2/y]	5,243.2
Own clinker production [tcl/y]	447,904.0	Total CO2 raw meal converted to clinker [t CO2/y]	236,268.5
Total Organic CO2 [t CO2/y]	5,087.5	Grid Factor [kg CO2/Mwh]	417.0
In-direct : CO2 from Purchased Electrical Energy [t CO2/y]	25,144.1	Cementitious Material [t]	485,708.0
Total Diesel Consumption [t/y]	1,387.0	Clinker Factor [%]	92.58

Figure 4-5: Main data input area in ‘Cement LCA Calculator’

The total calculated area is divided in to four main segments as; mass input, direct scope 01 emission inputs, indirect scope 2 and scope 3 emission inputs and analysis. These four segments are again split in to two main areas: process units 01 and 02 as defined in chapter 4.4. These different phases are shown in below figures from

Figure 4-6 to Figure 4-7 from 'Cement LCA Calculator'.



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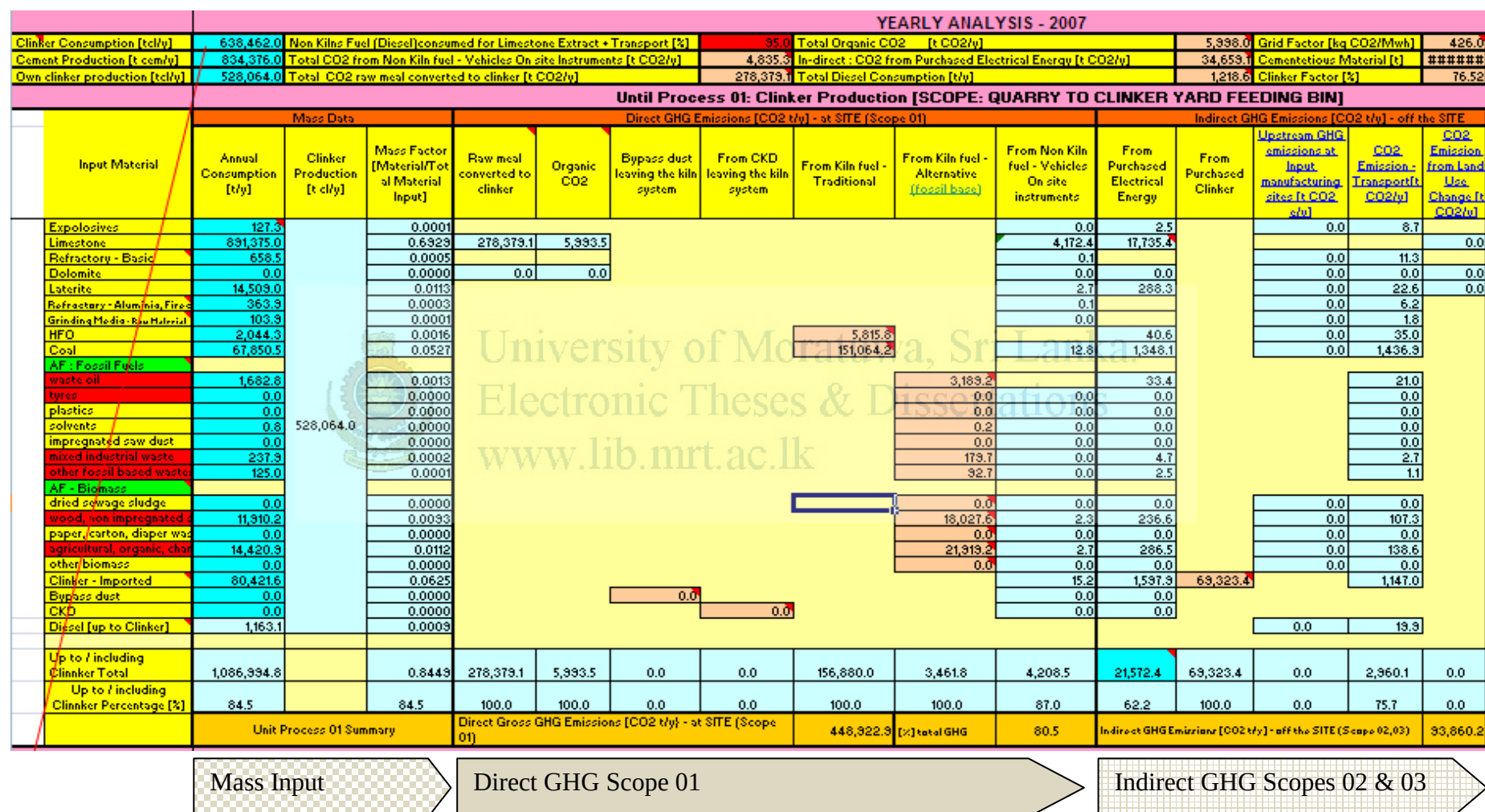


Figure 4-6: LCI data input analysis area - Unit process 01

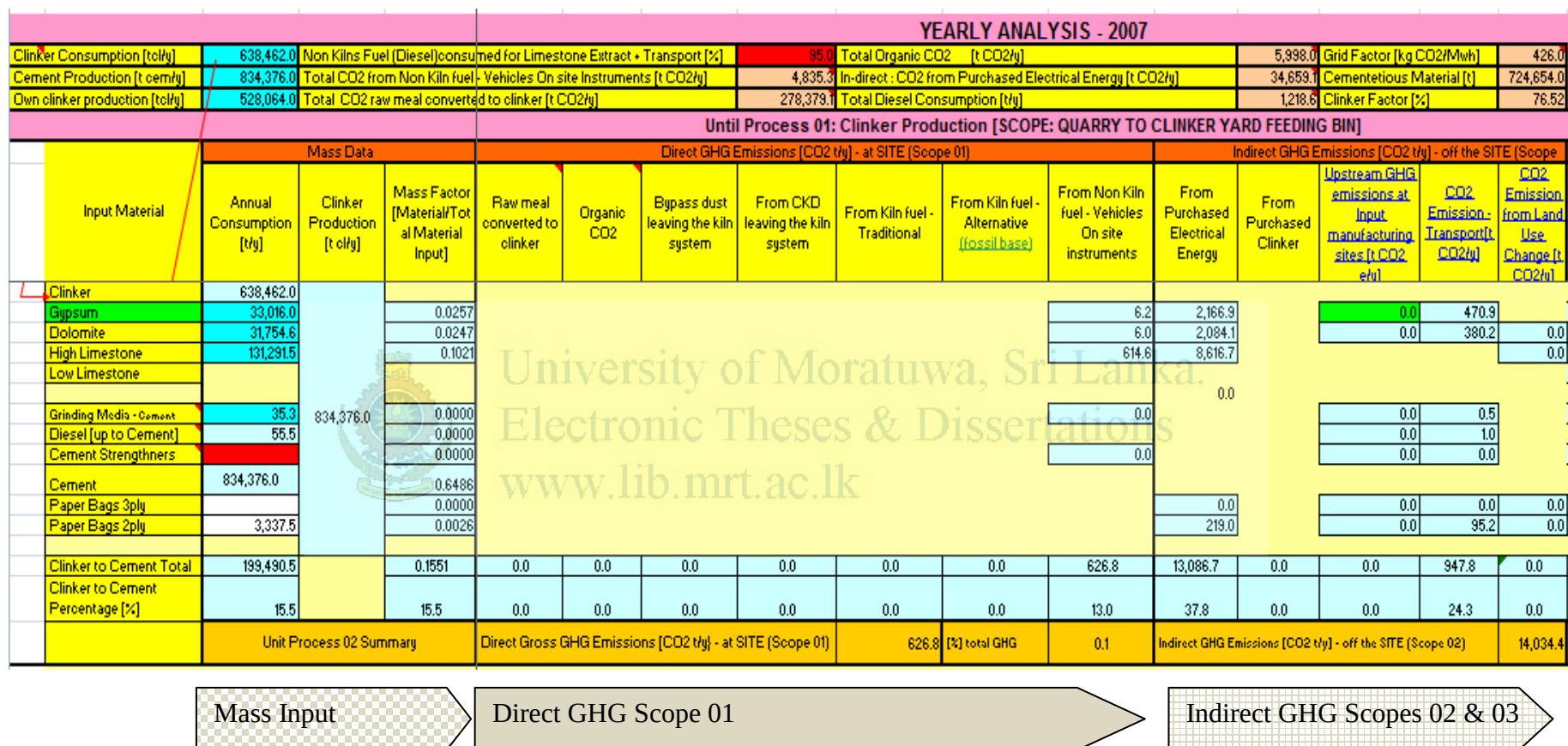


Figure 4-7: LCI data input analysis area - Unit process 02

Main output sheets in LCIA phase are shown in below figure which found in two output sheets in Cement LCA Calculator. The GHG analyses in scope, factor and unit process wise are calculated right hand side of the same LCI (input) sheets. Material balance sheets are presented separately.

Input Material		Analysis				
		Total GHG Emission (Direct) Gross Absolute [tCO ₂ /y]	Total GHG Emission (Indirect) Gross Absolute [tCO ₂ /y]	Credits for GHG Savings Excess AF	AF Biomass (tCO ₂ /y)	Net GHG Direct & Indirect [tCO ₂ /y]
Explosives		0.0	8.9			9.0
Limestone		245,430.6	14,043.5			260,480.1
Refractory - Basic		0.2	12.6			12.8
Dolomite		0.0	0.0			0.0
Laterite		5.8	381.1			387.5
Refractory - Alumina, Fireclay		0.1	3.2			3.3
Grinding Media - Raw Material		0.0	1.4			1.4
HFO		134,428.9	1,458.0			135,886.9
Coal		0.0	0.0			0.0
AF - Fossil Fuels						
waste oil		0.0	0.0	0.0		0.0
tyres		0.0	0.0	0.0		0.0
plastics		0.0	0.0	0.0		0.0
solvents		0.0	0.0	0.0		0.0
impregnated saw dust		0.0	0.0	0.0		0.0
mixed industrial waste		0.0	0.0	0.0		0.0
other fossil based wastes		0.0	0.0	0.0		0.0
AF - Biomass						
dried sewage sludge		0.0	0.0		0.0	0.0
wood, non impregnated saw		0.0	0.0		0.0	0.0
paper, carton, disposable		0.0	0.0		0.0	0.0
agricultural, organic, charcoal		0.0	0.0		0.0	0.0
other biomass		0.0	0.0		0.0	0.0
Clinker - Imported		11.7	36,788.0			36,799.7
Bypass dust		0.0	0.0			0.0
CKD		0.0	0.0			0.0
Diesel [up to Clinker]			22.6			22.6
Up to / including Clinker Total		380,877.4	52,725.9	0.0		433,603.3
Up to / including Clinker Percentage [%]		100.0	84.6	0.0		97.8
Input Material		Analysis				
		Total GHG Emission (Direct) Gross Absolute [tCO ₂ /y]	Total GHG Emission (Indirect) Gross Absolute [tCO ₂ /y]	Credits for GHG Savings Excess AF	AF Biomass (tCO ₂ /y)	Net GHG Direct & Indirect [tCO ₂ /y]
Clinker		4.2	3,637.7	0.0	4.2	3,701.9
Gypsum		0.0	0.0			0.0
Dolomite		0.0	0.0			0.0
High Limestone		141.8	5,348.1			5,489.9

Phase 01: Material Balance		Mass input [kg/ton cem]		
		HFO, OP C, 2001	Coal, O PC, 2003	Coal+A FR+ABC, 2007
Unit Process 01 [upto clinker production]	Raw material	Limestone	1686.933	1518.746
		Dolomite	0.000	2.984
		Laterite	42.056	28.624
	Support material	Explosives	0.216	0.201
		Refractory - Alumina, Fireclay	0.386	0.368
	Consumables	Refractory - Basic	1.514	1.444
		Grinding Media - Raw Material	0.167	0.164
	Conventional fuel	HFO	87.664	0.567
		Coal	0.000	142.056
	AF - Fossil Fuels	Waste oil	0.000	0.000
		Tyres	0.000	0.498
		Solvents	0.000	0.000
		Mixed industrial waste	0.000	0.328
		Other fossil based wastes	0.000	0.172
	AF - Biomass	Wood, non impreg saw dust	0.000	0.000
Unit Process 02 [clinker to cement]		Agricultural, organic, charcoal	0.000	19.900
		Clinker - Imported	84.779	0.000
	Waste	Bypass dust	0.000	0.000
		CKD	0.000	0.000
	Non kiln fuel	Diesel [up to Clinker]	2.722	2.305
Up to / including Clinker Percentage [%]			95.9	92.8
Unit Process 03 [cement]		Clinker	922.167	879.402
	Regulator	Gypsum	30.691	34.622
	Additives	Dolomite	0.000	0.000
	MIC	High Limestone	47.098	92.584

Figure 4-8: LCIA sheet and an output summary data sheet

Selecting the functional unit is a very useful option in the Cement LCA Calculator. Program has the facility to change the functional unit programming cell in order to calculate different functional analysis which enables to provide the LCI data specific to the requirement. Different functional approaches are supported on specific comparative analysis which is a primary objective of the whole LCA concept. Depend on the selected functional unit the appropriate factor can be fed in to the functional unit programming bar, which enables to convert and access all the specific figures with respect to the selected functional unit. In this LCA study since ‘one tonne of cementitious material’ was selected, below conversion factor for was used.

FUNCTIONAL UNIT	1ton cem mat	Convertor	0.0021
------------------------	--------------	------------------	---------------

Figure 4-9: Functional unit programming bar

		Unit Process 02 Summary	Direct Gross GHG Emissions (CO2 t/y) - at SITE (Scope 01)				0.3	% total GHG	0.0	kg
Total Mass & GHG Analysis Percentage (absolute net) [%]	1,988.6	0.0	1.0000	486.4	10.5	0.0	0.0	276.8	0.0	10.8
				53.3	1.1	0.0	0.0	30.3	0.0	1.2
		Total Process (Unit 01 & 02) Summary	Direct Gross GHG Emissions (CO2 t/y) - at SITE (Scope 01)				784.4	% total GHG	85.9	kg

Figure 4-10: Specific functional analysis snap shot

The other features and facilities of the Cement LCA Calculator software are mentioned under the appropriate sub chapters.

4.9 LCI preparation: Direct GHG (Scope 01) emissions

Direct GHG emissions (also known as Scope 01 GHG emissions) occur from sources that are owned or controlled by the company as introduced in chapter 4.1.2. Common examples for direct GHG emissions are emissions from combustion in owned or controlled boilers, furnaces, vehicles, emissions from chemical production in owned or controlled process equipment (WBSCD, WRI, 2004).

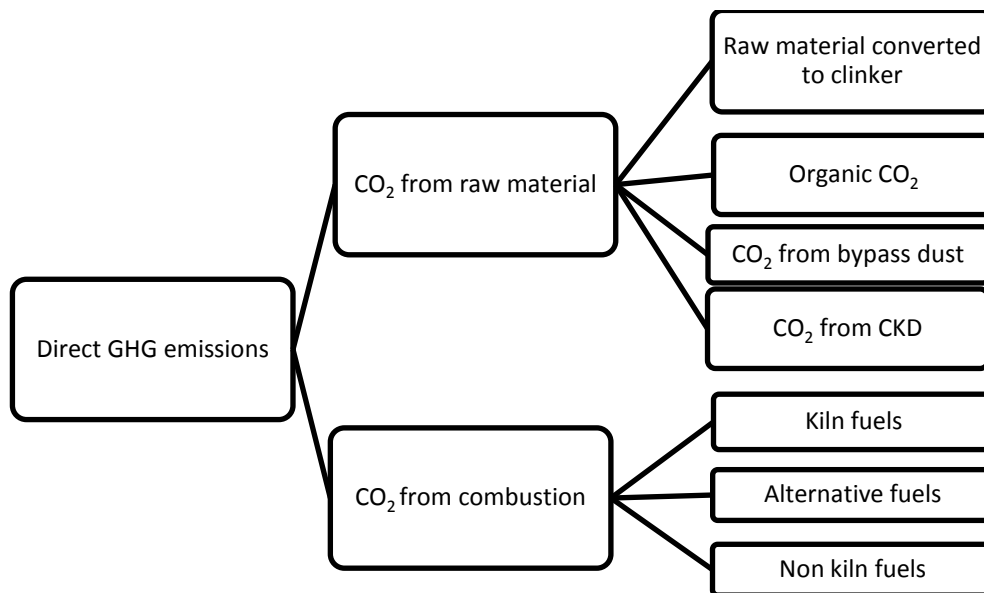


Figure 4-11: Direct GHG elements in cement manufacturing process

Direct GHG emission relates to cement manufacturing process can be categorized in to two main streams as shown in Figure 4-11, mainly as CO₂ from raw materials and from fuel combustion. Direct CO₂ emissions from the combustion of biomass shall not be included in scope 1 but reported separate (WBSCD, WRI, 2004). Cement LCA Calculator was designed considering these GHG generating aspects. The related GHG emission category with respect to input materials can be identified in a separate color which eases the process of inventorying and analysis. Only the respective input materials are given active cell to input GHG emissions to ensure the accuracy during data processing.

Input Material	Mass Data			Direct GHG Emissions [CO ₂ t/y] - at SITE (Scope 01)						
	Annual Consumption [t/y]	Clinker Production [t cl/y]	Mass Factor [Material/Total Material Input]	Raw meal converted to clinker	Organic CO ₂	Bypass dust leaving the kiln system	From CKD leaving the kiln system	From Kiln fuel - Traditional	From Kiln fuel - Alternative (fossil base)	From Non Kiln fuel - Vehicles On site instruments
Explosives	104.9	447,904.0	0.0001							0.0
Limestone	819,357.0		0.8483	236,268.5	5,082.9					5,079.3
Refractory - Basic	735.5		0.0008							0.2
Dolomite	0.0		0.0000	0.0	0.0					0.0
Laterite	20,427.0		0.0211							5.8
Refractory - Alumina, Fireclay	187.5		0.0002							0.1
Grinding Media - Raw Material	81.2		0.0001							0.0
HFO	42,579.0		0.0441					134,428.9		
Coal	0.0		0.0000					0.0		0.0
AF - Fossil Fuels			0.0000							
waste oil	0.0		0.0000						0.0	
tyres	0.0		0.0000						0.0	0.0
plastics	0.0		0.0000						0.0	0.0
solvents	0.0		0.0000						0.0	0.0
impregnated saw dust	0.0		0.0000						0.0	0.0
mixed industrial waste	0.0		0.0000						0.0	0.0
other fossil based wastes	0.0		0.0000						0.0	0.0

Figure 4-12: Direct GHG emission fields in 'Cement LCA Calculator'

A special focus was given to scope 1 emissions during LCIA phase, due to majority of GHG emission sources and absolute contribution is from this cluster. The LCI analysis was performed by splitting the direct GHG emissions into two main streams, aligned to ‘Cement CO₂ Protocol’ as shown in Figure 4-11.

