University of Southern Queensland
Faculty of Engineering and Surveying

# Life Cycle Assessment of Cement in Malaysia

A dissertation submitted by

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# Abstract

Cement is one of the major materials used in construction. The demand of the cement has been increasing significantly for the past few years and the forecast of the cement demand will continue to grow. Considering the impact of the cement production brings to the environment it is important to reduce its impact as the production of cement continues to increase.

Life Cycle Assessment can use to assess the environmental impact of cement production. Thus, the aim of this project is to produce an outline of Life Cycle Assessment to analyse the impact of the cement production to the environment in Malaysia. Tasek Corporation Sdn Bhd is one of the cement manufacturers in Malaysia with the vision to be leading manufacturer in cement industry and operating in harmony with the environment. Tasek Corporation Sdnn Bhd is the target group of this project.

This project has carried out the four main phases of Life Cycle Assessment using the SimaPro software. The functional unit used is one kilogram production of cement. The flow chart of cement manufacturing process and input data collected is carried out in the life cycle inventory. Life cycle impact assessment and life cycle interpretation is carried out and comparison of alternatives fuel and type of cement is carried out. The assessment shown the clinker has the highest impact on the environment.

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## Limitation of Use

# Certification

I certify that the ideas, designs and experiment work, results, analyses and conclusions set out in this dissertation are entirely my own effort, except where otherwise indicated and acknowledged.

I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

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Signature

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Date

# Acknowledgements

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**Table of Content** **Page**

## Chapter 1



## Chapter 2

## Chapter 3



## Chapter 4



## Chapter 5

# List of Tables

# List of Figures

# ***Chapter 1***

**1.0 Introduction**

Sustainability has become a very hot issue for the developed or non developed country nowadays. Due to the global warming and other negative environment impact such as greenhouse, acid rain and ozone depletion many country are now more concern to develop their country with fine balance of sustainability. Cement has been one of the main materials in construction since the days it has been discovered. The demands of the cement are never going to be decrease and it will keep on increasing especially in the country such as China due to the rapid developing. But the cement manufacture causes environmental impacts at all stages of the process. These include emissions of airborne pollution in the form of dust, gases, noise and vibration when operating machinery and during blasting in quarries, consumption of large quantities of fuel during manufacture, release of $CO_2$ from the raw materials during manufacture, and damage to countryside from quarrying. This project is to conduct the life cycle assessment (LCA) on the cement manufacturing process using the SimaPro. The LCA can help us to understanding and identifying where the environmental impacts and damages occur during the manufacture of cement. With the understanding it can help to reduce negative environment impact and maintain fine balance of sustainability development.

**1.1.0 LCA in Malaysia**

In spite of the rapid development and certification to ISO14001, LCA has yet to gain wide spread interest in Malaysia. Governmental systematic support to date is confined to international standardization activities under ISO/TC 207. Some universities, research institutions and leading LCA researchers have carried out case studies.

### 1.1.1 NATIONAL LCA PROJECT of MALAYSIA (2006 -2010)

Under the Ninth Malaysia Plan of Malaysia, SIRIM has been mandated to develop a National Life Cycle Inventory Database for Primary Industries and Activities such as:

1. Electricity Generation
2. Water Supply
3. Petroleum and Natural Gas Exploration
4. Production of Petrochemicals

The LCI Database will facilitate efforts by industries to develop LCAs in their production and manufacturing process, leading to the promotion of environmentally sound technologies and adoption of self-regulatory measures. Their objectives are:

1. To develop the national life cycle inventory database
2. To develop a critical mass of local LCA practitioners.
3. To develop ecolabelling criteria documents for the National Ecolabelling Programme.
4. To create awareness among industry and consumer groups on the importance of LCA in today's manufacturing and purchasing practice.

## 1.2 SimaPro

SimaPro is a professional tool to collect, analyse and monitor the environmental performance of products and services. It is first released in 1990 and is a proven, reliable and flexible tool used by major industries, consultancies and universities. It consist of a large standard database and some optional databases. This data is meant to be used as background data which is not specific for the life cycle we are modeling, like electricity or transport. SimaPro has features that support its extensive use as a product development and LCA management tool. Though a graphical interface for system development is not offered, SimaPro is very easy to use and flexible. Access to, and unrestricted editing of the five database files is the characteristic which offers most of this flexibility and ease. Aside from data protection, all data and data management options are excellent and easy to operate. Embedded data are extensive and well documented; adequate descriptive fields are offered for each database entry; and user-defined data are easily input through templates offered by the software program. Various impact assessment options for system and block impact (e.g., easily accessible indicator values, characterization /normalization/ valuation calculations, and 'thermometer' scales) are available at all times while in the program. Results presented in a graphical format are supported, but tables are not. Unique features of SimaPro include the following:

1. The ability to link database entries;
2. Access to numeric and visual indications of impact for each stage, assembly, process, and material in a life cycle system; and
3. A multiple-users version of SimaPro is available (at a reduced cost for educational purposes) which offers unique features such as data protection and networking.