4.9.1 CO₂ from raw material

There are several emission components which are fallen into category ‘CO₂ from raw materials’ and GHG generating components and relationship is shown in below equation.

$$\begin{aligned} \text{Total CO}_2 \text{ from raw materials} = & \text{CO}_2 \text{ from raw meal converted to clinker} + \\ & \text{CO}_2 \text{ from bypass dust leaving the kiln system} + \\ & \text{CO}_2 \text{ from calcination of CKD leaving the kiln} + \\ & \text{CO}_2 \text{ from organic carbon content of raw meal} \quad (4-8) \end{aligned}$$

Source: (WBCSD, 2005)

Below figure shows the LCI data input area of the CO₂ from raw material.

ption (tcl/y)	470,057.0	Non Kilns Fuel (Diesel) consumed for Limestone Extract + Transport (%)	95.0	Total Organic CO ₂ (t CO ₂ /y)	5,954.5							
ction (t cem/y)	541,943.0	Total CO ₂ from Non Kiln fuel - Vehicles On site Instruments (t CO ₂ /y)	5,580.2	In-direct - CO ₂ from Purchased Electrical Energy (t CO ₂ /y)	28,017.7							
duction (tcl/y)	524,238.0	Total CO ₂ raw meal converted to clinker (t CO ₂ /y)	276,370.5	Total Diesel Consumption (t/y)	1,433.0							
Until Process 01: Clinker Production [SCOPE: QUARRY TO CLIN]												
Input Material	Mass Data			Direct GHG Emissions (tCO ₂ tcl ⁻¹) - at SITE (Scope 01)								
	Annual Consumption (t/y)	Clinker Production (t cl/y)	Mass Factor (Material/Total Material Input)	Raw meal converted to clinker	Organic CO ₂	Bypass dust leaving the kiln system	From CKD leaving the kiln system	From Kiln fuel - Traditional	From Kiln fuel - Alternative (fossil base)	From Non Kiln fuel - Vehicles On site instruments	From Purchased Electrical Energy	From Purchased Clinker
Explosives	119.6	524,238.0	0.000							0.0	2.2	
Limestone	905,370.0		0.8304	275,828.5	5,937.2					5,229.1	16,650.5	
Refractory - Basic	860.9		0.0008							0.2		
Dolomite	1,779.0		0.0018	542.0	11.7					0.5	32.7	
Laterite	17,063.5		0.0158							4.4	313.5	
Refractory - Alumina, Fireclay	219.5		0.0002							0.1		
Grinding Media - Raw Material	97.5		0.000							0.0		
HFO	338.0		0.0003						1,063.2			6.2
Coal	84,684.0		0.0777						186,510.7		21.7	1,555.7
AF - Fossil Fuels			0.0000									
Waste oil	0.0		0.0000							0.0		0.0
Waxes	297.1		0.0003							808.2	0.1	5.5
Plastics	0.0		0.0000							0.0	0.0	0.0
Solvents	0.0		0.0000							0.0	0.0	0.0
Impregnated saw dust	0.0		0.0000							0.0	0.0	0.0
Mixed industrial waste	0.0		0.0000							0.0	0.0	0.0
Other fossil based wastes	0.0		0.0000							0.0	0.0	0.0
AF - Biomass			0.0000									
Dried sewage sludge	0.0		0.0000							0.0	0.0	0.0
Wood, non impregnated saw	0.0		0.0000							0.0	0.0	0.0
Paper, carton, diaper waste	0.0		0.0000							0.0	0.0	0.0
Agricultural, organic, charcoal	0.0		0.0000							0.0	0.0	0.0
Other biomass	0.0		0.0000							0.0	0.0	0.0
Clinker - Imported	0.0	0.0000								0.0	0.0	0.0
Bypass dust	0.0	0.0000				0.0				0.0	0.0	0.0
CKD	0.0	0.0000					5,504.5			0.0	0.0	
Eqv Balance Sheet Mass												

Figure 4-13: LCI data input in ‘Cement LCA Calculator’ - CO₂ from raw material

- Calcination CO₂

Calcination is the release of CO₂ from carbonates during pyroprocessing of the raw meal. Calcination CO₂ is directly linked with clinker production (WBCSD - CSI, 2005). In addition, calcination of cement kiln dust (CKD) and bypass dust can be a relevant source of CO₂ where such dust leaves the kiln system for direct sale, addition to cement or for discarding as a waste. On plant level, calcination CO₂ can be basically calculated in two ways: based on the volume and carbonate content of the raw meal consumed or based on the volume and composition of clinker produced plus dust leaving the kiln system (WBCSD - CSI, 2005). The raw meal-based method is often used in the U.S. and Japan, while the clinker-based method is being suggested in the revised IPCC guidelines for national GHG inventories of 1996. The two methods are, in theory, equivalent (WBCSD - CSI, 2005). CSI decided to focus on the clinker-based method in the protocol spreadsheet.

HLL is also selected the clinker based methodology since Holcim Group is one of the pioneer members of CSI. In doing so, possible sources of error such as direct additions of carbonate-containing materials to the kiln, internal recycling of dust, as well as incomplete calcination of dust leaving the kiln system shall be accounted. To apply the clinker-based method, companies use their plant-specific data. Calcination CO₂ shall be calculated based on the volume of clinker produced and an emission factor per tonne of clinker. The emission factor shall be determined based on the measured CaO (Calcium oxide) and MgO (Magnesium oxide) contents of the clinker and corrected if relevant quantities of CaO and MgO in the clinker stem from non-carbonate sources. This could be the case, for example, if calcium silicates or fly ash are used as raw materials entering the kiln.

In HLL dolomite is used as a corrective material which contains both CaO and MgO and the correction is been made for it. The determination of the emission factor for clinker is clearly documented in HLL CO₂ calculation spreadsheet and in the ATR. In the absence of better data, a default of 525 kgCO₂e/t cli shall be used. This value is a conservative figure comparable to the IPCC default (510 kgCO₂e/t cli). In HLL case, the calculated figures are used as per the below equation, instead of the default value. LCI results of the calcination CO₂ component are shown in Figure 5-3.

$$\text{CO}_2 \text{ from raw meal converted to clinker} = \frac{\text{Calcination emission factor [kgCO}_2\text{/t]} \times \text{Clinker production [t]}}{\text{Clinker production [t]}} \quad (4-9)$$

Source: (WBCSD - CSI, 2005)

▪ CO₂ from bypass dust and cement kiln dust (CKD)

Emissions are calculated based on the relevant volumes of dust and an emission factor. The calculation shall account for the complete volumes of dust leaving the kiln system, irrespective of whether the dust is sold directly, added to cement, or discarded as waste. Bypass dust is usually fully calcined. Therefore, emissions related to bypass dust shall be calculated using the emission factor for clinker. CKD, as opposed to bypass dust, is usually not fully calcined. The emission factor for CKD shall be determined based on the emission factor for clinker and the calcination rate of the CKD, which is mentioned in equation below.



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$$EF_{CKD} = \frac{EF_{Cli} * d}{1 + EF_{Cli} * d} \quad (4-10)$$

EF_{CKD} = emission factor of partially calcined cement kiln dust (tCO₂/tCKD)

EF_{Cli} = plant specific emission factor of clinker (tCO₂/t cli)

d = CKD calcination rate (released CO₂ expressed as a fraction of the total carbonate CO₂ in the raw meal)

Source: (WBCSD, 2005)

The calcination rate 'd' of the CKD shall preferably be based on plant-specific data. In the absence of such data, a default value of 1 shall be used. This value is conservative, i.e. it will in most cases lead to an overstatement of CKD-related emissions, because CKD is usually not fully calcined, with calcination rates often being closer to zero than one.

In the absence of plant-specific data on dust volumes, the IPCC default for CO₂ from discarded dust - 2% of clinker CO₂, shall be used. It should be noted, however, that

this default is clearly too low in cases where relevant quantities of dust leave the kiln system (WBCSD - CSI, 2005). Therefore, using plant or company-specific data is preferable and HLL has been using plant specific figures for CO₂ calculating purposes from the reporting started phase to date. However as per the HLL ATR data sources, the bypass dust leaving was not reported from the date CO₂ reporting started.

- CO₂ from organic carbon in raw materials

In addition to inorganic carbonates, the raw materials used for clinker production usually contain a small fraction of organic carbon which is mostly converted to CO₂ during pyroprocessing of the raw meal. The total organic carbon (TOC) contents of raw materials can vary substantially between locations, and between the types of materials used. Data compiled by the CSI indicate that a typical value for TOC in the raw meal is about 0.1 – 0.3% (dry weight). This corresponds to CO₂ emissions of about 10 kg /t clinker, representing about 1% of the typical combined CO₂ emissions from raw material calcination and kiln fuel combustion. CO₂ emissions from organic carbon in raw materials quantification and reporting ensure completeness of the GHG inventory. Since their contribution to overall emissions is small, however, a simplified self-calculating mechanism has been implemented in the CO₂ calculating spreadsheet which multiplies clinker production with the default value raw meal to clinker ratio is 1.55 and default TOC content of raw meal: 2 kg /t raw meal (dry weight, corresponding to 0.2%)

Input Material	Mass Data			Direct G		
	Annual Consumption [t/y]	Clinker Production [t cl/y]	Mass Factor [Material/Tot al Material Input]	Raw meal converted to clinker	Organic CO2	Bypass leaving kiln syst
Explosives	127.3		0.0001			
Limestone	891,375.0		0.6929	278,379.1	5,993.5	
Refractory - Basic	658.5		0.0005			
Dolomite	0.0		0.0000	0.0	0.0	
Laterite	14,509.0		0.0113			

Figure 4-14: LCI calcination and organic CO₂ data - Cement LCA Calculator

Companies are not required to analyze these emissions any further unless they have

indications that organic carbon is more relevant in their context. (WBCSD, 2005)
This could be the case, for example, if a company consumes substantial volumes of shale or fly ash, high in TOC content as raw materials entering the kiln. HLL doesn't feed slag or fly ash in raw meal phase and uses the default figure in GHG calculations which is derived in below equation. 3.664 is the conversion factor from ton of Carbon to ton of CO₂.

$$\begin{aligned} \text{Raw meal organic carbon CO}_2 = & \text{Raw meal consumption [t/yr, dry weight]} \times \\ & \text{Organic carbon content of raw meal (average)} \\ & [\%, \text{ dry weight} = 0.2\%] \times \\ & 3.664 \end{aligned} \quad (4-11)$$

Table 5-4 shows the LCI results of organic CO₂ which is calculated according to the above equation for the three scenarios.

4.9.2 CO₂ from fuel combustion

In cement GHG calculations, emission due to combustion process (known as fuel CO₂) of cement industry is similarly important as calcination CO₂. The calculation process of fuel CO₂ is according to the below equation which covers each and every aspect of combustion related GHG sources.

$$\begin{aligned} \text{Total CO}_2 \text{ from fuel combustion} = & \text{CO}_2 \text{ from conventional kiln fuel combustion} + \\ & \text{CO}_2 \text{ from AF biomass fuel combustion} + \\ & \text{CO}_2 \text{ from alternative fossil fuel combustion} + \\ & \text{CO}_2 \text{ from non kiln fuel combustion} \end{aligned} \quad (4-12)$$

Source: (WBCSD, 2005)

LCI data input area of the CO₂ from fuel combustion in Cement LCA calculator is shown in below figure.

.

				YEARLY ANALYSIS - 2007			
Clinker Consumption [tcl/y]	638,462.0	Non Kilns Fuel (Diesel)consum		Total Organic CO2 [t CO2/y]			
Cement Production [t cem/y]	834,376.0	Total CO2 from Non Kiln fuel		In-direct : CO2 from Purchased Electrical Energy [t CO2/y]			
Own clinker production [tcl/y]	528,064.0	Total CO2 raw meal convert		Total Diesel Consumption [t/y]			
				Clinker Production [SCOPE: QUARRY TO CLINKE			
Mass Data							
Input Material	Annual Consumption [t/y]	Clinker Production [t cl/y]	Mass Factor [Material/Total Material Input]	From Kiln fuel - Traditional	From Kiln fuel - Alternative (fossil base)	From Non Kiln fuel - Vehicles On site instruments	From Purcha Electricity
Explosives	127.3	528,064.0	0.000			0.0	
Limestone	891,375.0		0.694			4,172.4	17.1
Refractory - Basic	658.5		0.000			0.1	
Dolomite	0.0		0.000			0.0	
Laterite	14,509.0		0.011			2.7	
Refractory - Alumina, Fireclay	363.9		0.000			0.1	
Grinding Media - Flu Material	103.9		0.000			0.0	
HFO	2,044.3		0.001	5,815.8			
Coal	67,850.5		0.052	151,064.2		12.8	1.1
AF - Fossil Fuels							
waste oil	1,682.8		0.001		3,189.2		
tyres	0.0		0.000		0.0	0.0	
plastics	0.0		0.000		0.0	0.0	
solvents	0.8		0.000		0.2	0.0	
impregnated saw dust	0.0		0.000		0.0	0.0	
mixed industrial waste	237.9		0.000		179.7	0.0	
other fossil based wastes	125.0		0.000		92.7	0.0	
AF - Biomass							
dried sewage sludge	0.0		0.000		0.0	0.0	
wood, non impregnated s	11,910.2		0.009		18,027.6	2.3	
paper, carton, diaper waste	0.0		0.000		0.0	0.0	
agricultural, organic, charc	14,420.9		0.011		21,919.2	2.7	
other biomass	0.0		0.000		0.0	0.0	
Clinker - Imported	80,421.6		0.062			15.2	1.5
Bypass dust	0.0		0.000			0.0	

Figure 4-15: LCI data input area - CO₂ from fuel combustion

- CO₂ from conventional kiln fuels

Conventional kiln fuels are fossil fuels including coal, petcoke, fuel oil and natural gas which in HLL case only coal and HFO. The preferred approach is to calculate CO₂ from conventional kiln fuels based on fuel consumption, lower heating values and the matching CO₂ emission factors. Fuel consumption and lower heating values of fuels are routinely measured at plant level. Default emission factors per GJ lower heating values are shown in Table 4-16. For the calculation of GHG emissions these values are extensively used which sourced from IPCC latest databases. For some fuel sources emission values are from CSI latest databases. These figures are used in the Holcim ATR and updates time to time whenever there is a revision. However CO₂ Accounting and Reporting, Standard for the Cement Industry (Version 2.0) encourage companies to use plant or country-specific emission factors if reliable data are available.

Table 4-16: Default GHG emission factors used for the study

Cement kiln fuel		Default Specific CO₂ emission factors [kgCO₂/GJ]
Traditional (fossil) fuels	Coal + anthracite + waste coal	96.0
	(Ultra) heavy fuel	77.3
	Diesel oil	74.0
Alternative fossil fuels	Waste oil	74.0
	Plastics	75.0
	Solvents	74.0
	Impregnated saw dust	75.0
	Mixed industrial waste	83.0
Alternative biomass fuels	Other fossil based wastes	80.0
	Other biomass	110
	Wood, non-impregnated saw dust	110
	Paper, carton, diaper waste	110

Source: (IPCC, CSI)

Direct calculation of emissions, based on fuel consumption (in tonnes) and fuel carbon content (in percent) is acceptable on the condition that material variations in the composition of the fuel and especially its water content, are adequately accounted for direct greenhouse gas emissions from cement manufacturing. Generally, IPCC recommends accounting for incomplete combustion of fossil fuels. In cement kilns, however, this effect is negligible, due to very high combustion temperatures and long residence time in kilns and minimal residual carbon found in clinker. Consequently, carbon in all kiln fuels shall be treated as fully oxidized and the equation below is used to calculate conventional kiln fuel GHG emissions. The LCI results for the conventional fuel GHG is presented in Figure 5-4.

$$\text{CO}_2 \text{ Emissions from kiln fuels} = \frac{\text{Consumption of fuel [t]} \times \text{Lower heat value [GJ/t]} \times \text{Kiln fuel CO}_2 \text{ factors}}{\text{[kgCO}_2\text{/GJ]}}$$

(4-13)

Source: (WBCSD, 2005)

▪ CO₂ from combustion of alternative kiln fuels – biomass

The cement industry increasingly uses a variety of AF's which are typically derived from wastes. Without this use, biomass would have to be disposed of in some other way, usually by land-filling or incineration. AF's include biomass fractions, such as waste wood and sewage sludge fall under this category. AF serves as a substitute for conventional fossil fuels.

CO₂ emissions from alternative biomass kiln fuels are considered climate-neutral, because emission can be compensated by re-growth of biomass in the short term. In the Cement GHG Protocol, CO₂ from biomass fuels only required to report as a "memo item". The fact that biomass is only really climate-neutral if sustainable harvesting techniques is promoted and used, is taken into account in the "Land use change and forestry" sections of the national inventories, where CO₂ emissions due to forest depletion are reported. This is further described as 'Emissions arising from the use of biomass (e.g. co-firing of biomass, biodiesel, bio-ethanol) shall include the GHG emissions arising from the production of the fuel, and shall exclude the CO₂ emissions arising from the biogenic carbon component of the fuel' (BSI, 2008). Where biofuel is produced from waste (e.g. cooking oil after it has been used in a cooking process), the GHG emissions arising from the production of the fuel are those arising from the conversion of the waste to fuel. Where the biofuel is not produced from waste (e.g. biodiesel produced from oilseed rape or palm oil, ethanol produced from wheat, sugar beet, sugarcane or corn), the GHG emissions associated with the use of the biofuel include the emission sources occurring within the boundaries of the life cycle of the biofuel. PAS 2050 standard promotes using biomass as alternative fuel sources. (BSI, 2008)

The IPCC default emission factor of 110 kgCO₂e/GJ for solid biomass (WBCSD, 2005) is used in LCA GHG calculations. This is not considered as a direct GHG

emission source but reported as a carbon neutral component.

Input Material	Annual Consumption [t/y]	Total GHG Emission (Indirect) Gross Absolute [tCO ₂ /y]	Credits for GHG Savings Fossil AF	AF Biomass Neutrals [tCO ₂ /y]
dried sewage sludge	0.0	0.0		0.0
wood, non impregnated	11,910.2	344.0		18,027.8
paper, carton, diaper waste	0.0	0.0		0.0
agricultural, organic, chaff	14,420.9	425.1		21,918.2
other biomass	0.0	0.0		0.0
Total	26,331.1	795.1		18,027.8

Figure 4-16: AF biomass GHG reporting as a carbon neutral component

Related LCIA results are presented in Figure 5-5 and Table 5-6

- Direct CO₂ from combustion of fossil AF

CO₂ from fossil fuel-derived wastes (also called alternative fossil fuels or fossil AF), in contrast, is not a priori climate-neutral. According to IPCC guidelines, GHG emissions from industrial waste-to-energy conversion are reported in the “energy” source category of national inventories, while GHG emissions from conventional waste disposal (land filling, incineration) are reported in the “waste management” category. To ensure consistency with the guidelines of IPCC as well as WRI / WBCSD, the need for transparent reporting of the direct CO₂ emissions resulting from AF combustion in cement plant is important. Therefore, the Cement GHG Protocol requires reporting as CO₂ emission factors depend on the type of AF used which is specified at plant level where practical (WBCSD, 2005).

Some AF sources such as used tires and impregnated saw dust, contain both fossil and biomass carbon. Ideally, a weighted emission factor should be calculated here, based on the share of the fossil carbon in the fuel's overall carbon content. However, this share is difficult and costly to measure, and variable for some fuels. Therefore, in HLL case it was used a conservative approach where carbon from such fuels is assumed to be of 100% fossil origin, until more precise data become available and the equation below is used to quantify the GHG.

Emission factors stated in Table 4-16 are used as default specific CO₂ emission factors respective to the lower heat values of the fuel and the calculated LCI and

LCIA results from Cement LCA Calculator is presented in Table 5-6.

CO₂ emissions from AF fossil fuels = Consumption of fuel [t] X

CO₂ emission factor of kiln fuels [kgCO₂/GJ]

Lower heat value [GJ/t] (4-14)

Source: (WBCSD, 2005)

Fossil AF is not reported as neutral but as GHG savings as per the Cement GHG Protocol. Utilization of AF by the cement industry typically results in GHG emission reductions at landfills and incineration plants where these wastes would otherwise be disposed. These indirect emission reductions can be equal, higher or lower than the direct CO₂ emissions from AF combustion at the cement plant, depending on the type of waste and the displaced disposal path. The combination of direct emissions impacts, indirect emission reductions, and resource efficiency makes the substitution of AF for conventional fossil fuels an effective way to reduce global GHG emissions. Hence fossil AF is reported as absolute emissions however the reduced CO₂ from fossil AF will be reported as net GHG emissions as introduced and defined in equation (5-1) and (5-2).

Input Material	Annual Consumption [t/yr]	Credits for GHG Savings Fossil AF
waste oil	1,682.8	3,189.2
tyres	0.0	0.0
plastics	0.0	0.0
solvents	0.8	0.2
impregnated saw dust	0.0	0.0
mixed industrial waste	237.9	179.7
other fossil based waste	125.0	92.7

Figure 4-17: Fossil AF CO₂ reporting in Cement LCA Calculator

- CO₂ from non-kiln fuels

Direct greenhouse gas emissions from non kiln emission in cement manufacturing are CO₂ associating with equipment and on-site vehicles, room heating / cooling, raw material drying (including mineral components such as slag or pozzolana) and on-site power generation which fuels consumed for drying of kiln fuels. In HLL case, non kiln fuel is only accounted for the diesel which used for internal transportation,

and logistics purposes and very minute amount for the generator use during grid power interruptions. More than 95% diesel consumption is used for company owned locomotives used for transporting limestone from quarry to plant. Non kiln fuel GHG is calculated as below equation.

$$\text{CO}_2 \text{ emissions from non kiln fuels} = \text{Consumption of fuel [t]} \times \text{CO}_2 \text{ emission factor of kiln fuels [kgCO}_2\text{/GJ]} \times \text{Lower heat value [GJ/t]} \quad (4-15)$$

Carbon in non-kiln fuels is assumed to be fully oxidized, i.e. carbon storage in soot or ash is not accounted for. The resulting overestimation of emissions will usually be small (approx. 1%).



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4.10 LCI preparation : Indirect GHG (Scope 02, 03) emissions

Cement production is associated with indirect greenhouse gas emissions from various sources (WBCSD, 2005). Other than direct GHG emissions or Scope 01 emissions, all the other GHG emissions are fallen under ‘indirect’ category, as defined in the Table 4-4.

Scope 3 activities related to this LCA study are extraction and production of purchased materials (product CO₂) and transportation related GHG emission (transport leakages). In this LCA study national level transport (input material) related scope 3 GHG emissions is only considered, aligning to the goal and scope. This scope is shown in below figure. Due to product carbon factors (product embodied carbon footprints) accessing constraints, the significant product footprint item ‘imported clinker’ only reported separately considering the volumes and product embodied CO₂ data.

The main pillars of indirect GHG data gathered and analyzed using Cement LCA Calculator, presented in Figure 4-18. Required Parameters under Indirect CO₂

reporting by Cement GHG Protocol (June 2005) is defined under secondary data in Table 4-11.

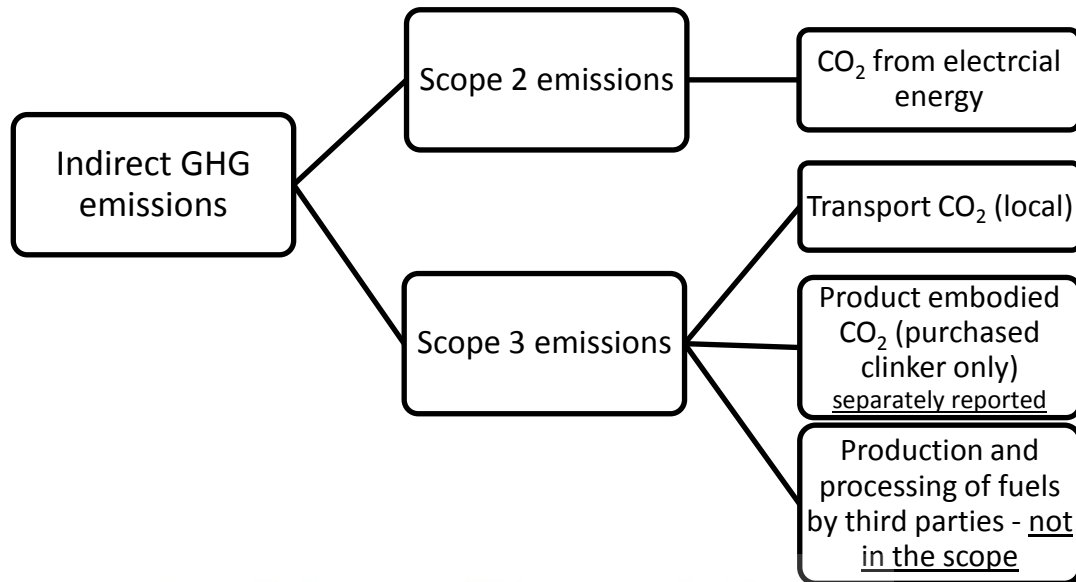


Figure 4-18: Indirect GHG emission in cement manufacturing

Below Figure 4-19 shows the summary of LCI data - indirect GHG emission scenario results which extracted from Cement LCA Calculator. This covers both scope 2 and 3 GHG emissions which accounts 10% of total gross GHG emissions in current manufacturing process of HLL - PCW. The indirect GHG emissions mainly transport CO₂ is analyzed in the section 5.3.3.

Clinker Consumption [tcl/y]	638,462.0	Non Kilns Fuel (Diesel) consume	5,998.0	Grid Factor [kg CO2/Mwh]	426.0				
Cement Production [t cem/y]	834,376.0	Total CO2 from Non Kiln fuel - 2/y]	34,659.1	Cementitious Material [t]	724,654.0				
Own clinker production [tcl/y]	528,064.0	Total CO2 raw meal converted	1,218.6	Clinker Factor [%]	76.52				
LINKER YARD FEEDING BIN									
	Input Material	Mass Data			Indirect GHG Emissions [CO2 t/y] - off the SITE (Scope 2 & 3)				
		Annual Consumption [t/y]	Clinker Production [t cl/y]	Mass Factor [Material/Total Material Input]	From Purchased Electrical Energy	From Purchased Clinker	Upstream GHG emissions at Input manufacturing sites [t CO2 e/y]	CO2 Emission - Transport [t CO2/y]	CO2 Emission from Land Use Change [t CO2/y]
	Explosives	127.3		0.000	2.5		0.0	8.7	
	Limestone	891,375.0		0.692	17,735.4				0.0
	Refractory - Basic	658.5		0.000			0.0	11.3	
	Dolomite	0.0		0.000	0.0		0.0	0.0	0.0
	Laterite	14,509.0		0.011	288.3		0.0	22.6	0.0
	Refractory - Alumina, Fireclay	363.9		0.000			0.0	6.2	
	Grinding Media - Raw Material	103.9		0.000			0.0	1.8	
	HFO	2,044.3		0.001	40.6		0.0	35.0	
	Coal	67,850.5		0.052	1,348.1		0.0	1,436.9	
	AF - Fossil Fuels								
	Transport	1,682.8		0.001					

Figure 4-19: Indirect GHG emission sources

CO₂ emissions associated with the production of cement-substituting mineral components (MIC) were not considered as an indirect emission of the cement industry, if these emissions are the result of another industrial process. This applies, in particular, for slag produced by the steel industry and for fly ash produced by power plants. The CO₂ emissions of the facilities generating these by-products are associated with the intended main product – steel and power – and not with the by-product. The utilization of these by-products by the cement industry does not cause additional CO₂ emissions in the steel or power production

The option is been kept by keeping provisions to add the upstream emissions (product embodied CO₂) in Cement LCA Calculator to use if the scope of the study expanded. This exercise depends on the product embodied carbon footprint data availability for the considering raw materials and consumables.

4.10.1 CO₂ from external electricity production (scope 02)

This was calculated based on the measured consumption of grid electricity and preferentially emission factors obtained from the electricity supplier. Alternatively, an average emission factor for the country may be used which is published by IPCC. The grid emission factor disclosed by Sri Lankan national electrical energy supplier - Ceylon Electricity Board could not found for the selected manufacturing years and instead of it the latest IPCC value (2002 onwards) – 426 kgCO₂e/MWh (WBSCD, 2005) was used in the calculations. Emissions associated with the consumption of electricity during transport and distribution (T&D) losses is not be included in this calculation. (WBSCD, WRI, 2004)

However PAS 2050 (2008) standard goes much deeper in the scope of CO₂ from external energy production; ‘Emissions from energy include the emissions arising from the life cycle of the energy. This includes emissions at the point of consumption of the energy (e.g. emissions from the burning of coal and gas) and emissions arising from the provision of the energy, including the generation of electricity and heat, and upstream emissions from transport fuels (e.g. the mining and transport of fuel to the electricity generator or other combustion plant)’.(BSI, 2008). Due to the constraint of

accessing product CO₂ data these scenarios were not considered. The LCI outputs for scope 02 is presented in Figure 5-6 and Table 5-9.

Cement LCA Calculator is a customized tool having provisions to feed ‘grid factor’ separately and linked to all related calculations. The total GHG reporting scope 02 emissions shared among all the input materials by proportionate to mass input separately to two unit processes

YEARLY ANALYSIS - 2007

Transport [%]	95.0	Total Organic Solvent (t CO ₂ /y)	5,886.4	Grid Factor [kg CO ₂ /Mwh]	426.0
CO ₂ /y]	4,835.8	In-direct : CO ₂ from Purchased Electrical Energy [t CO ₂ /y]	34,659.1	Cementitious Material [t]	12,709.70
	278,379.7	Total Diesel Consumption [kg]	1,210.0	Clinker Factor [%]	76.52

Until Process 01: Clinker Production [SCOPE: QUARRY TO CLINKER YARD FEEDING BIN]

Direct GHG Emissions [CO ₂ t/y] - at SITE (Scope 01)						Direct GHG Emissions [CO ₂ t/y] - off the SITE (Scope 02)			
---	--	--	--	--	--	--	--	--	--

Pass dusting the kiln system	From CKD leaving the kiln system	From Kiln fuel - Traditional	From Kiln fuel - Alternative (fossil base)	From Non Kiln fuel - Vehicles On site instruments	From Purchased Electrical Energy	From Purchased Clinker	Upstream GHG emissions at Input manufacturing sites [t CO ₂ e/y]	CO ₂ Emission - Transport [t CO ₂ /y]	CO ₂ Emission from Land Use Change [t CO ₂ /y]
				0.0	2.5		0.0	8.7	
				4,172.0	17,735.4				0.0
				0.0			0.0	11.3	
				0.0	0.0		0.0	0.0	0.0
				2.0	288.3		0.0	22.6	0.0
				0.0			0.0	6.2	
				0.0			0.0	1.8	
					40.6		0.0	35.0	
				12.0	1,348.1		0.0	1,436.9	
				3,189.2	33.4			21.0	
				0.0	0.0			0.0	
				0.0	0.0			0.0	
				0.2	0.0			0.0	
				0.0	0.0			0.0	
				179.7	0.0	4.7		2.7	
				92.7	0.0	2.5		1.1	
				0.0	0.0			0.0	
				18,027.6	2.0	236.6		107.3	
				0.0	0.0			0.0	
				21,919.2	2.0	286.5		138.6	
				0.0	0.0			0.0	
				15.0	1,597.9	69,323.4		1,147.0	
				0.0	0.0				
				0.0	0.0				
							0.0	19.9	

GHG Summary charts Intermediate Env Balance sheet 2007 scroll 1

Figure 4-20: Grid factor program cell and scope 02 output

4.10.2 Transport related GHG emissions

Transport related GHG emissions are not covered under Cement GHG protocol. However it was included to the scope of this LCA study considering the set LCA goals. Transport related GHG data collection and analysis is an important component in LCI & LCIA processes, since Sri Lanka is a country which is fully depended on imported fuels. Local level transportation GHG leakages were taken in to LCA scope.

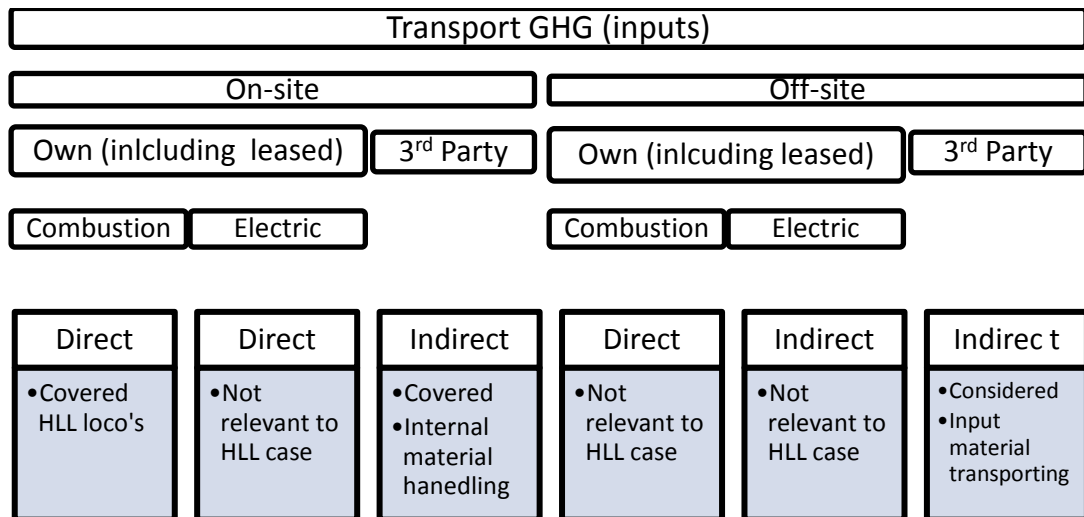


Figure 4-21: Transport GHG emission model

Source: (WBCSD, 2005)

Above figure shows the breakdown of transport related emissions into different GHG reporting scopes. Figure 4-22 shows the transport related CO₂ calculation input sheet from Cement LCA Calculator. Calculation of transport related GHG has been made using the following equation.

$$\begin{aligned}
 \text{Annual GHG CO}_2 \text{ for material}_i \text{ [t CO}_2\text{/y]} &= \text{Distance One-way trip X} \\
 &\quad \text{Number of trips [\#] /1000 [km] X} \\
 &\quad \text{Lower heat value of the fuel [GJ/l] X} \\
 &\quad \text{fuel emission factor [kgCO}_2\text{e/GJ] X} \\
 &\quad \{(1/ \text{Fuel consumption for a loaded} \\
 &\quad \text{Trip})+ (1/ \text{Fuel consumption for an} \\
 &\quad \text{empty Trip})\}
 \end{aligned}
 \tag{4-16}$$

The primary data for fuel consumption data were collected from HLL registered vendors during primary data collection process. Loaded volume data is directly collected from SAP records (primarily weigh bridge records). For emission factor for the fuel (in kgCO₂e/GJ) calculation IPCC, 1999 values and for the lower heat values American Petroleum Institute (API) figures 2001 were extensively used. Transport related emission for limestone is calculated under Direct 01 emissions and not covered in this section.

CO2 Emission -Transport[t CO2/y]		Road transportation										Annual Road Transport CO2 within Country [ton CO2/y]
Input	Annual Consumption [t/a]	Distance Oneway trip [km]	Average Load per trip [ton/trip]	Trips to transport [#]	Fuel consumption - Empty Trip [km/l]	Fuel consumption - Loaded Trip [km/l]	kg CO2 / GJ (IPCC, 1999)	GJ / liter (API, 2001)	Empty Trip [kgCO2/km]	Loaded Trip [kgCO2/km]		
Explosives	127.3	170.0	2.0	63.7	8.000	6.000	74.010	0.037	0.343	0.458	8.7	
Limestone	891,375.0											
Refractory - Basic	658.5	132.0	10.0	65.9	4.500	4.000	74.010	0.037	0.610	0.686	11.3	
Dolomite	0.0	140.0	17.2	0.0	4.000	3.500	74.010	0.037	0.000	0.000	0.0	
Laterite	14,509.0	18.0	17.0	853.5	4.000	3.500	74.010	0.037	0.686	0.785	22.6	
Refractory - Alumina, Fire	363.9	132.0	10.0	36.4	4.500	4.000	74.010	0.037	0.610	0.686	6.2	
Grinding Media - Raw Material	103.9	132.0	10.0	10.4	4.500	4.000	74.010	0.037	0.610	0.686	1.8	
HFO	2,044.3	132.0	10.0	204.4	4.500	4.000	74.010	0.037	0.610	0.686	35.0	
Coal	67,850.5	196.0	12.0	5,654.2	4.500	4.000	74.010	0.037	0.610	0.686	1,436.9	
AF - Fossil Fuels												
waste oil	1,682.8	125.0	13.0	129.4	4.500	4.000	74.010	0.037	0.610	0.686	21.0	
tyres	0.0			0.0	4.500	4.000	74.010	0.037	0.000	0.000	0.0	
plastics	0.0			0.0	4.500	4.000	74.010	0.037	0.000	0.000	0.0	
solvents	0.8	132.0	15.0	0.1	4.500	4.000	74.010	0.037	0.610	0.686	0.0	
impregnated saw dust	0.0	132.0	15.0	0.0	8.000	6.000	74.010	0.037	0.000	0.000	0.0	
mixed industrial waste	237.9	132.0	15.0	15.9	4.500	4.000	74.010	0.037	0.610	0.686	2.7	
other fossil based wastes	125.0	132.0	15.0	8.3	8.000	4.000	74.010	0.037	0.343	0.686	1.1	
AF - Biomass												
dried sewage sludge	0.0		15.0	0.0	4.500	4.000	74.010	0.037	0.000	0.000	0.0	
wood, non impregnated saw	11,910.2	90.0	8.0	1,488.8	8.000	6.000	74.010	0.037	0.343	0.458	107.3	
paper, carton, diaper waste	0.0		15.0	0.0	4.500	4.000	74.010	0.037	0.000	0.000	0.0	
agricultural, organic, charco	14,420.9	60.0	5.0	2,884.2	8.000	6.000	74.010	0.037	0.343	0.458	138.6	
other biomass	0.0		15.0	0.0	4.500	4.000	74.010	0.037	0.000	0.000	0.0	
Clinker - Imported	80,421.6	132.0	12.0	6,701.8	4.500	4.000	74.010	0.037	0.610	0.686	1,147.0	
Bypass dust	0.0			0.0	4.500	4.000	74.010	0.037	0.000	0.000	0.0	
CKD	0.0			0.0	4.500	4.000	74.010	0.037	0.000	0.000	0.0	
Diesel [up to Clinker]	1,163.1	132.0	10.0	116.3	4.500	4.000	74.010	0.037	0.610	0.686	19.9	
Up to / including Clinker	1,086,994.8											
	0.0											
Clinker	800,462.0											

Figure 4-22: LCI input sheet : transport related GHG

4.10.3 CO₂ from bought clinker (separately reported)

Imported clinker shall be calculated based on the net clinker purchases (bought clinker minus sold clinker) of the reporting entity and the default emission factor 862 kgCO₂e/t cli (WBCSD, 2005) was used. This is not an emission class which require to report as per the CSI - Cement GHG Protocol under scope 03. Aligning to national GHG reporting protocols of IPCC, this has to report as a direct emission of the clinker producing entity which accounts for the generating country national GHG inventory. Considering the magnitude of the clinker related product embodied carbon emission, it was decided to report 'CO₂ from bought clinker' as a separate line item. In Cement LCA Calculator the default factor (from Cement GHG Protocol) was used for bought clinker CO₂ calculations. The LCI data for the three manufacturing scenarios for bought clinker GHG is presented in Figure 5-7.

4.10.4 Upstream GHG emissions

GHG impacts under this category were excluded from the LCA scope due to lack of data access to input materials. Still most of the companies do not maintain and report their product CO₂ (GHG) footprint counting. Use of publically accessible generic data instead of specific product related LCA data, may create a large data inconsistency apart from using specific data. This includes all the fuel sources, raw material, other additives and packaging material suppliers. However CO₂ counting related to the imported clinker is reported as per the GHG protocol (CSI). Through an extended LCA scope up to upstream level shall make a much accurate picture in GHG mapping and produce PAS 2050 compliant product carbon footprint which is not practical in current context due to lack of data availability.

4.10.5 Land use change CO₂

This GHG impact category is defined in PAS 2050: 5.5 as 'Inclusion and treatment of land use change and the GHG emissions arising from direct land use change shall be assessed for any input to the life cycle of a product originating from agricultural activities, and the GHG emissions arising from the direct land use change shall be

included in the assessment of GHG emissions of the product' (BSI, 2008). The GHG emissions occurring as a result of direct land use change shall be assessed in accordance with the relevant sections of the IPCC guidelines for national greenhouse gas inventories.

Land use change GHG impacts are highly related with agricultural industries & processes which involve annual croplands or perennial croplands and no specific GHG impact is related to cement industry. Hence land use change CO₂ is not considered in the LCI phase. However in the Cement LCA Calculator, provision is kept to use in the future if any bio-fuel plantation generated to use as an alternative cement kiln fuel.

4.11 Life cycle interpretation

Analyze results, reach conclusions, explain limitations and provide recommendations based on the findings of the preceding phases of the LCA or LCI study and to report the results of the life cycle interpretation in a transparent manner are the objectives of life cycle interpretation.

This is the most important phase in communicating the outcomes of the detailed LCA study and presenting the findings to the interested parties in an understandable manner. This phase also act as the research linking phase since it opens the limitations and gaps of the performed LCA study.

'Environmental balance sheet' is the extended version of a 'mass balance sheet'. Instead of concentrating only the material and mass count, looking further presents all the environmental sensitive inputs and outputs is the simplest way of introducing this concept.

It is also defined as 'In the course of such one examines all environmental relevant withdrawals from the environment (e.g. ores, crude oil) as well as emissions into the environment (e.g. wastes, carbon dioxide emissions) and analyzes the associated environmental impact by the investigation object. The ecological balance belongs to the ecology-oriented planning instruments of the controlling.' (Ecological Balance, 2006)

Since environmental balance sheet is a simple way to present the LCA findings, it

was selected as an objective of this study. For the specific study the environmental balance sheet also will be the 'LCIA – profile'. The collection of the indicator results, referred to as the LCIA profile, provides information on the environmental issues associated with the inputs and outputs of the product system. It also provides information for the lifecycle interpretation phase. (Narayan, 2010)

Environmental balance sheet is consisted with two main pillars which shown in below tables which are the outcome of LCI through Cement LCA Calculator. Own software Cement LCA Calculator facilitates the both features of environmental balance sheet: material and energy. Creating the environmental balance sheet for the current business scenario of HLL – PCW operation was identified in the research objectives. Life cycle interpretation is covered in Chapter 6.



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Chapter 5 RESULTS AND DISCUSSION

This chapter presents the life cycle inventory output and impact analysis phase with selected life cycle interpretation tools.

5.1 LCI & LCIA findings : material flow

Table 5-1: Consumed material & fuel sources

Area	Unit process 01	Unit process 02
Scope	Material extraction to clinker production	Clinker to ready to dispatch cement
Consumed materials	Explosives Limestone Refractory – Alumina, Fireclay Laterite Dolomite Grinding media-	Clinker Gypsum Clinker – imported Clinker substituted material - Limestone Cement Strengtheners Grinding media Paper Bags
Used fuel	Traditional fuel : HFO, coal Fossil AF : Waste oil, impregnated saw dust, mixed industrial waste, other fossil based wastes AF – Biomass : non-impregnated saw dust, agricultural, organic, charcoal, other biomass Diesel [up to Clinker]	Diesel [up to Cement]
End product	Clinker – intermediate product	Cement
Waste	Bypass dust, CKD, gaseous emissions, waste heat	Fugitive dust, gaseous emissions from vehicles

Items in Table 5-1 shows the consumed material and fuel during cement manufacturing process at selected cement plant Holcim – PCW. This was studied and analyzed during the LCI process. Consumables were limited to three materials as expressed in chapter 4.2.