Limitations of SimaPro include the lack of graphical interface, sensitivity analysis and possibly the DOS interface.

## 1.3 Project Aim

The main aim of this research project is to produce an outline of the Life Cycle Assessment to analyse the impact of the cement production to the environment in Malaysia.

## 1.4 Project Objectives:

1. To provides information on potential environmental impacts of various life cycle stages of cement production.
2. To create awareness of the importance of the Life Cycle Assessment
3. Set up a basic model to confirm the feasibility of the method, and to characterize the environmental impact of cement manufacturing process. Carry out model sensitivity analyses.
4. To identify the hot spots and potential improvements of manufacturing processes, in order to provide a scientific basis for the optimum use of natural resources, and the optimum selection of manufacturing methods

## 1.5 Project Scope

The scope of this project is to comprise the production of Ordinary Portland cement in Malaysia such as proportioning, blending, grinding, preheater tower, kiln, clinker cooler and finishing. In life cycle assessment these unit processes in the manufacturing process is known as cradle-to-gate analysis. This report analyzes the results and gave recommendations to further research area.

# *Chapter 2*

**2.0 Life Cycle Assessment (LCA)**

Life cycle assessment (LCA) defined as a methodology and framework use for identification of products or processes environmentally friendly level. It is characterised by the analysis of cumulative environmental impacts over extended system boundaries. Other techniques of environment usually focus on either manufacturing process or end of life disposal. In LCA it considers the life cycle of a product or the entire chain of activities involve supporting the product or process. This is often called the cradle-to-grave approach, and has the obvious advantage of revealing potentially significant but "hidden" environmental impacts. Besides focusing on large and readily point source of impact such as manufacturing plant, LCA also takes into account dispersed activities whose cumulative effects may prove to be critical as well. Thus it gives more accurate picture of the environmental impacts than conventional techniques. For the last three decades LCA has evolve from a relatively vague framework for conducting assessments, into a rigorous set of internationally standardized guidelines.

LCA analysis is consists of the four phases:

1. Goal Definition – The basis and scope of the evaluation are defined.
2. Inventory Analysis – Create a process tree in which all processes from raw material extraction through waste water treatment are mapped out and connected.
3. Impact Assessment – Emissions and consumptions are translated into environmental effects. These environmental effects are grouped and weighted.
4. Improvement assessment/ Interpretation – Areas for improvement are identified.

## 2.1 History of LCA

The earliest forerunners of LCA were the Resource And Environmental Profile Analyses (REPAs) of the late 1960s and early 1970s. A series of studies were conducted by the Midwest Research Institute, and later by the consulting firm Franklin Associates Ltd., mostly for the private sector. The Coca Cola Company and Mobil Corporation were two of the firms for which REPA studies were done (Assies, 1993; Curran, 1996). A REPA study of different beverage packaging systems by Hunt et al (1974) was a typical example of these LCA predecessors. Interest continued through the 1980s, with studies by Gaines (1981) and Lundholm and Sundstrom (1985) being typical of the REPA studies used for policy- and decision-making. As the term REPA suggests, these early studies emphasized raw material demands, energy inputs, and waste generation flows; attempts on more sophisticated analysis through environmental impact classifications would come later in the evolution of LCA methodology. Another early type of LCA emerged in the late 1970s in the form of net energy analysis (Boustead and Hancock, 1979). During the global oil crises of 1973 and 1979, many countries, including the Philippines, the United States and Brazil, began to explore petroleum substitutes. Bioethanol (ethyl alcohol produced through the fermentation of carbohydrate biomass) was one of the most extensively tested fuel; Brazil was particularly successful in its commercialization, and its *ProAlcool* program has continued for the past 20-odd years (Moreira and Goldemberg, 1999). One of the problems that became apparent was that the production of bioethanol on a life-cycle basis was highly energy-intensive. Net energy analysis was used to compare the cumulative energy inputs into the bioethanol life cycle (including agricultural inputs for feedstock production) with the energy value of the final product; such a comparison gave a true indication of the extent to which a substitute fuel displaced conventional energy sources. Early studies in the United States found a net energy deficit – more energy was needed to make the alcohol than could be recovered from its eventual combustion (Chambers et al, 1979; Lewis, 1980). Such studies continued to be used for the assessment of bioethanol and other alternative fuels, with the net energy approach being favored in North America (Shapouri et al, 1995) and an alternative energy ratio approach being more common in Europe (Culshaw and Butler, 1992). Eventually these energy analysis techniques led to the emergence of specialized LCAs for fuel and energy systems. These LCAs are now called Full Fuel Cycle Assessments (FFCAs). Modern LCA methodology is rooted in the development of standards through the 1990s. The Society for Environmental Toxicology and Chemistry (1991) published "A Technical Framework for Life Cycle Assessments," the first attempt at an international LCA standard. It explicitly outlined the components of contemporary LCA: goal definition, inventory assessment, impact assessment, and improvement analysis. By extending LCA beyond the mere quantification of material and energy flows (the predominant theme in REPA, net energy analysis, and other early forms of LCA), SETAC paved the way for the use of LCA as a comprehensive decision support tool. Similar developments took place some time later in Northern Europe, particularly in the Scandinavia. In 1995 detailed LCA protocols were specified in the "Nordic Guidelines on Life Cycle Assessments" (Nordic Council of Ministers, 1995). In the late 1990's, the International Organisation for Standardisation (ISO) released the ISO 14040 series on LCA as an adjunct to the ISO 14000 Environmental Management Standards. The series includes standards for goal and scope definition and inventory assessment (ISO 14041, 1998), impact assessment (ISO 14042, 2000a), and interpretation (ISO 14043, 2000b), as well as a general introductory framework (ISO 14040, 1997). The ISO 14040 series actually bears a strong resemblance to the original SETAC framework; Azapagic's review (1999) gives a comparison between the two LCA standards. However, because of ISO's dominant position in the development of international standards, the ISO 14040 series may eventually supercede the SETAC guidelines among LCA practitioners.