The material flow of cement manufacturing process was discussed under chapter 2.6 focusing the two unit processes and graphically illustrated and discussed in Annexure VI. Clinker is the intermediate product which is the output from unit process 01. Majority of the materials and fuels are used in this unit process. During both LCI and LCIA processes, a large focus given to this unit process due to this reason. There is no significant involvement of any fuel source in unit process two as a direct process input, except the diesel usage for the vehicle utilized for internal logistic purposes. Cement LCA Calculator provide option to analyze full material flow for the full study. All the collected data is tabulated in formats which can analyze easier

Table 5-2: LCI - material inventory

Input material flow			Mass input / output[t/y]		
			HFO,OPC, 2001	Coal,OPC, 2003	Coal+AFR, ABC, 2007
Unit Process 01 [upto clinker production]	Raw material	Limestone	819,357	905,370	891,375
		Dolomite		1,779.0	
		Laterite	20,427.0	17,063.5	14,509.0
	Support material	Explosives	104.9	119.6	127.3
	Consumables	Refractory - Alumina, Fireclay	187.5	219.5	363.9
		Refractory - Basic	735.5	860.9	658.5
		Grinding Media - Raw Material	81.2	97.5	103.9
	Conventional fuel	HFO	42,579.0	338.0	2,044.3
		Coal		84,684.0	67,850.5

	AF : Fossil Fuels	Waste oil			1,682.8
		Tires		297.1	
		Solvents			0.8
		Mixed industrial waste			237.9
		Other fossil based wastes			125.0
	AF - Biomass	Wood, non impreg saw dust			11,910.2
		Agricultural, organic			14,420.9
	Clinker imported		41,178.0		80,421.6
	Waste	Bypass dust			
		CKD			
	Non kiln fuel	Diesel	1,322.3	1,374.0	1,163.1
	Up to clinker main input (w/w) [%]		95.9	92.8	84.5
Unit process - 02		Clinker	447,904	524,238	528,064
	Regulator	Gypsum	14,907.0	20,639.2	33,016.0
	Additives	Dolomite			31,754.6
	MIC	High Limestone	22,876.0	55,192.3	131,291.5
	Support material	Grinding media - Cement	22.4	62.1	35.3
	Non kiln fuel	Diesel	64.7	65.0	55.5
	Package	Paper Bags 3ply	2,036.7	2,167.8	
		Paper Bags 2ply			3,337.5
Clinker to cement (w/w) [%]			4.1	7.2	15.5
		Cem. material	485,708	596,130	724,654
		Cement	509,168	541,949	834,376

5.2 LCI & LCIA findings: Direct GHG (Scope 01) emissions

Direct GHG emission was introduced in chapter 4.1.2. GHG scope 1 emissions were specially focused during LCIA phase due to majority of GHG emission sources and absolute contribution is from this cluster. This is the general scenario for the cement manufacturing process due to GHG emissions from pyro-processing activities. The specific direct GHG emissions for the selected three scenarios are shown in above figure.

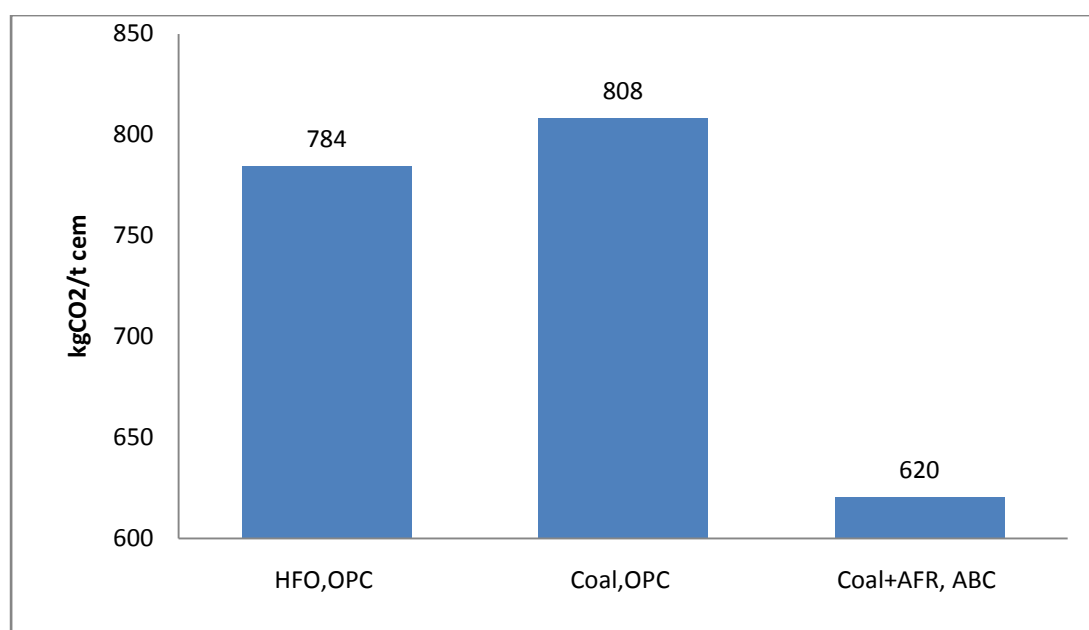


Figure 5-1: Direct GHG specific emissions

A clear direct GHG reduction is observed from Coal,OPC scenario to current manufacturing scenario Coal+AFR, ABC. Classified GHG direct emissions from Cement LCA Calculator are illustrated in below Figure 5-2.

As per the LCI data kiln fuel emissions and calcination emissions are the contributors for 80% of specific GHGs from two emissions. Decreasing figures from 486 to 384 kgCO₂e/t cem from HFO,OPC scenario to Coal+AFR,ABC scenario is mainly due to the application based cement promotion with improved clinker substitution material. Significant reduction of fuel CO₂ is due to the alternative fuel introduction to PCW. It has also shown an increase during the fuel switching from HFO to coal from 277 to

315 kgCO₂e/t cem in first two scenarios which again decreased to 216 kgCO₂e/t cem due to high utilization of AF in cement scenario. The other factors in direct emission scope are almost retained same where a peak shown in CKD related GHG emission in Coal, OPC scenario. Non kiln GHG – mainly due to company own vehicles and leased transport fleets has also gone down which is a result of company owned locomotive optimization program and some process changes focusing minimizing material handling.

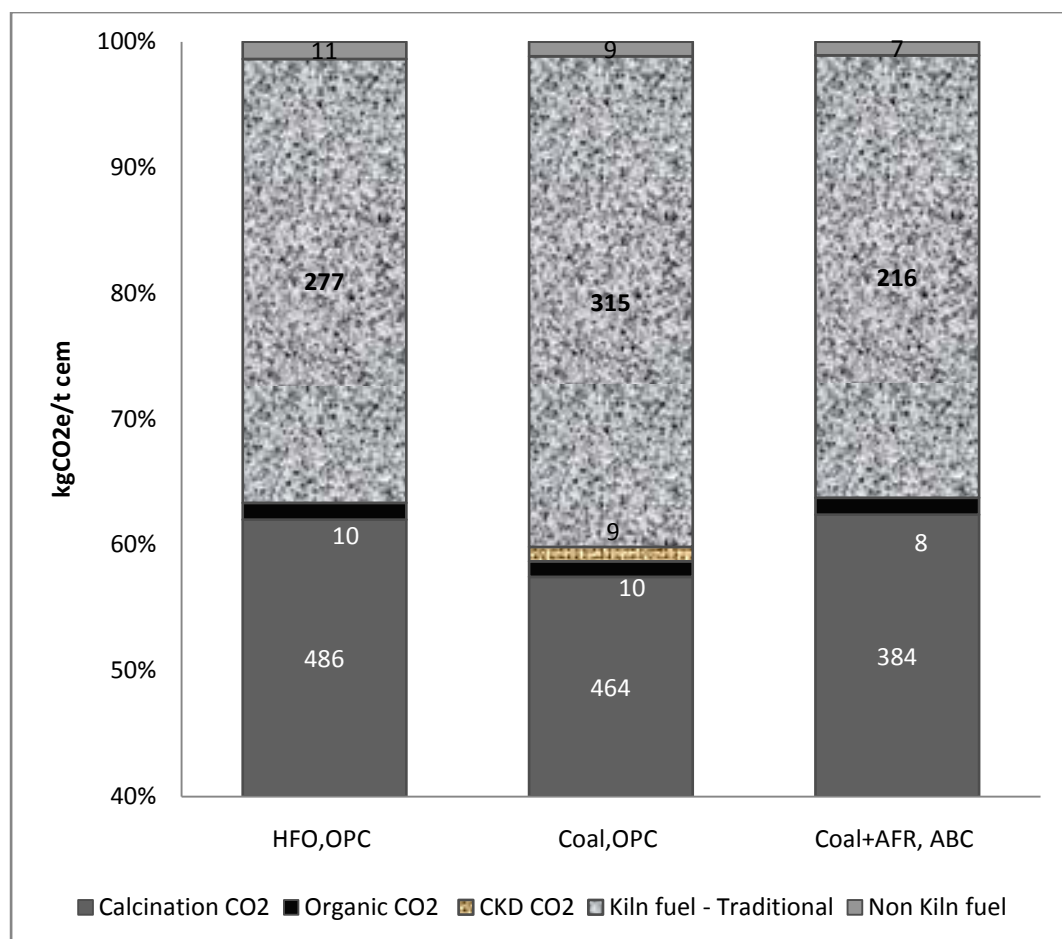


Figure 5-2: Cement LCA Calculator LCI data – scope 1 specific GHG emissions

5.2.1 CO₂ from raw material

The GHG emissions generated from ‘CO₂ from raw material’ decreased from 496 kgCO₂e/t cem in HFO, OPC scenario to 392 kgCO₂e/t cem Coal+AFR, ABC scenario. This mainly due to introduction of the clinker substituted cement types.

This is further presented in below three chapter analysis, the main three emission components under CO₂ from raw material.

- Calcination CO₂

LCI results of the calcination CO₂ component is shown in Figure 5-3. Specific GHG reduction with respect to baseline (year 2001) OPC & HFO scenario is 21%.

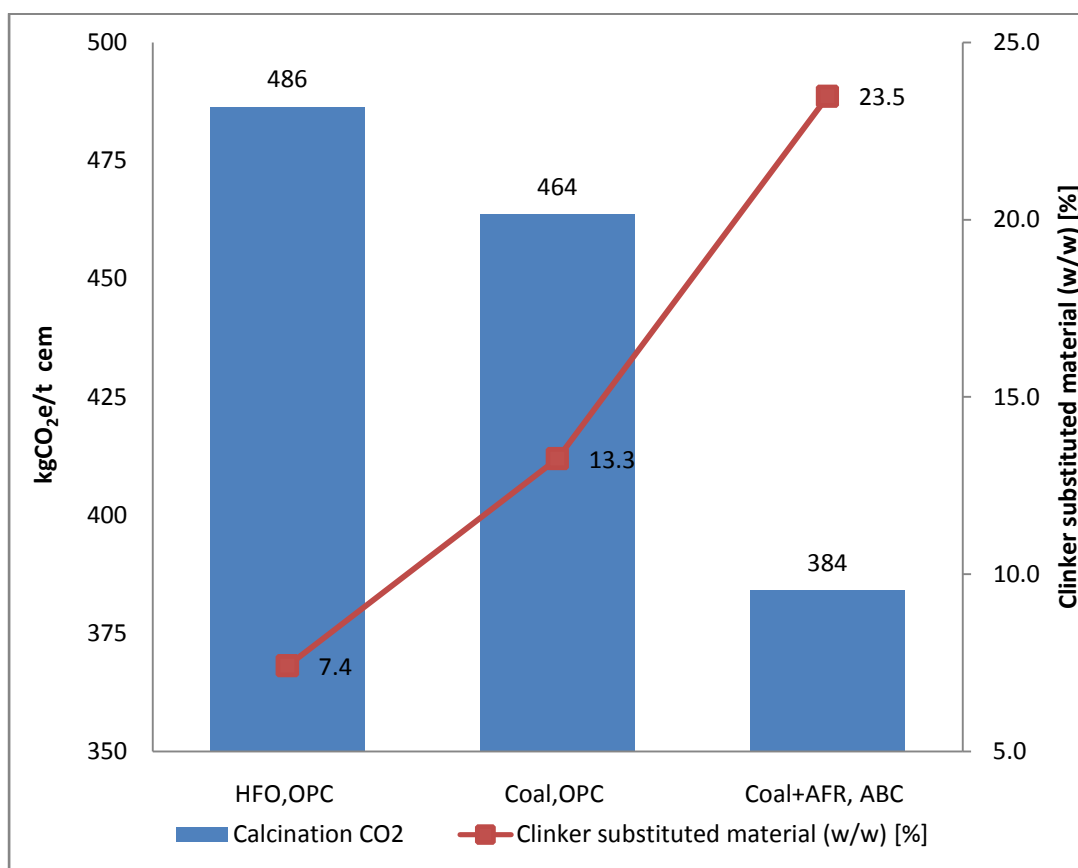


Figure 5-3: Product related GHG emissions (calcination GHG)

Main reason for this reduction is introducing and promoting of clinker substituted application based cement types. The percentage of clinker substituted material is increased from 7.4% (w/w) in baselines year 2001 HFO,OPC scenario to 23.5% (w/w) in current manufacturing scenario. This initiative reduced a significant volume of GHG emissions which related to product (calcination) GHG.

- CO₂ from bypass dust and cement kiln dust (CKD)

The LCI calculated figures for bypass dust & CKD CO₂ from Cement LCA Calculator is shown below table. This hasn't shown much deviation from the

baseline figures since the HLL – PCW plant produces neither bypass dust nor CKD generation. However the selected year 2003 for the scenario 02 has shown a generation of CKD which again zero by 2007. The installation of modern state of the art bag filter unit for the PCW kiln stack ‘Blue sky project’ was the main reason to reduce CKD.

Table 5-3: LCI results of bypass & CKD CO₂

Boundary	Scope	Process	Absolute			Specific			Specific GHG savings 2007 (Coal+AFR,ABC) wrt 2001 (HFO, OPC) [%]
			[tCO ₂ /year]			[kgCO ₂ /ton cem]			
			HFO, OPC	Coal, OPC	Coal+AFR, ABC	HFO, OPC	Coal, OPC	Coal+AFR, ABC	
Direct	1	Bypass dust CO ₂	0	0	0	0	0	0	
Direct	1	CKD CO ₂	0	5,504	0	0	9	0	

- CO₂ from organic carbon in raw materials

Below Table 5-4 shows the LCI results of organic CO₂ calculated for the three scenarios. There is no significant increment in the absolute emissions other than the proportionate increment. A 21% significant reduction shown in specific figure due to the cement product increased with more clinker substituted products.

Table 5-4: LCI results of organic CO₂

Boundary	Scope	Process	Absolute			Specific			Specific GHG savings 2007 (Coal+AFR, ABC) wrt 2001 (HFO, OPC) [%]
			[tCO ₂ /year]			[kgCO ₂ /ton cem]			
			HFO, OPC	Coal, OPC	Coal+AFR, ABC	HFO, OPC	Coal, OPC	Coal+AFR, ABC	
Direct	1	Organic CO ₂	5,083	5,949	5,994	10	10	8	21

5.2.2 CO₂ from fuel combustion

The results are further analyzed by splitting in them in to main emission categories in below four sub chapters.

- CO₂ from conventional kiln fuels

The LCI results for the conventional fuel GHG shows an achievement of 22% significant reduction. Increasing figures shown in kiln fuel CO₂ due to fuel switching process from scenario ‘HFO & OPC’ to ‘Coal & OPC’.

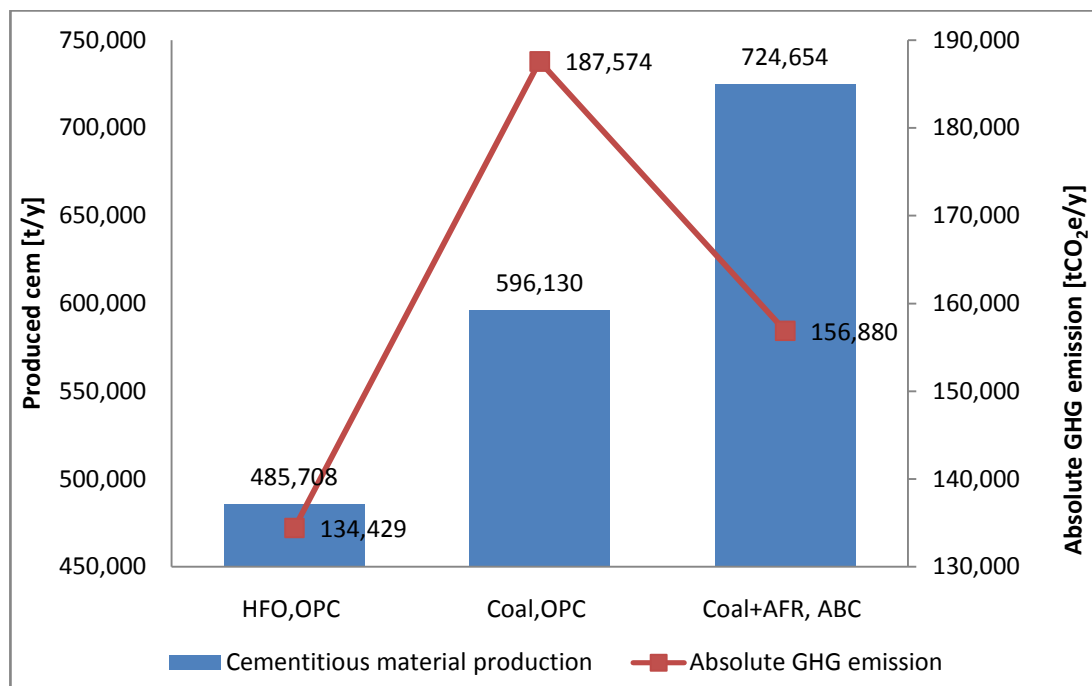


Figure 5-4: Kiln fuel GHG and production

Though cement production increased from 541,949 (2003) to 834,376 tonnes (2007) a significant GHG reduction was achieved in scenario 3 with the introduced AF utilization. Introduced biomass AF are carbon neutral and the sourced fossil based AF are carbon negative as per the Cement GHG Protocol.

▪ CO₂ from combustion of alternative kiln fuels – biomass

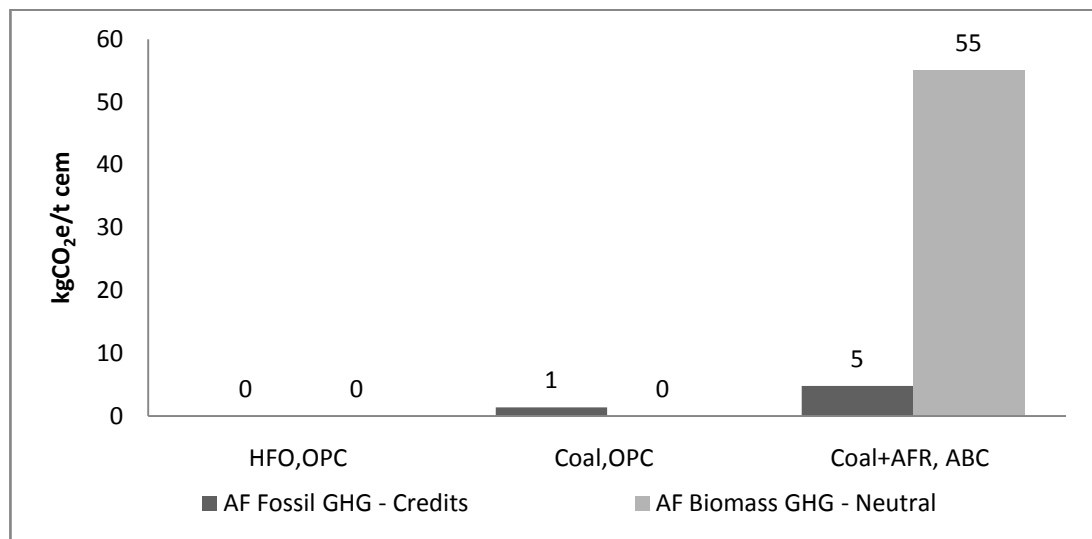


Figure 5-5: LCA output data - AF CO₂

Above figure shows the increasing trend of the AF CO₂ and CO₂ emission from alternative biomass kiln fuels which is considered climate-neutral. Increasing trend of using AF biomass significantly influenced to get down the specific CO₂ footprint. However a specific GHG reduction percentage is not calculated due to the baseline year AF biomass consumption is zero. Specific figures shows in year 2007 biomass GHG contribution which as a neutral GHG emitter is 55 kgCO₂/t cem which is a larger value. One of the significant benefits of AF other than contributing to reduce GHG is, substituting the traditional fuel (coal) which is identified as a limited resource.

Table 5-5: LCI results of AF biomass CO₂

Boundary	Scope	Process	Absolute			Specific			Specific GHG savings 2007 (Coal+AFR, ABC) wrt 2001 (HFO, OPC) [%]
			[tCO ₂ /year]			[kgCO ₂ /ton cem]			
			HFO, OPC	Coal, OPC	Coal+AFR, ABC	HFO, OPC	Coal, OPC	Coal+AFR, ABC	
Direct	1	Kiln fuel - AF Biomass	0	0	39,947	0	0	55	

- Direct CO₂ from combustion of fossil AF

LCI results are presented in below table on direct CO₂ from raw material of fossil AF, which is extracted from the Cement LCA Calculator. Results shows the AF – fossil based waste utilization in HLL cement kilns which increased the GHG savings to 3,462 tCO₂e/y in year 2007 with specific weight 5 kgCO₂e/t cem. Fossil AF is not reported as neutral but as GHG savings as per the Cement GHG Protocol and presented as net CO₂ emissions per ton of cementitious material.

Table 5-6: LCI results of AF fossil CO₂

Boundary	Scope	Process	Absolute			Specific			Specific GHG savings 2007 (Coal+AFR,ABC) wrt 2001 (HFO, OPC) [%]
			[tCO ₂ /year]			[kgCO ₂ /ton cem]			
			HFO, OPC	Coal, OPC	Coal+AFR, ABC	HFO, OPC	Coal, OPC	Coal+AFR, ABC	
Direct	1	Kiln fuel - AF Fossil	0	808	3,462	0	1	5	

- CO₂ from non-kiln fuels

LCI outputs for non kiln fuel GHG shows a reduction in this GHG emission class mainly due to high focused given to locomotive material transportation optimization process. In-house transport fleets and quarry heavy vehicle fleet optimization

programs by process and material storage location at both sites (quarry and plant) were supported on reducing diesel consumption caused by internal material transportation.

Table 5-7: LCI results of non kiln fuel CO₂

Boundary	Scope	Process	Absolute			Specific			Specific GHG savings 2007 (Coal+AFR, ABC) wrt 2001 (HFO, OPC) [%]
			[tCO ₂ /year]			[kgCO ₂ /ton cem]			
			HFO, OPC	Coal, OPC	Coal+AFR, ABC	HFO, OPC	Coal, OPC	Coal+AFR, ABC	
Direct	1	Non Kiln fuel	5,243	5,580	4,835	11	9	7	38

5.3 LCI & LCIA findings : Indirect GHG (Scope 02, 03) emissions

The overall LCI results of indirect GHG emissions from ‘Cement LCA Calculator’ are presented in below table and discussed main emission sources from sub chapter 5.3.1 to 5.3.3. the overall indirect GHG emission has shown a 4% decrease with respect to baseline scenario.

Table 5-8: LCI results of total indirect (gross) CO₂

Boundary Scope Process			Absolute			Specific			GHG %
			[tCO ₂ /year]			[kgCO ₂ /ton cem]			
			HFO,OPC	Coal,OPC	Coal+AFR, ABC	HFO,OPC	Coal,OPC	Coal+AFR, ABC	
Indirect	2,3	Indirect Gross Tot	26,811	30,285	38,567	55	51	53	96

5.3.1 CO₂ from external electricity production (scope 02)

The LCI results representing reporting GHG emission for the purchased electricity is shown in below table. As Table 5-9 and Figure 5-6 shows electrical energy has gone higher in the absolute field, which proportionate to the increased cement production and the fuel pre-processing for coal milling

Table 5-9: LCI results of purchased electricity CO₂

Boundary	Scope	Process	Absolute			Specific			Specific GHG savings 2007 (Coal+AFR,ABC) wrt 2001 (HFO, OPC) [%]
			[tCO ₂ /year]			[kgCO ₂ /ton cem]			
			HFO,OPC	Coal,OPC	Coal+AFR, ABC	HFO,OPC	Coal,OPC	Coal+AFR, ABC	
Indirect	2	Electrical Energy	25,144	28,018	34,659	52	47	48	8

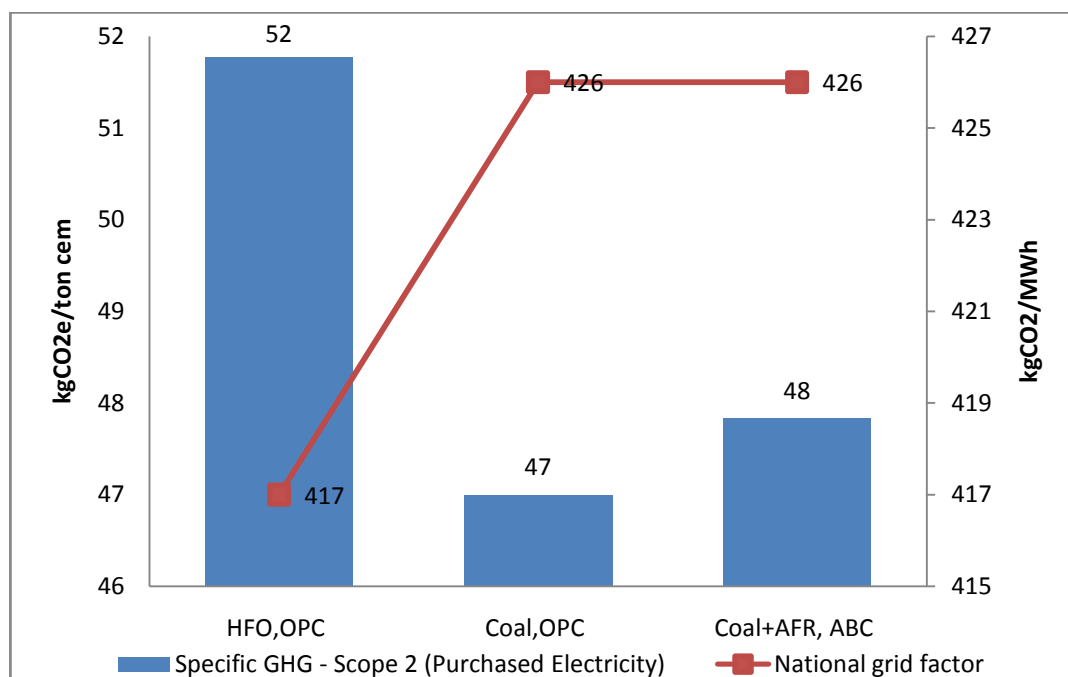


Figure 5-6: LCA data - Scope 2 GHG emission (grid electricity)

The 4% decrease (from 52% to 48%) in scope 02 GHG has shown the effectiveness of company focus on electrical consumptions which driven through process optimizations while the national grid CO₂ factor also increased from 417 (2001 reporting year) to 426 (2007 reporting year).

5.3.2 CO₂ from bought clinker (separately reported)

Cement demand and the economics decide the clinker importation to the country. Therefore the GHG emissions related to imported clinker is not a direct function of selected three manufacturing scenarios. Since HLL – PCW is the only operating integrated cement plant; it can't cater for the market with locally produced clinker and cement. However HLL continuously investing on increasing the capacity of clinker production in PCW which will reduce this impact category in the future.

The LCI data for the three manufacturing scenarios for bought clinker GHG is presented in below figure.

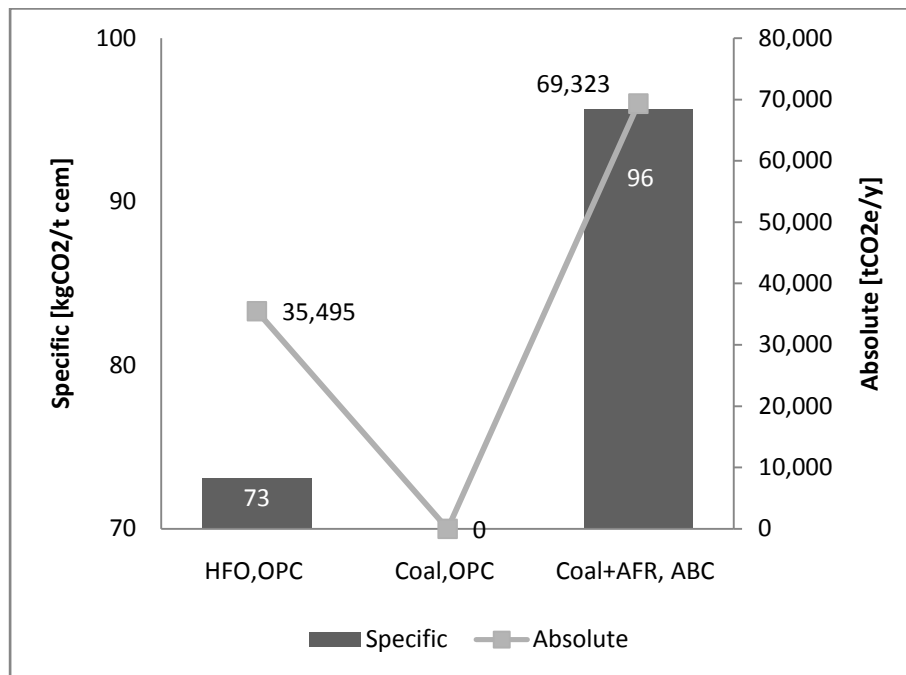


Figure 5-7: LCI results of bought clinker CO₂

5.3.3 Transport related GHG emissions

Transport GHG - LCI data extracted from Cement LCA Calculator is listed in below table.

Table 5-10: LCI results of transport (leakage) CO₂

Boundary	Scope	Process	Absolute			Specific			Specific GHG savings 2007 (Coal+AFR, ABC) wrt 2001 (HFO, OPC) [%]
			[tCO ₂ /year]			[kgCO ₂ /ton cem]			
			HFO, OPC	Coal, OPC	Coal+AFR, ABC	HFO, OPC	Coal, OPC	Coal+AFR, ABC	
Indirect	3	Transport CO ₂	1,667	2,267	3,908	2	4	5	-148

Results show a 148% specific increment in transport sector GHG, with respect to 2001 manufacturing scenario. The identified main reason for this increase is the relatively increased material consumption and its impact on increased transportation. Below figure shows the transport GHG analysis from Cement LCA Calculator focusing the distance and volumes transported. In current scenario the increasing distance mainly due to local coal transportation activities from Trincomalee ports to PCW and AF biomass increased highest number of fleet trips due to carrying low dense biomass material. However this emission only accounts for 0.7% of the total absolute GHG emissions. Below figure shows the increasing trend of distance

travelling on local supply chain of input materials. Similarly road transported material loads also increased from 121,810 to 260,810 tonnes.

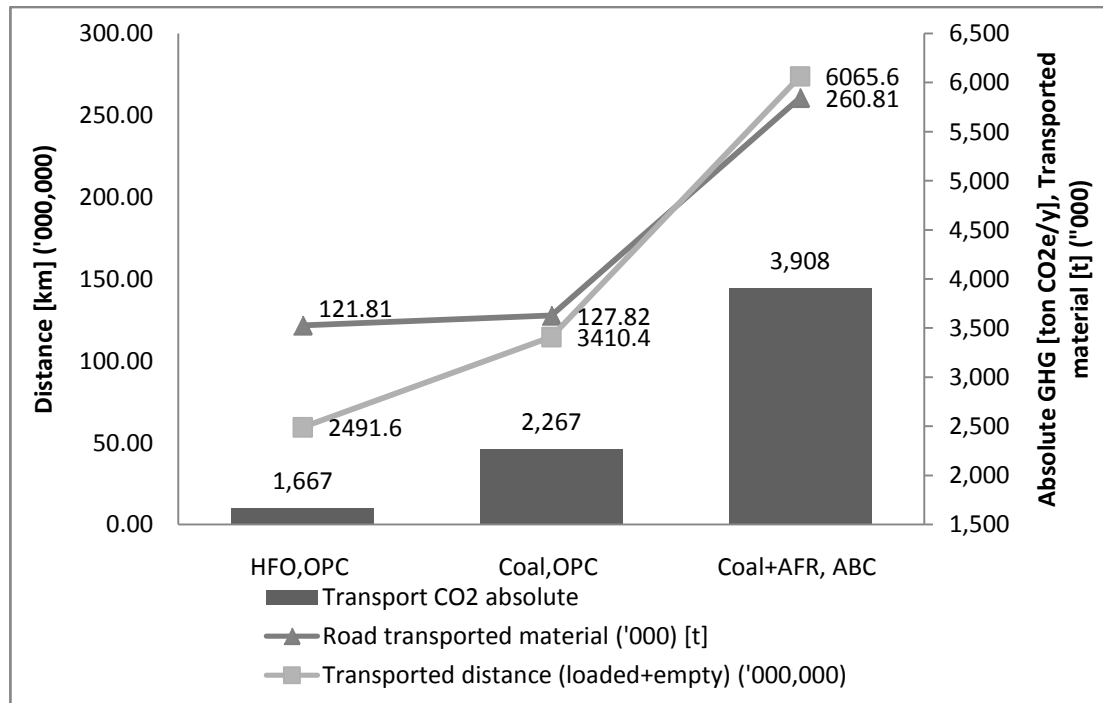


Figure 5-8: LCIA: Transport GHG analysis

5.4 LCIA Profile - Environmental balance sheet

The scope of the environmental balance sheet was defined to GHG reporting scope 1 and 2 in order to assess the real material input. This also can be extended to scope 3, however it requires more data collection efforts including inputs to lorry transport fleets (lubricants, tyres etc). The environmental balance sheet was presented in specific figures which also in equal units kgCO₂e/t cem. Both material & energy inputs and outputs are presented in the below environmental balance sheet. Including waste heat and water in to the balance sheet are the identified future activities. HLL-PCW kilns are long dry type since water is only used for domestic purposes and equipment cooling. Waste heat was not taken in to account due to primary data validation constraints.

Including gaseous emissions to the environmental balance sheet supports to further research and study the changes occurred to other (waste) gaseous parameters with the

manufacturing process changes. Hence these were tabulated separately only for the current manufacturing scenario due to lack of data for each gaseous parameters in year 2001 and 2003. HLL is appreciated for the effort made to monitor all the required emission parameters annually by professionally qualified accredited test houses. Also the test methods are uniformly set according to the internationally accepted USEPA and EU guidelines. These results are also included in the environmental balance sheet shown below.

Environmental Balance Sheet [scenario: Coal + AF, Application Based Cement]						
Inputs		[g/t cem]	[kJ/t cem]	Outputs [g/t cem]		
Raw material	Limestone	1,230,069.85		Cement	Cement	1,151,413.03
	Dolomite	-			(Cementitious material)	(1,000,000.00)
	Laterite	20,021.97			(Clinker)	(881,057.73)
	Clinker - Imported	110,979.28		Waste - solid	Bypass dust	-
Consumables	Explosives	175.74			CKD	-
Wear & tear	Refractory - Basic	908.76		Waste - gaseous emissions	CO ₂ e scope 1 & 2 (net)	663,413.35
	Refractory - Alumina, Fireclay	502.16			Dust particulate	45.11
	Grinding media - raw material	143.38			NO _x	1,202.88
	Grinding media - cement	48.71			SO ₂	22.55
Set regulator	Gypsum	16,435.69			HCl	37.59
Additives	Dolomite	-			VOC	3.01
Clinker substituted	High grade limestone	19,900.45			NH ₃	3.01
Packaging	2 ply paper bags	116.87			CO	60.14
Traditional fuel	HFO	2,821.00	103.82		Benzene	1.07
	Coal	93,631.56	2,171.50		Dioxins & Furans [I-TEQ g/t cem]	0.00000012
AF : Fossil Fuels	waste oil	2,322.26	59.47			
	solvents	1.15	-			
	mixed industrial waste	328.34	2.99			
	other fossil based wastes	172.50	1.60			
AF - Biomass	wood, non impregnated saw	16,435.69	226.16			
	agricultural, organic, charcoal	19,900.45	274.98			
Non kiln fuel (scope 01)	Diesel	1,681.61	72.31			
Electrical energy	[kWh/t cem]	N/A	112.27			

Figure 5-9: Environmental balance sheet (current manufacturing scenario)

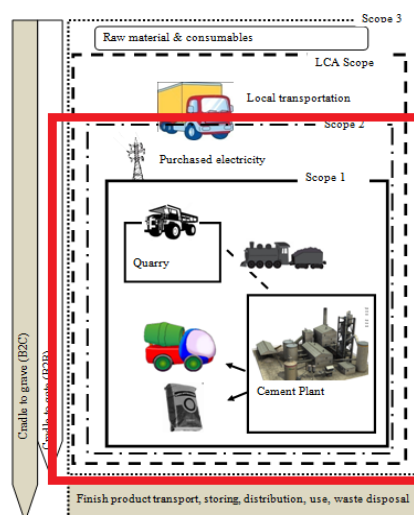


Figure 5-10: Scope of the LCIA profile (environmental balance sheet)

Material Balance			Specific Mass input [kg/ton cem]			Absolute Mass input [T/y]		
		Input Material	HFO,O PC, 2001	Coal,O PC, 2003	Coal+A FR,ABC , 2007	HFO,O PC, 2001	Coal,O PC, 2003	Coal+A FR,ABC , 2007
Unit Process 01 [upto clinker production]	Raw material	Limestone	1,686.9	1,518.7	1,230.1	819,357	905,370	891,375
		Dolomite	-	3.0	-	-	1,779	-
		Laterite	42.1	28.6	20.0	20,427	17,063	14,509
	Support material	Explosives	0.2	0.2	0.2	105	120	127
		Refractory - Alumina, Fireclay	0.4	0.4	0.5	187	219	364
	Consumables	Refractory - Basic	1.5	1.4	0.9	736	861	659
		Grinding Media - Raw Material	0.2	0.2	0.1	81	98	104
	Conventional fuel	HFO	87.7	0.6	2.8	42,579	338	2,044
		Coal	-	142.1	93.6	-	84,684	67,850
	AF : Fossil Fuels	Waste oil	-	-	2.3	-	-	1,683
		Tyres	-	0.5	-	-	297	-
		Solvents	-	-	0.0	-	-	1
		Mixed industrial waste	-	-	0.3	-	-	238
		Other fossil based wastes	-	-	0.2	-	-	125
	AF - Biomass	Wood, non impreg saw dust	-	-	16.4	-	-	11,910
		Agricultural, organic, charcoal	-	-	19.9	-	-	14,421
		Clinker - Imported	84.8	-	111.0	41,178	-	80,422
Waste	Bypass dust	-	-	-	-	-	-	
	CKD	-	-	-	-	-	-	
Non kiln fuel	Diesel [up to Clinker]	2.7	2.3	1.6	1,322	1,374	1,163	
Up to / including Clinker Percentage [%]			95.9	92.8	84.5	96	93	84
Unit process 02 [from clinker to cement]		Clinker	922.2	879.4	728.7	447,904	524,238	528,064
	Regulator	Gypsum	30.7	34.6	45.6	14,907	20,639	33,016
	Additives	Dolomite	-	-	43.8	-	-	31,755
	MIC	High Limestone	47.1	92.6	181.2	22,876	55,192	131,292
	Support	Grinding Media - Cement	0.0	0.1	0.0	22	62	35
	Non kiln fuel	Diesel [up to Cement]	0.1	0.1	0.1	65	65	56
	Package	Paper Bags 3ply	4.2	3.6	-	2,037	2,168	-
	Paper Bags 2ply	-	-	4.6	-	-	3,338	
Clinker to Cement Percentage [%]			4.1	7.2	15.5	4	7	16
	Cementitious material	1,000.0	1,000.0	1,000.0	485,708	596,130	724,654	
	Cement	1,048.3	909.1	1,151.4	509,168	541,949	834,376	

Figure 5-11: LCI data - Material balance sheet

A detail energy study is the second part of an environmental balance sheet which is a similarly important analysis to material analysis. The results energy balance sheet results are split in to two sections thermal and electrical in order to simplify the results.

Table 5-11: Environmental balance sheet– energy

Phase 01: Thermal Energy Balance		Absolute input [TJ/year]			Specific input [kJ/t cem]		
		HFO,OPC, 2001	Coal,OPC, 2003	Coal+AFR,ABC, 2007	HFO,OPC, 2001	Coal,OPC, 2003	Coal+AFR,ABC, 2007
Conventional fuel	HFO	1,739	14	75	3,580	23	104
	Coal	0	1,943	1,574	0	3,259	2,171
Conventional Total		1,739	1,957	1,649	3,580	3,282	2,275
AF : Fossil fuels	Waste oil	0	0	43	0	0	59
	Tyres	0	10	0	0	16	0
	Solvents	0	0	0	0	0	0
	Mixed industrial waste	0	0	2	0	0	3
	Other fossil based wastes	0	0	1	0	0	2
Fossil AF Total		0	10	46	0	16	64
AF - Biomass	Wood, non impreg saw dust	0	0	164	0	0	226
	Agricultural, organic, charcoal	0	0	199	0	0	275
Biomass AF Total		0	0	363	0	0	501
Non kiln fuels	Diesel (scope 01)	58	62	52	120	104	72
Waste heat		Not performed					
Phase 02: Electrical Energy Balance		Absolute input [MWh/year]			Specific input [kWh/t cem]		
		HFO,OPC, 2001	Coal,OPC, 2003	Coal+AFR,ABC, 2007	HFO,OPC, 2001	Coal,OPC, 2003	Coal+AFR,ABC, 2007
Purchased electrical energy		60,298	65,769	81,359	124	110	112
Grid emission factor [kg CO ₂ /MWh]		417	426	426			

Chapter 6 CONCLUSIONS AND RECOMMENDATIONS

Chapter 6 covers the final episode of the LCA study, life cycle interpretation phase for the three cement manufacturing scenarios. ISO 14043 – Environmental management – Life cycle assessment – Life cycle interpretation (version 2000) recommends the requirements, were followed in this chapter. It is also similarly looks like a concluding or interpretation of a study. The limitations of the LCIA is also identified and discussed in this chapter which opens the areas to future researching in same topic.