(Source http://www.lcacenter.org/library/pdf/PSME2002a.pdf)

## 2.2 Uses of LCA

LCA is one of many environmental management tools (ISO, 1997). It can be used by governments, private firms, consumer organizations, and environmental groups as a decision support tool (Wenzel et al, 1997; Krozer and Vis, 1998; Field and Ehrenfeld, 1999). The scope of the decisions covered by LCA ranges from broad management and policy choices to specific selection of product or process characteristics during design. Also, LCA may be applied prospectively or retrospectively (Ludwig, 1997).
LCA applications (ISO, 1997) can be classified into the following:

1. Indentification of opportunities to improve the environmental aspects of products at various points in their life cycles.
2. Decision-making in industry, government, and non-government organizations (NGOs).
3. Selection of indicators of environmental performance and measurement procedures.
4. Marketing, including ecolabelling and improvement of corporate image.

Table 2.1 lists LCA applications based on broad objectives of "focus" and "choice" as suggested by Wenzel et al (1997). "Focus" refers to a stand-alone diagnostic LCA to identify points of interest within a single life cycle system, whereas "choice" refers to comparative LCAs of competing alternatives with the ultimate objective of ranking and selection. They also give a more detailed description of the uses of LCA in the private and public sectors as well as NGOs. LCA applications grouped according to users are given in Table 2.2

| Objective | Application | Support for Decision |
|---|---|---|
| Diagnosis | Product Development | Background for environmental specification; design strategies, principles and rules. |
| | Ecolabelling | Identifies important environmental problems for the product category. |
| | Community Action Plans | Identifies environmentally important product groups |
| Selection | Product Development | On-going identification of the best choices from alternative solutions. |
| | Cleaner Technology | Identifies the best available technology by means of LCA |
| | Community Action Plans | Identifies the best community, strategy for a certain problem or product. |
| | Consumer Information | Documents potential environmental impacts from a certain product. |

**Table 2.1 LCA Applications According to Objectives (Wenzel et al, 1997)**

| LCA User | Application | Example |
|---|---|---|
| | Community Action Plans | Incineration versus Recycling |
| | | Public Transport Systems |
| | Environmentally Conscious Public Purchase | Cars, Office Supplies |
| | Consumer Information | Ecolables and Standards |
| Company | Establish Environmental Focus | Identification of Areas of Improvement |
| | | Product-Oriented Environmental Policy |
| | | Environmental Management |
| | Design Choices | Concept Selection |
| | | Component Selection |
| | | Material Selection |
| | | Process Selection |
| | Environmental Documentation | ISO 14000 Certification, Ecolabels |

**Table 2.2 LCA Applications According to User Type (Wenzel et al, 1997)**

**2.3 List of LCA Software Tools**

From the U.S. and Europe, 37 software tools (and vendors) were identified; the comprehensive list is presented in Table 2.3. The 37 LCA software tools listed in Table 1 are in various forms of development and use. Four software tools are not yet fully developed (EcoSys, EDIP, LCAD, and SimaTool) and are denoted “Prototype” in the third column of Table 1. Some software tools are only available in a language other than English or French; CUMPAN, REGIS, and Umcon are examples of these software tools. Still other software tools were developed exclusively for private industry clients and are not commercially available (e.g., LCA1).