6.1 Comparative analysis of different manufacturing scenarios

LCA is a methodology which can used to evaluate different manufacturing scenarios to make a better judgment on each process and this was already identified as the first objective of this research which discussed in section 1.3. GHG emission specifically measured and presented by selected functional unit $\text{kgCO}_2\text{e/t cem}$ is the used indicator for all the comparisons under this section. Comparative analysis options and interpretation charts are also integrated parts of Cement LCA Calculator mini software.

Results are showing that absolute GHG emission is increased from selected manufacturing scenario 01 – ‘HFO, OPC’ to scenario ‘Coal+AFR, ABC’ (current scenario) from 443,330 to 557,400 $\text{tCO}_2\text{e/y}$ by 125.7%. In order to analyze the GHG emission growth in a scientific manner comparing it with the production quantities is essential. During the manufacturing changes from ‘HFO, OPC’ to scenario ‘Coal+AFR, ABC’ production of cementitious material increased from 485,708 to 724,654 t/y by 149.2%. Figure 6-1 shows the changes in absolute GHG emission and the production.

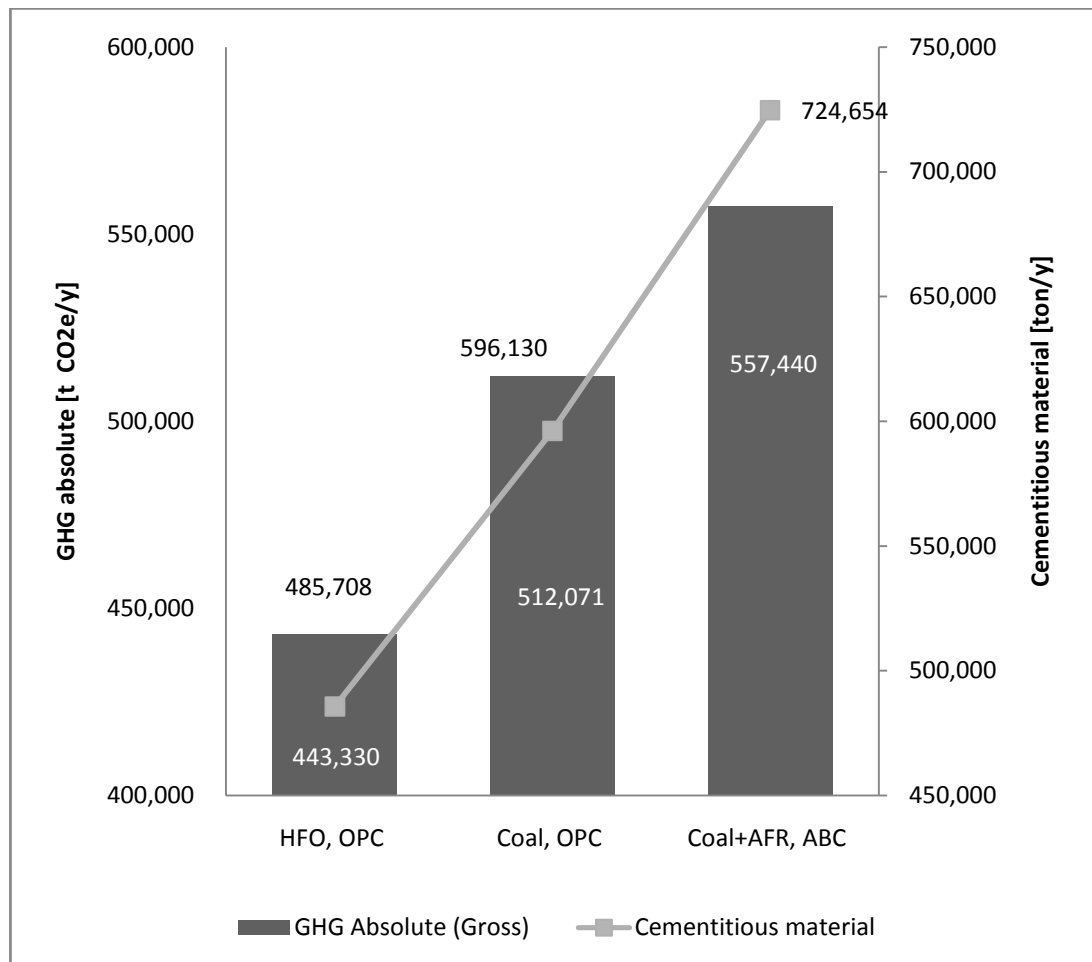


Figure 6-1: LCA data - GHG absolute & cementitious material

Analysis of GHG emissions in specific figures is an important criterion to identify the changes in GHG emissions with respect to products and production volumes. This has to be done in a rational manner in order to provide an unbiased interpretation which ensured by selecting the functional unit as kgCO₂e/t cem. Selecting the product unit as ‘cementitious material’ instead of ‘cement’ and functional unit as ‘kgCO₂e/t cem’ were the research initiatives taken in order to fulfill this requirement of unbiased comparison. This selection supported on comparing the different cement product ‘one to one’ basis which is not possible in the case of selecting cement as the functional unit.

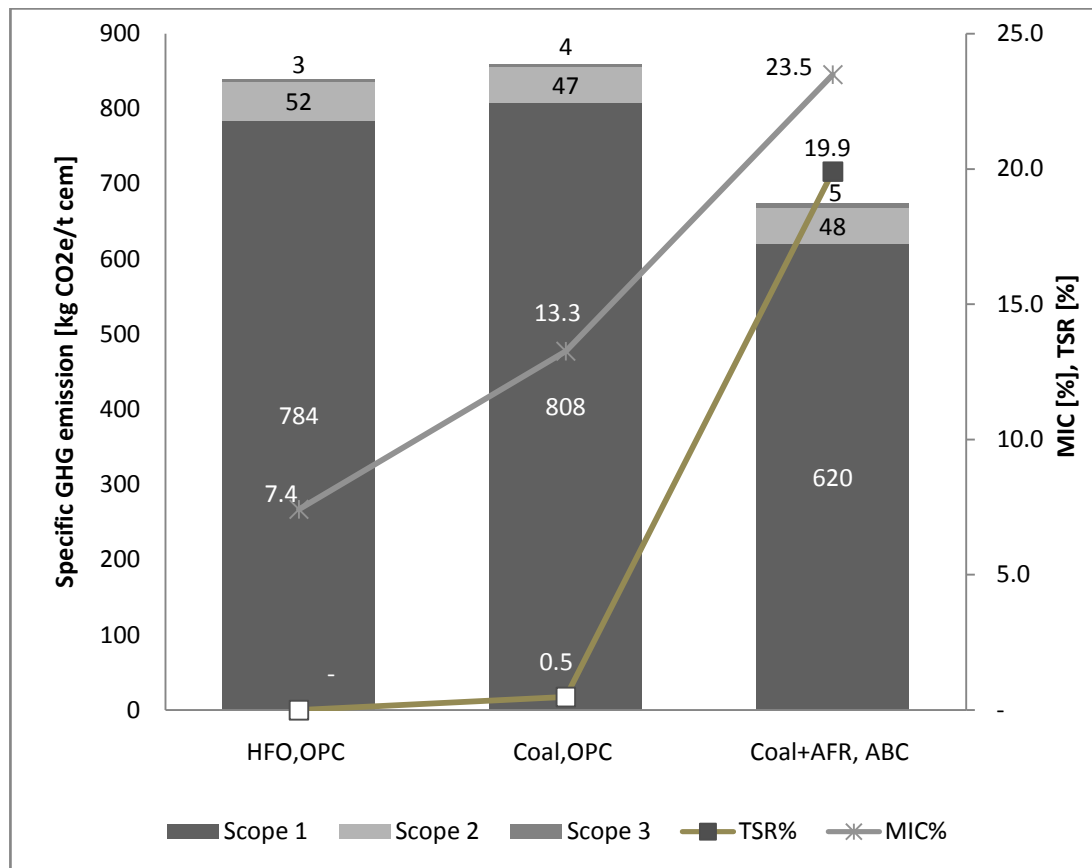


Figure 6-2: LCA data - specific GHG emission

GHG reporting scope wise analysis in above Figure 6-2 shows the reduction of specific GHG emission due to process changes. Majority of the reduced emissions are fallen under direct GHG (scope 01) which is from 784 kgCO₂e/t cem to 620 kgCO₂e/t cem from HFO,OPC scenario to Coal+AFR, ABC scenario. It is also observed, there is a slight increase of direct GHG emissions during the kiln fuel switching from HFO to coal. Scope 2 emission has only shown a slight decrease from 52 to 48 kgCO₂e/t cem. However the scope 3 emission one to one comparison is somewhat difficult due to absolute transportation of material increased significantly. However the increased specific CO₂ with respect to baseline scenario is from 2 kgCO₂e/t cem.

Figure 6-3 is a comparison of the specific and absolute emission outputs for the selected three manufacturing scenarios, providing scientific interpretation on the performed LCA.

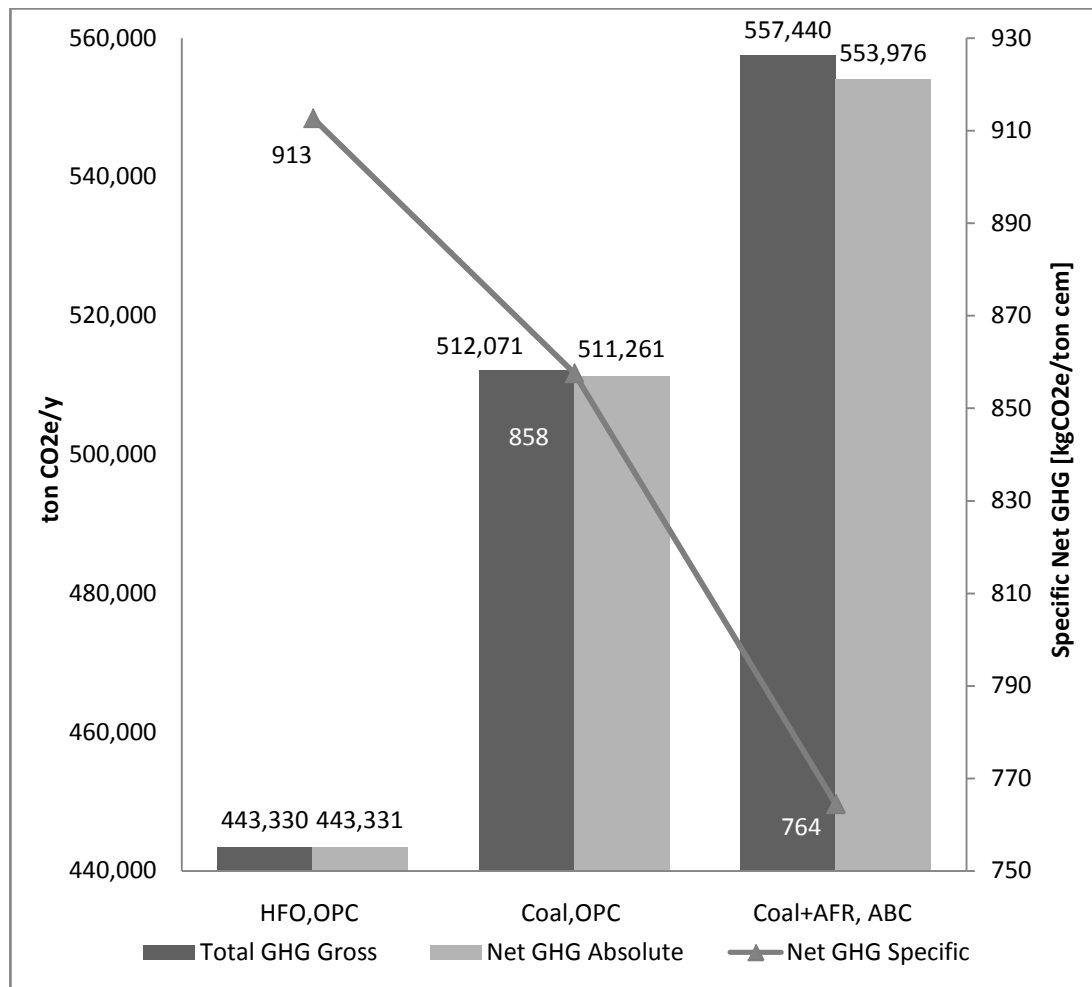


Figure 6-3: GHG - absolute, net and specific

Both absolute gross and absolute net GHG emission increasing trend is caused by the increased cement volumes, pushed through demanding market. Baseline scenario gross and net absolute GHG emissions are same. This is GHG credits are zero since no utilization of fossil AF. With the increasing trend of AF utilization this has been changed and in the current manufacturing scenario the positive difference between absolute gross and net emission is 3,464 tCO₂e. Specific net GHG trend also decreased significantly from 913 to 764 kgCO₂e/t cem from baseline scenario to current manufacturing scenario. This was mainly due to introducing AF and promoting more clinker substituted cement products under ‘Application Based Cement’ concept.

LCA study was split in to few unit processes, aiming high focus process wise. GHG

emission effects of the two identified unit processes for three manufacturing scenarios are shown in below Figure 6-4.

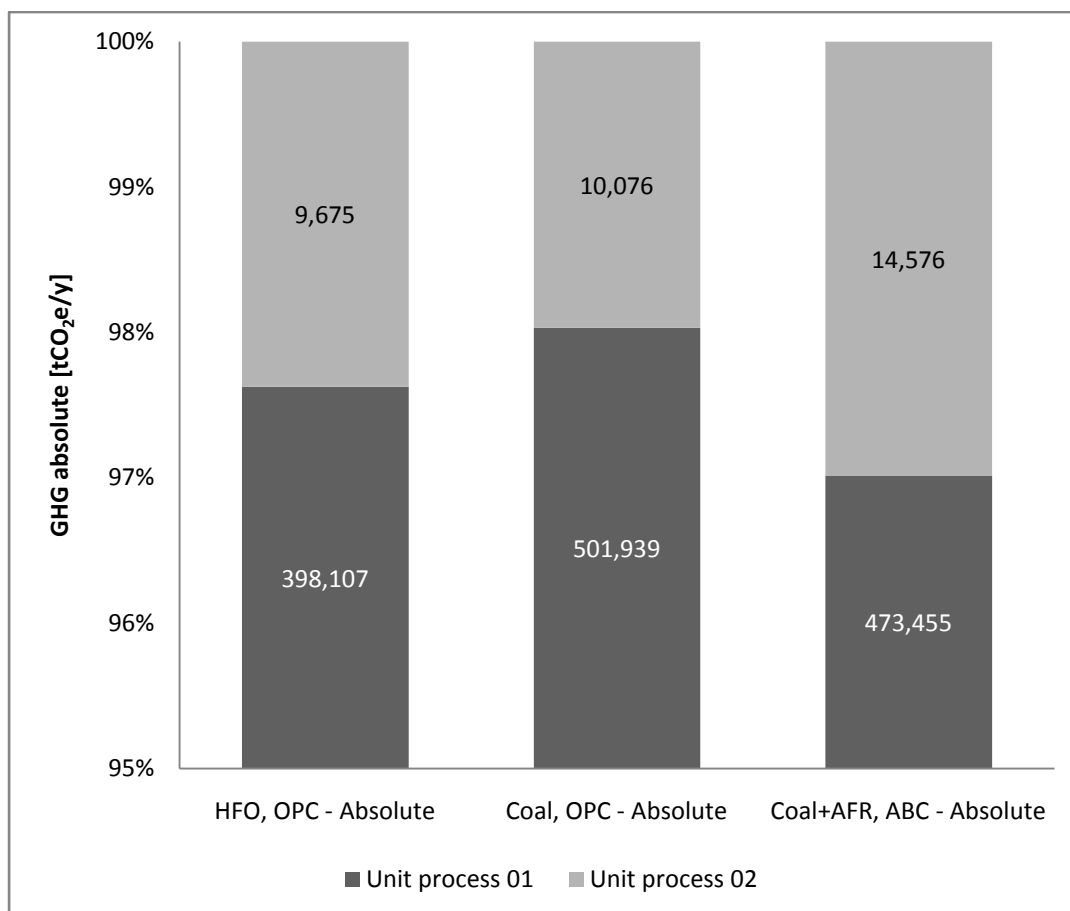


Figure 6-4: LCIA output : GHG emissions unit process analysis

The analysis clearly shows the decreasing trend of the unit process one related GHG, which is mainly due to the increasing AF and promoting clinker substituted products. Nearly 2-3% GHG emissions only accounts for the unit process two.

The scenario 03 Coal+AF, ABC shows the absolute emission increase of the Unit process 01 GHG emissions from 398,107 to 473,455 tCO₂e/y. However it similarly shows the decrease trend of unit process 01 emission with respect to unit process 02 emissions, comparing the two unit processes.

Overall summary of the performed LCA study is shown in the below table, a summary sheet from “Cement LCA Calculator”. Analysis are discussed ahead the main reasons for the GHG reductions and material optimization processes.

Table 6-1: LCA output summary

		HFO, OPC, 2001	Coal, OPC, 2003	Coal+AFR, ABC, 2007
Inputs	Material input [t/t cem]	1.985	1.826	1.771
	Electrical energy input [kWh/t cem]	124.1	110.3	112.3
	Thermal energy input traditional fuel	3580.5	3282.1	2275.3
	Thermal energy input alternative fuel [kJ/t cem]	0.0	16.0	565.2
Thermal substituted ratio with AF [%]		0.0	0.5	19.9
Clinker substituted material factor (w/w) [%]		7.4	13.3	23.5
GHG emissions	Scope 01 GHG [kgCO ₂ e/t cem]	784.4	808.2	620.3
	Scope 02 GHG [kgCO ₂ e/t cem]	51.8	47.0	47.8
	Transport GHG [kgCO ₂ e/t cem]	2.2	3.8	5.4

In creased clinker substituted material (MIC) in cement composition and alternative fuel utilization are the identified two main reasons for the environmental friendly GHG reduction. These two reasons are separately further studied, under ‘comparative assertion’ in below, LCA interpretation phase. Reduction of specific material inputs and specific energy reduction are also positive observation towards climate change mitigation driven actions in HLL.

6.1.1 Comparative advantages of AF utilization

GHG reduction due to utilization of AF can further study by looking at the below Figure 6-5 a graphical analysis which shows the increased trend of GHG neutral emissions by AF-biomass.

The GHG emission due to traditional fuel use is gone down. Increasing trend of thermal substitution ratio shows the positive contribution for local waste problem and conserving the traditional fuel sources by replacing it for future.

Increased utilization of AF can have an influence on the direct CO₂ emissions of a cement company, because the emission factors of the AF can differ from those of the displaced fuels. Utilization of AF by the cement industry typically results in GHG emission reductions at landfills and incineration plants where these wastes would otherwise be disposed. These indirect emission reductions can be equal, higher or lower than the direct CO₂ emissions from AF combustion at the cement plant, depending on the type of waste and the displaced disposal path.

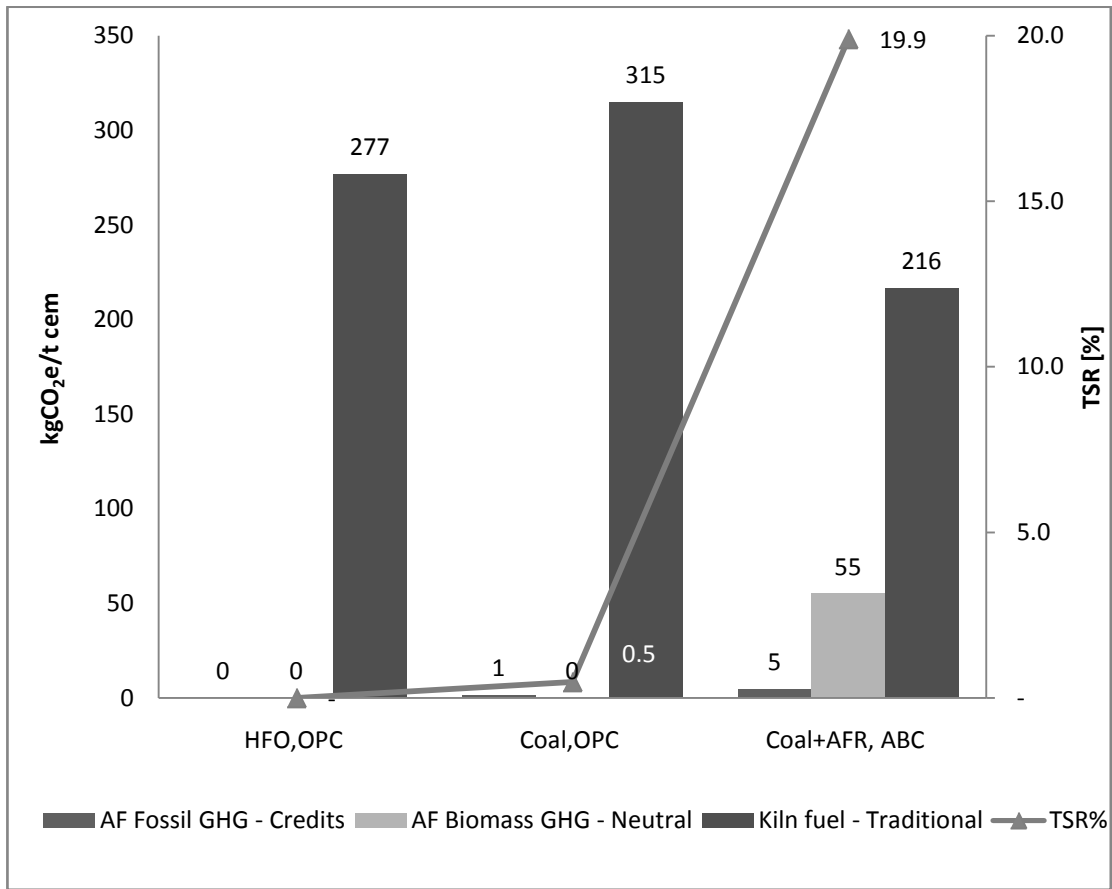


Figure 6-5: LCIA direct GHG emission combustion

6.1.2 Comparative Advantages of usage of clinker substitutions

Process changes made during the years from 2005 to 2007 were highly focused on

product composition improvements. New cement standard for ‘PLC – Portland Limestone Cement’ was locally introduced and demand increased for application based cement. Maintaining cement standards with more clinker substituted material (mineral components – MIC) was the key technical driving factor behind this process. The specific GHG emission emitted during calcination process considerably reduced due to relatively less clinker composited cement manufacturing. Graph in Figure 6-6 shows the clear relationship of increasing clinker substituted material (weight to weight) percentage and product related calcination GHG emissions. Calcination GHG accounts for 53.2% in HFO,OPC scenario which decreased to 50.2% in current business scenario. Similarly this reduced the limestone consumption from 1686.9 to 1230.1 kg limestone/t cem representing the manufacturing years 2001 and 2007 respectively. This results more indirect benefits like reducing the biodiversity impact at quarry site, reducing effect of transpiration related GHG and other impacts and specifically natural resource savings for the future generation use.

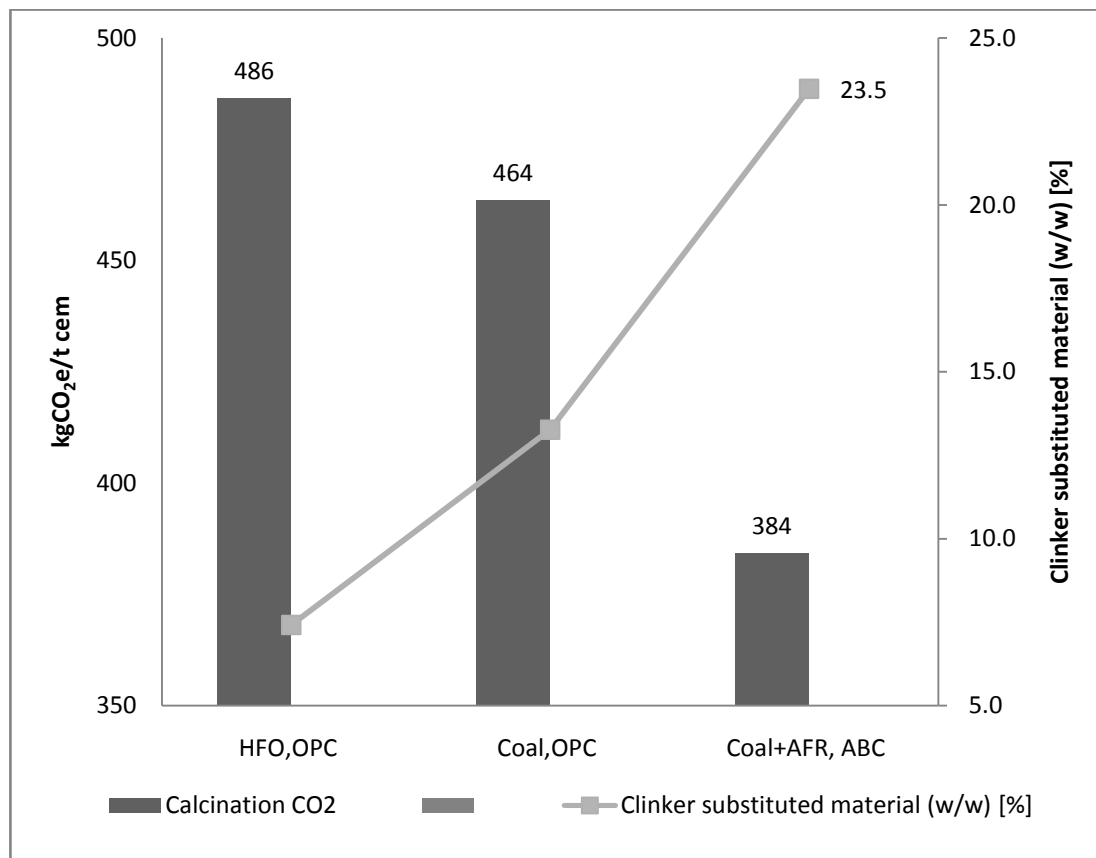


Figure 6-6: Calcination GHG scenarios

6.1.3 Comparative analysis on transportation GHG

Due to manufacturing scenarios were changed, inputs also changed. This was directly changed the supply chain practices. Changes in fuel sources, impacted on transportation, specifically due to AF increasing trend. The GHG emission involved for the transportation of main kiln fuel source also increased, from HFO scenario to coal scenario. The overall transport related GHG increased while shifting to Coal+AF,ABC scenario. However the main fuel source - coal transportation related GHG reduced from 1793 to 1432 tCO₂e/y due to AF implementation. AF transportation related GHG increased from 10 (2003) to 251 tCO₂e/y year 2007. The fluctuations of imported clinker related local transportation GHG emissions contributed significantly on the overall transportation GHG fluctuations in between scenarios. However this is an environmental achievement even with the increasing production volumes. Figure 6-7 shows the local transportation related absolute GHG emissions aligned to the above interpretations.

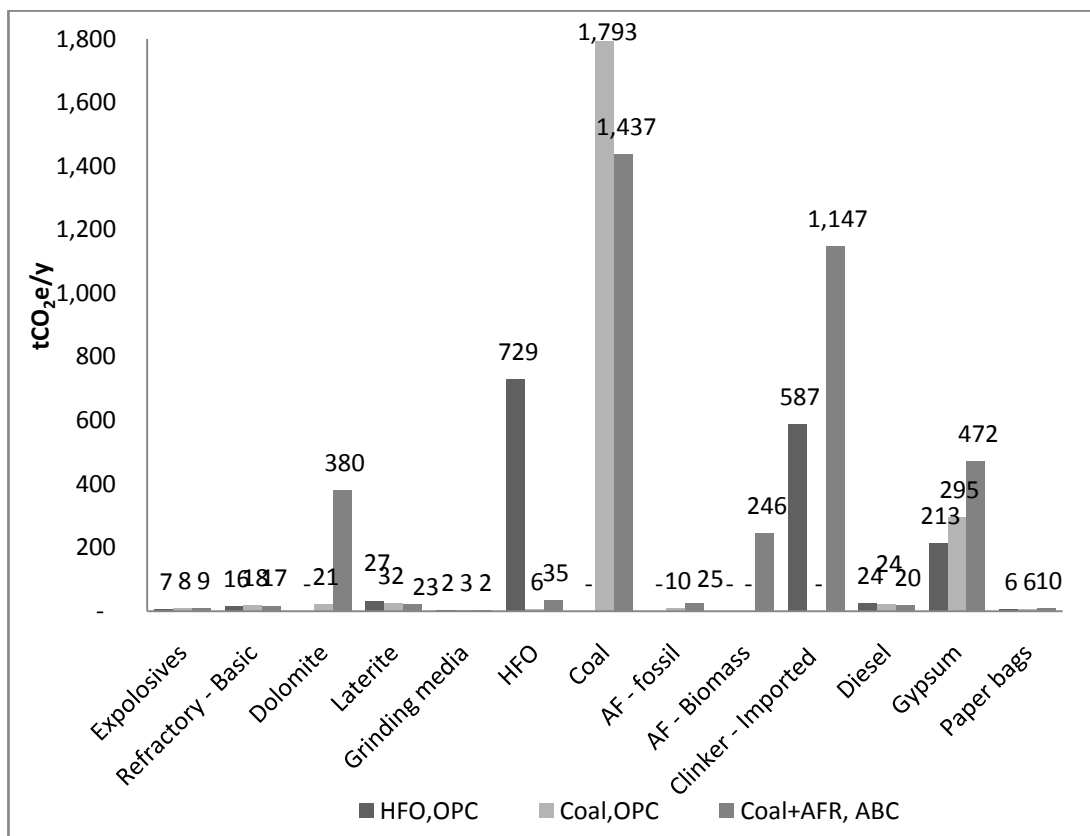


Figure 6-7: LCA data – local transport related absolute GHG

Below, extended analysis shows the material wise average tonnage per shipment.

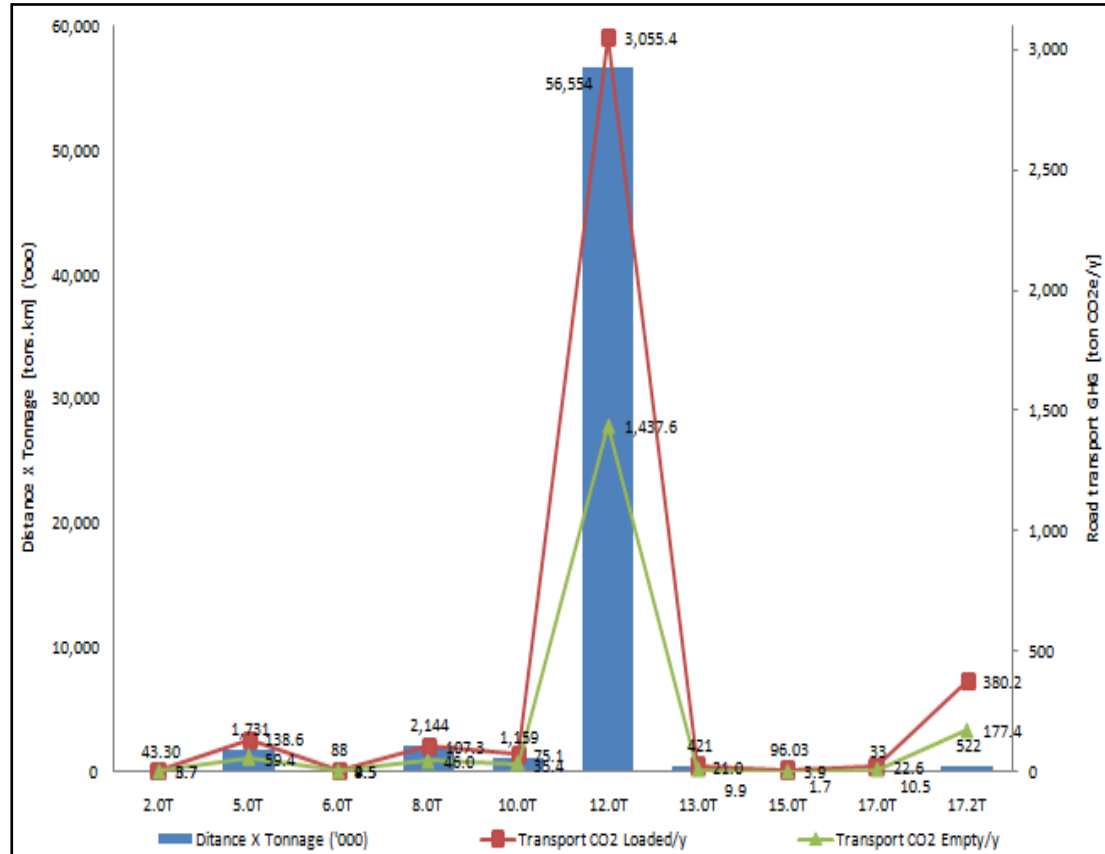


Figure 6-8: Distribution of average tonnage by road (2007)

This above extended analysis option was integrated to Cement LCA Calculator, as an extended interpretation tool carry out deeper analysis in the supply chain related GHG. Figure 6-8 shows the majority of the GHG emissions were generated in 12 t class. Contribution of the empty truck GHG emissions also significant which 1,457 tCO₂e with respect to loaded truck GHG tonnage 3,044 tCO₂e. This LCA outcome opens a new area of study and research on optimizing the logistics of cement inputs materials. Increasing trend observed in the class 5 t due to increasing AF inputs, which is a potential alternative to backhaul cement to dispatch channel.

6.2 Limitations

Identifying limitations of the performed LCA is a definite support for future studies aiming on similar process areas. Also, it is a mandatory requirement from the

selected methodology – ISO 14040 guideline. Data acquisition is a pre identified typical constraint for most of the LCA studies. However for the specific study data collection was not a significant issue excluding for few data series, this is due to the established proper data management systems by HLL. Below limitations are listed for the benefit of future LCA practitioners.

- The main limitation was access to commercial LCA software which enables to expand the LCA study on validation process with global data.
- Finding product embodied data for most of the inputs was a difficult task. Lack of interest and low regulatory enforcements towards GHG aspects hasn't promoted monitoring and reporting of GHG emissions. This limited performing the LCA with product embodied carbon, which might led to PAS 2050 compliant assessment.
- Obtaining local data on transportation activities (vehicle GHG factors and road network density data) was not practical. A national database on transportation and its related environmental impacts couldn't source. This issue limited adding more accurate values on transport related local GHG data. (This study was carried out utilizing WRI and WBCSD commissioned vehicle emission factors which most of the data are customized to Europe region.)
- Usage of LCA related findings in corporate marketing strategies is still not practicing locally. This unable in creating the real value on LCA among corporate due to lack of scientific awareness with marketing responsible. Similarly this dragged a lot on extended data acquisition process.
- National grid GHG factor was sourced from the IPCC reports since national level reliable published data was not found for the comparing years.
- Since there was no similar local studies performed earlier, comparing final figures with an existing study couldn't carry out.

6.3 Recommendations / future activities

This LCA study can be extended to different streams in future, based on the interest of the LCA practitioners and target groups. There are few identified areas which will open interest areas for future LCA researches.

One of the key outcome of performing a LCA study is to provide recommendation, to the interested parties how to improve the environmental responsibilities through justifiable findings. This is mostly by integrating findings in to company marketing strategies to enhance the product value creation which considered during objective setting up process of the LCA study. Below list of recommendations are categorized to two main pillars (section 6.3.1 and 6.3.2) focusing research continuation and industrial aspects

6.3.1 Recommendations future activities focused local cement industry

Identified major environmental influencing outcomes were already discussed in section 6.1. The selected three areas shown the sustainability drive of HLL and the benefits for the climate combats through specific GHG reductions. These initiatives can be further optimized by considering the recommendations provided below. The practicality of applying those is highly depended on the managerial vision and the extent of the marketing value creation.

- Eco labeling

HLL monitor and report process related GHG as per the GRI guidelines complying Cement GHG Protocol. The specific GHG figures considering the functional unit 'tonne of cementitious material' monthly monitored, reported and validated in company management reviews. By integrating few extended GHG reporting aspects an eco label can be introduced starting with product GHG footprint which will create a definite environmental marketing value for the product. This will differentiate the product from other imported cement brands as well.

This can be further expanded to use phase material consumption and water which are having direct link to construction finance. This may also integrate to MSDS or technical specification of the product.

- Initiating green procurement

HLL has publically reported direct GHG emissions and indirect GHG scope 02 emissions in a transparent and consistence manner for number of years. Company

had made decision to publically report these outcomes though it is not a mandate. HLL maintains a number of selected vendors to assure timely stock maintenance and for better cost management purposes.

Involving the registered large scale vendor in green initiatives will create extended business benefits to the company by demonstrate the environmental responsibility to its indirect impacts which are offsite too.

This may also linked to important financial indicators like ‘net work capital’ – NWC on material stock maintenance and related environmental burdens during stocks management and storing. Some of the key features of green procurement is dual benefiting both ecology and economy aspects. In cement industry this can be used to optimize the material double handling processes and linked as a corporate leadership initiative which HLL promote its vendors uplifting towards better environmental performance.

- Eco-costing of AF

The increasing trend of AF use in cement kilns supported a lot on reducing the cement process related GHG impacts. Cement kiln AF co-processing is one of the best methods on utilizing the material and energy in a waste stream. The social service value creation by accepting the waste streams which is considered as an environmental burden and transferring in to a economical cum ecological value can be financially assessed. A total cost benefit analysis will provide the benefits of such service specially in a developing country like Sri Lanka where incinerators are not available and not viable too.

The financial valuing is a accepted way that justified the further investments towards the expansions of AF related business streams within the company and also applying government concessionary benefits on developing the AF field.

- Initiating green supply chain management options

Increasing cement demand observed after the post war developments and after regaining from the local and international financial crisis. The material supply also increases proportionate to the cement demand related manufacturing increasing trends.

Logistics fleet management is an important function to cover the input supply and product dispatch. Initiating the green supply chain management practices is a globally acceptable mechanism to reduce supply chain related expenses. It serves both financial and ecological aspects. Optimizing the logistics fleets reduces the fuel consumption which is directly proportionate to cost and GHG emissions cum other ecological impacts.

HLL input material fleet management operations are outsourced to few large scale vendors and implement such management programs are not a difficult task. These initiatives will further support on local traffic and logistic safety management too.

6.3.2 Recommendations and future activities specific research focus

Research focused identified developments are listed in below sections. These identifications will be a set of good guidelines for the future studies which intend to focus on the same processes, scope and future LCA's.

- Cement LCA Calculator software

LCA software played a critical role through out the LCA process both in LCI and LCIA processes. The software can be further developed in below areas and develop to commercial scale as a management tool focusing cement industry related, GHG mitigation activities.

- Expand the number of category indicators to energy efficiency, water pollution and other LCA impact categories
- Include a separate customized LCI data collection sheet for grinding units and cement dispatch centers – will simplify the usage for specific scale of the operation
- Create data reporting formats which linked to company business ERP system LCI and LCIA input/output sheets which reduces the data entry resources, time and reduce the number of errors.
- Improve the data entry format by improving the LCI phase with more user friendly appearance.
- Improve the graphical interpretation outputs (charts) by adding more

environmental marketing values

- Develop a separate customized summary sheet complying to GRI (climate change related) requirements which can be used as a direct input for the organization's annual public reports and sustainable development reports.
- Validating the software through a technical qualified, independent party which ensures the commercial acceptance.

- Product embodied emissions

Due to data unavailability and accessibility issues, product embodied carbon footprint for input materials was excluded from the scope. During scoping the LCA 'cradle to grave' considering the product embodied environmental impacts are also important. The data should also be customized to the local scenarios than using a product related figure found for a different geographical region since the economical, technical and social aspects of a product or a service differs with location. There are several databases which are updated frequent basis on product related environmental impacts. However most of them are developed using the actual figures of European region and other developed countries and it was observed differences with respect to local scenarios.

In developing future LCA developments creating scientific research on customizing these databases to Sri Lankan case will be a definite advantage and a need. Similarly this step will further increase the accuracy of the product with more accurate and realistic set of life cycle interpretation outcomes.

- Creating national level supply chain GHG database

Supply chain is an essential process unit in product related LCA's. For all the LCA's and product carbon foot-printing activities, supply chain GHG databases are used which developed in some other country due to no local database is available for Sri Lanka. Most of the instances this is an over estimation since existing databases are generated and maintained in highly industrialized countries. Developing a national GHG LCA database for the local transportation industry is a timely requirement, as Sri Lanka is now growing its infrastructure towards modern transporting medias and highways etc.

Annexure I – SLS & BSEN standards related to cement

Both chemical and physical properties are specifically mentioned by SLS & BSEN standards. Quality assurance teams use the most stringent criteria during production in order to maintain the both standards.

Table 6-2: Physical & chemical properties required by SLSI

Parameter	SLS 1253:2003	SLS 515:2003	SLS 107:2008
Physical parameters			
Compressive strength 2 days [N/mm ²]	NA	NA	>10
Compressive strength 3 days [N/mm ²]	>20	NA	NA
Compressive strength 7 days [N/mm ²]	NA	>10	NA
Compressive strength 28 days [N/mm ²]	40 – 62.5	>22.5	42.5-62.5
Setting time – initial [mins]	>45	>60	>60
Setting time – Final [mins]	<600	<600	NA
Fineness [cm ² /g]	>3300	>400	>225
Soundness [mm]	<10	<10	<10
Chemical Properties			
SO ₃ [%w/w]	<3.5	<3.0	<3.0
Loss of ignition [%w/w]	<11	NA	<0.1
Chloride [%w/w]	<0.1	<0.1	<5.0
Fresh mortar properties			
Water retention [m/m%]	NA	80-95	NA
Air content [v/v%]	NA	<6.0	NA
Flow [%]	NA	80-120	NA

(SLS , 2008), (SLS , 2008), (SLS , 2008)

HLL product portfolio related BSEN product quality standards are as below.

Table 6-3: Physical & chemical properties required by BSEN

Parameter	BS EN 197-1:2000	BS EN 413-1:2004
Physical parameters		
Compressive strength 2 days [N/mm ²]	>10	NA
Compressive strength 7 days [N/mm ²]	NA	>10
Compressive strength 28 days [N/mm ²]	<42.5	>12.5
Setting time – initial [mins]	>60	>60
Soundness [mm]	<10	<10
Chemical Properties		
SO ₃ [%w/w]	<3.5	<3.0
Chloride [%w/w]	<0.1	0.10
Fresh mortar properties		
Water retention [m/m%]	NA	>75
Air content [v/v%]	NA	<6.0

Source (HLL, 2009)

Annexure II – Wet kiln and dry kiln processes

From the earliest times, two different methods of raw mix preparation were used: the mineral components were either dry-ground to form a flour-like powder, or wet-ground with added water to produce a fine slurry with the consistency of paint, and with a typical water content of 40–45%.

The wet process suffered the obvious disadvantage that, when the slurry was introduced into the kiln, a large amount of extra fuel was used in evaporating the water. Furthermore, a larger kiln was needed for a given clinker output, because much of the kiln's length was used up for the drying process. On the other hand, the wet process had a number of advantages. Wet grinding of hard minerals is usually much more efficient than dry grinding. When slurry is dried in the kiln, it forms a granular crumble that is ideal for subsequent heating in the kiln. In the dry process, it is very difficult to keep the fine powder raw mix in the kiln, because the fast-flowing combustion gases tend to blow it back out again. It became a practice to spray water into dry kilns in order to "damp down" the dry mix, and thus, for many years there was little difference in efficiency between the two processes, and the overwhelming majority of kilns used the wet process. By 1950, a typical large, wet process kiln, fitted with drying-zone heat exchangers, was 3.3 x 120 m in size, made 680 tonnes per day, and used about 0.25–0.30 tonnes of coal fuel for every tonne of clinker produced. Before the energy crisis of the 1970s put an end to new wet-process installations, kilns as large as 5.8 x 225 m in size were making 3000 tonnes per day. An interesting footnote on the wet process history is that some manufacturers have in fact made very old wet process facilities profitable through the use of waste fuels. Plants that burn waste fuels enjoy a negative fuel cost (they are paid by industries needing to dispose of materials that have energy content and can be safely disposed of in the cement kiln thanks to its high temperatures and longer retention times). As a result the inefficiency of the wet process is an advantage—to the manufacturer. By locating waste burning operations at older wet process locations, higher fuel consumption actually equates to higher profits for the manufacturer, although it produces correspondingly greater emission of CO₂.

However with the new cement kiln technology improvements there are more types introduced. Mainly this is due to optimize the heat consumptions and reduce unnecessary emissions.

There are four types of kilns in use - long wet kilns, long dry kilns, kilns with a preheater and kilns with a precalciner. The long wet and dry kilns and most preheater kilns have only one fuel combustion zone, whereas the newer precalciner kilns and preheater kilns with a riser duct have two fuel combustion zones. In a wet kiln, the ground raw materials are suspended in water to form a slurry. In a dry kiln, the raw materials are dried to a powder. Newer U.S. cement plants normally use the dry process because of its lower energy requirement. Because the typical operating temperatures of these kilns differ, the NO_x formation mechanisms also differ among these kiln types. In a primary combustion zone at the hot end of a kiln, the high temperatures lead to predominantly thermal NO_x formation. In the secondary combustion zone, however, lower gas-phase temperatures suppress thermal NO_x formation. Energy efficiency is also important in reducing NO_x emissions; for example, a high thermal efficiency means less heat and fuel are consumed and, therefore, less NO_x is produced. (STAPPA, ALAPCO, 1994)

Wet process kilns

The original rotary cement kilns were called 'wet process' kilns. In their basic form they were relatively simple compared with modern kilns. The raw meal was fed into the kiln at ambient temperature in the form of a slurry.

A wet process kiln may be up to 200m long and 6m in diameter. It has to be long because a lot of water has to be evaporated and the process of heat transfer in a wet process kiln is not very efficient.

The slurry may contain about 40% water. This takes a lot of energy to evaporate and various developments of the wet process were aimed at reducing the water content of the raw meal. An example of this is the 'filter press' (imagine a musical accordion 10-20 metres long and several metres across) - such adaptations were described as 'semi-wet' processes.

The wet process has survived for over a century because many raw materials are suited to blending as a slurry. Also, for many years, it was technically difficult to get dry powders to blend adequately.

Quite a few wet process kilns are still in operation, usually now with higher-tech bits bolted on. However, new cement kilns are of the 'dry process' type.

Dry process kilns

In a modern works, the blended raw material enters the kiln via the pre-heater tower. Here, hot gases from the kiln, and probably the cooled clinker at the far end of the kiln, are used to heat the raw meal. As a result, the raw meal is already hot before it enters the kiln.

A dry process kiln is much more thermally efficient than a wet process kiln.

Firstly, and most obviously, this is because the meal is a dry powder and there is little or no water that has to be evaporated.

Secondly, and less obviously, the process of transferring heat is much more efficient in a dry process kiln.

An integral part of the process is a heat exchanger called a 'suspension preheater.' This is a tower with a series of cyclones in which fast-moving hot gases keep the meal powder suspended in air. All the time, the meal gets hotter and the gas gets cooler until the meal is at almost the same temperature as the gas.

The basic dry process system consists of the kiln and a suspension preheater. The raw materials, limestone and shale for example, are ground finely and blended to produce the raw meal. The raw meal is fed in at the top of the preheater tower and passes through the series of cyclones in the tower. Hot gas from the kiln and, often, hot air from the clinker cooler are blown through the cyclones. Heat is transferred efficiently from the hot gases to the raw meal.

The heating process is efficient because the meal particles have a very high surface area in relation to their size and because of the large difference in temperature between the hot gas and the cooler meal. Typically, 30%-40% of the meal is decarbonated before entering the kiln.

A development of this process is the 'precalciner' kiln. Most new cement plant is of this type. The principle is similar to that of the dry process preheater kiln but with the major addition of another burner, or precalciner. With the additional heat, about 85%-95% of the meal is decarbonated before it enters the kiln. (Understanding-cement, 2010)

Below Figure 6-9 shows the process technology shifting of cement kilns from wet

kilns to dry kilns by selecting the CSI member cement plants.

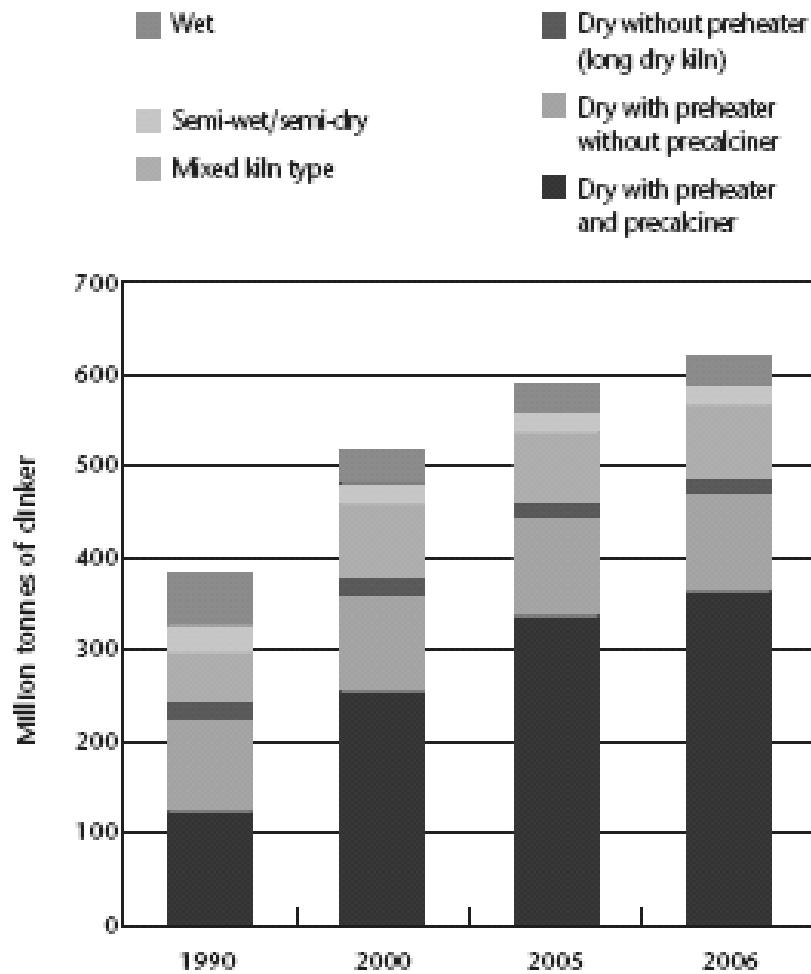


Figure 6-9: Clinker volumes by technology

Source: (WBCSD, 2008)

Annexure III - A brief history of LCA

Life Cycle Assessment (LCA) had its beginnings in the 1960's. Concerns over the limitations of raw materials and energy resources sparked interest in finding ways to cumulatively account for energy use and to project future resource supplies and use. In one of the first publications of its kind, Harold Smith reported his calculation of cumulative energy requirements for the production of chemical intermediates and products at the World Energy Conference in 1963. (Scientific Applications International Corporation (SAIC), 2006)

Later in the 1960's, global modeling studies published in *The Limits to Growth* (Meadows *et al* 1972) and *A Blueprint for Survival* (Goldsmith *et al* 1972) resulted in predictions of the effects of the world's changing populations on the demand for finite raw materials and energy resources. The predictions for rapid depletion of fossil fuels and climatological changes resulting from excess waste heat stimulated more detailed calculations of energy use and output in industrial processes. During this period, about a dozen studies were performed to estimate costs and environmental implications of alternative sources of energy.

In 1969, researchers initiated an internal study for The Coca-Cola Company that laid the foundation for the current methods of life cycle inventory analysis in the United States. In a comparison of different beverage containers to determine which container had the lowest releases to the environment and least affected the supply of natural resources, this study quantified the raw materials and fuels used and the environmental loadings from the manufacturing processes for each container. Other companies in both the United States and Europe performed similar comparative life cycle inventory analyses in the early 1970's. At that time, many of the available sources were derived from publicly-available sources such as government documents or technical papers, as specific industrial data were not available.

The process of quantifying the resource use and environmental releases of products became known as a Resource and Environmental Profile Analysis (REPA), as practiced in the United States. In Europe, it was called an Ecobalance. With the formation of public interest groups encouraging industry to ensure the accuracy of

information in the public domain, and with the oil shortages in the early 1970's, approximately 15 REPAs were performed between 1970 and 1975. Through this period, a protocol or standard research methodology for conducting these studies was developed. This multi-step methodology involves a number of assumptions. During these years, the assumptions and techniques used underwent considerable review by EPA and major industry representatives, with the result that reasonable methodologies were evolved.

From 1975 through the early 1980's, as interest in these comprehensive studies waned because of the fading influence of the oil crisis, environmental concerns shifted to issues of hazardous and household waste management. However, throughout this time, life cycle inventory analysis continued to be conducted and the methodology improved through a slow stream of about two studies per year, most of which focused on energy requirements. During this time, European interest grew with the establishment of an Environment Directorate (DG X1) by the European Commission. European LCA practitioners developed approaches parallel to those being used in the USA. Besides working to standardize pollution regulations throughout Europe, DG X1 issued the Liquid Food Container Directive in 1985, which charged member companies with monitoring the energy and raw materials consumption and solid waste generation of liquid food containers.

When solid waste became a worldwide issue in 1988, LCA again emerged as a tool for analyzing environmental problems. As interest in all areas affecting resources and the environment grows, the methodology for LCA is again being improved. A broad base of consultants and researchers across the globe has been further refining and expanding the methodology. The need to move beyond the inventory to impact assessment has brought LCA methodology to another point of evolution (SETAC 1991; SETAC 1993; SETAC 1997).

In 1991, concerns over the inappropriate use of LCAs to make broad marketing claims made by product manufacturers resulted in a statement issued by eleven State Attorneys General in the USA denouncing the use of LCA results to promote products until uniform methods for conducting such assessments are developed and a consensus reached on how this type of environmental comparison can be advertised non-deceptively. This action, along with pressure from other environmental

organizations to standardize LCA methodology, led to the development of the LCA standards in the International Standards Organization (ISO) 14000 series (1997 through 2002).

In 2002, the United Nations Environment Programme (UNEP) joined forces with the Society of Environmental Toxicology and Chemistry (SETAC) to launch the Life Cycle Initiative, an international partnership. The three programs of the Initiative aim at putting life cycle thinking into practice and at improving the supporting tools through better data and indicators. The Life Cycle Management (LCM) program creates awareness and improves skills of decision-makers by producing information materials, establishing forums for sharing best practice, and carrying out training programs in all parts of the world. The Life Cycle Inventory (LCI) program improves global access to transparent, high quality life cycle data by hosting and facilitating expert groups whose work results in web-based information systems. The Life Cycle Impact Assessment (LCIA) program increases the quality and global reach of life cycle indicators by promoting the exchange of views among experts whose work results in a set of widely accepted recommendations.

Annexure IV – Bag filter mechanism

The dust-laden air enters the bag filter bustle. The air is uniformly distributed avoiding channeling. Initially a coat of material forms on the bags. Subsequently, the coat acts as the filtering medium. The dust is accumulated on filter elements while the air passes through the filter bags from outside to inside. The accumulated powder is dislodged from the bags by reverse pulse-jet air intermittently. The dislodged powder falls on bottom cone and is discharged through powder discharge valves. The dust free air is sucked by induced draft fan and is exhausted to atmosphere (Figure 6-10). Knockers are provided on conical portion especially for sticky/hygroscopic materials. In a cement plant there are number of these installations and Figure 2-17 shows a set up de-dusting units fixed on blending silos at PCW – HLL. (Transparency Technology Pvt Ltd, 2009)

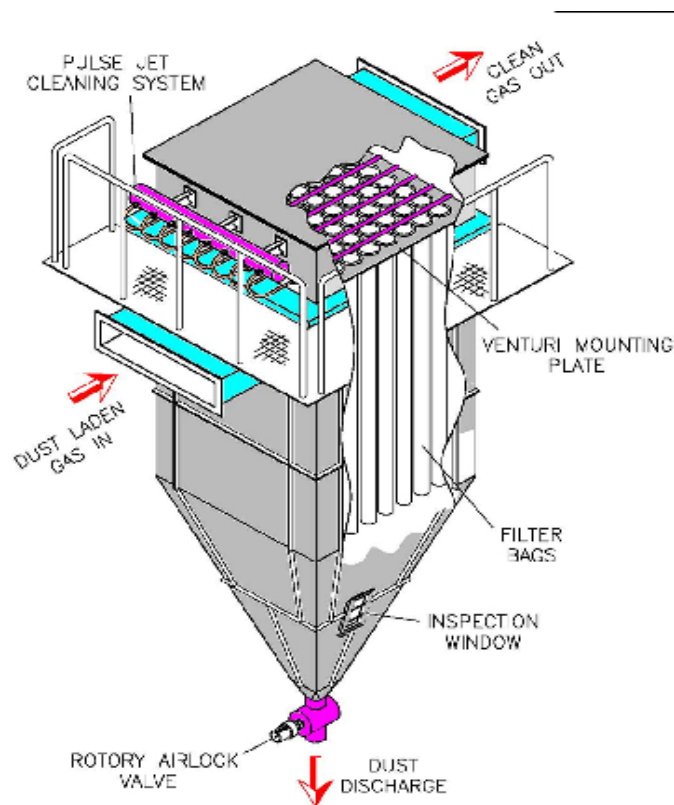


Figure 6-10: Typical bag filter unit in cement plants

Annexure V – Non CO₂ emission monitoring

Gaseous emissions other than CO₂ are also significant environmental impacts in cement manufacturing process. Emissions of SO₂, NO_x and VOC's are mostly common emission parameters which is given similar importance to GHG emissions in cement industry. However these three gaseous emissions are depended on raw material source, fuel composition and the specific process technology.

HLL PCW has invested and installed a continuous emissions monitoring (CEMs) system to monitor twelve important emission parameters including above three parameters. The availability and the accuracy is maintained and annually validated by a third party accredited test house.

While focusing on the GHG emission impacts in cement manufacturing some of the gaseous emissions were monitored as discussed in Table 6-4 below. LCIA phase these emission parameters also presented in the specific figures. HLL has already reported in publicly these parameters demonstrating the corporate transparency.

Table 6-4: Gaseous Emissions parameters monitored through CEMs

Parameters	Measuring Device(s)	Reporting Units	Measuring frequency
Dust (PM)	CEMs : FW101 Units	mg/Nm ³ (@ 10% O ₂)	Continuous
VOC's (Volatile Organic Compounds)	CEMs : FID (Flame Ionization Detector)	mg C/Nm ³	
CO, SO ₂ , NO _x as NO ₂ (In cement kilns NO _x is reported as NO as NO ₂ , hence the NO also converted to NO ₂) HCl, NH ₃	CEMs: MCS100E	mg/Nm ³ (@ 10% O ₂)	

Table 6-5: Gaseous parameters monitored and reported annually

Parameters	Measuring Methodology	Reporting Units	Measuring frequency	Remarks
Heavy Metals in gaseous phase	Method : USEPA 29	mg/Nm ³ (@ 10% O ₂)	Annually	A certified test house is occupied
Benzene	NIOSH - 1501	mg/Nm ³ (@ 10% O ₂)		
Dioxin & Furans	EPA Method - 23a	ngTEQ/Nm ³ (TEQ = Toxic equivalent)		

Annexure VI – Detail material & energy flow of cement manufacturing process

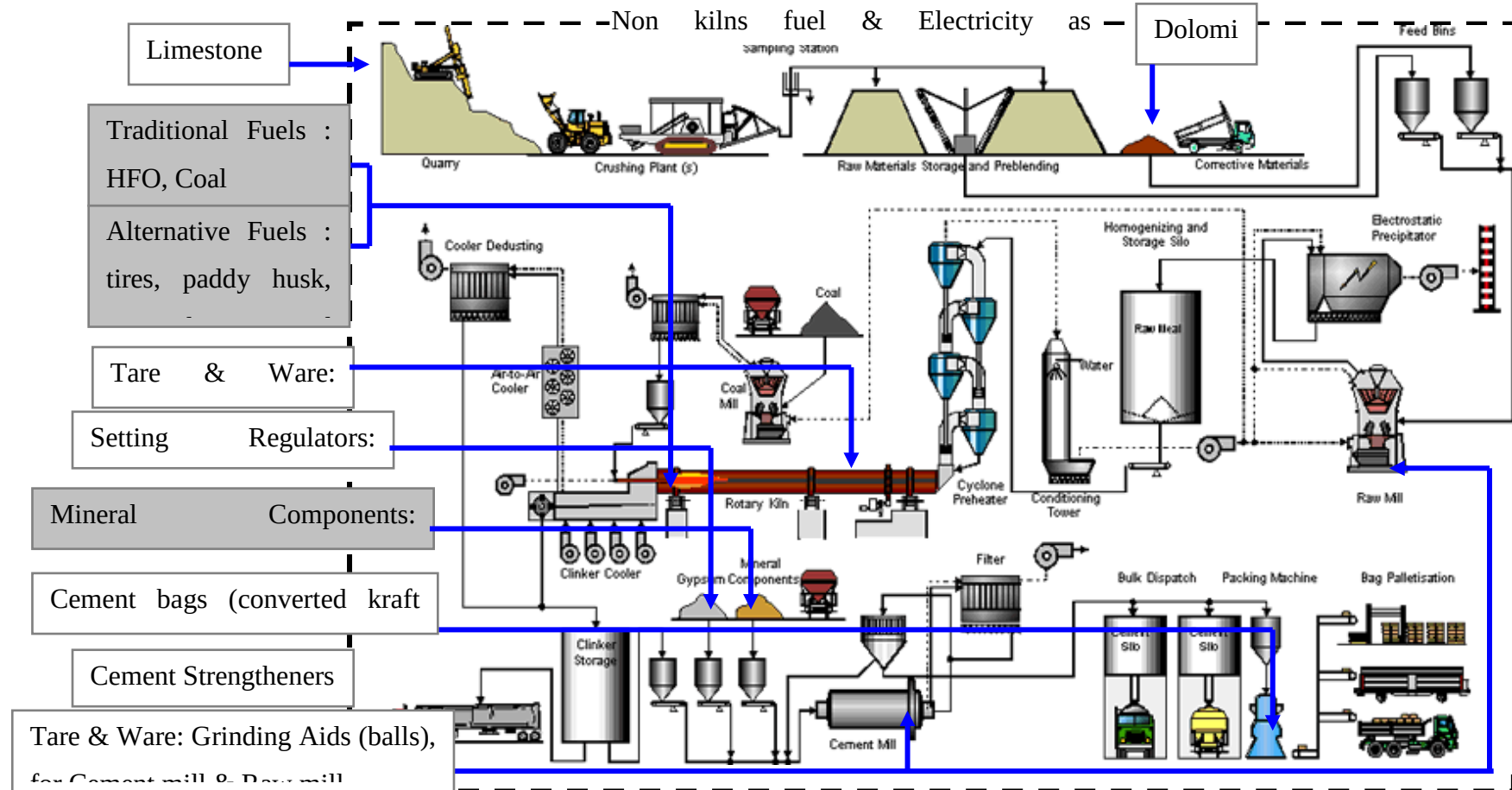


Figure 6-11: Material and energy input stages at HLL - PCW

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