| Name | Vendor | Version | Cost, $K | Data Location |
|---|---|---|---|---|
| **Boustead** | Boustead | 2 | 24 | Europe |
| **CLEAN** | EPRI | 2 | 14 | U.S. |
| **CUMPAN** | Univ. of Hohenheim | Unknown | Unknown | Germany |
| **EcoAssessor** | PIRA | Unknown | Unknown | UK |
| **EcoManager** | Franklin Associates, Ltd | 1 | 10 | Europe/U.S. |
| **6.ECONTROL** | Oekoscience | Unknown | Unknown | Switzerland |
| **Ecopack2000** | Max Bolliger | 2.2 | 5.8 | Switzerland |
| **EcoPro** | EMPA | 1 | Unknown | Switzerland |
| **EcoSys** | Sandia/DOE | Prototype | Unknown | U>S |
| **EDIP** | Inst. For Prod. Devel. | Prototype | Unknown | Denmark |
| **.EMIS** | Carbotech | Unknown | Unknown | Switzerland |
| **12.EPS** | IVL | 1 | Unknown | Sweden |
| **GaBi** | IPTS | 2 | 10 | Germany |
| **Heraklit** | Fraunhofer Inst. | Unknown | Unknown | Germany |
| **IDEA** | ILASA | Unknown | Unknown | Europe |
| **KCL-ECO** | Finnish Paper Inst | 1 | 3.6 | Finland |
| **LCA1** | P&G/ETH | 1 | Not Avail. | Europe |
| **18.LCAD** | Batelle/DOE | Prototype | <1 | U.S. |
| **LCAiT** | Chalmers | 1.1 | 3.5 | Sweden |
| **LCASys** | Philips/ORIGIN | Unknown | Unknown | Netherlands |
| **LIMS** | Chem Systems | 1 | 25 | U.S. |
| **LMS Eco-Inv.** | Christoph | 1 | Unknown | Austria |

| | | | | |
|---|---|---|---|---|
| **Tool** | Machner | | | |
| **Oeko-Base II** | Peter Meier | Unknown | Unknown | Switzerland |
| **PEMS** | PIRA | 3.1 | 9.1 | U.S |
| **PIA** | BMI/TME | 1.2 | 1.4 | Europe |
| **PIUSSOECOS** | PSI AG | Unknown | Unknown | Germany |
| **PLA** | Visionik ApS | Unknown | Unknown | Denmark |
| **REGIS** | Simum Gmbh | Unknown | Unknown | Switzerland |
| **REPAQ** | Franklin Associates, Ltd | 2 | 10 | U.S. |
| **SimaPro** | Pre' Consulting | 3.1 | 3 | Netherlands |
| **Sima Tool** | Leiden Univ. | Prototype | Unknown | Netherlands |
| **Simbox** | EAWAG | Unknown | Unknown | Switzerland |
| **TEAM** | Ecobalance | 1 | 10 | Europe |
| **TEMIS** | Oko-Institute | 2 | Unknown | Europe |
| **TetraSolver** | TetraPak | Unknown | Unknown | Europe |
| **Umberto** | IFEU | Unknown | Unknown | Germany |
| **Umcon** | Particip Gmbh | Unknown | Unknown | Germany |

**Table 2.3 List of Life-Cycle Assessment Tools**

## 2.4 Evaluation of Life Cycle Assessment Software

Five software tools had been selected for evaluation. The five software tools evaluated have many common capabilities. There are, however, a number of unique features/capabilities not found in every LCA software tool. A condensed and comparative evaluation of these unique software features is presented in Table 2.4. A brief description of these unique features is presented below.

| | KCL-ECO | LCAiT | PEMS | SimaPro | TEAM |
|---|---|---|---|---|---|
| Graphical Interface | ✓ | ✓ | ✓ | | ✓ |
| Data Protection | | | ✓ | ✓ | ✓ |
| Unit Flexibility | ✓ | | | ✓ | ✓ |
| Use of Formulas | ✓ | | | | ✓ |
| Uncertainty Analysis | ✓ | | ✓ | | ✓ |
| Impact Assessment | | ✓ | ✓ | ✓ | ✓ |
| Comparison of Results | | | ✓ | ✓ | ✓ |
| Graphical Display of Results | | ✓ | ✓ | ✓ | |

**Table 2.4 Comparison of unique software feature**

SimaPro was the only LCA software tool evaluated that did not offer a graphical interface for system development. PEMS, SimaPro, and TEAM are the only software tools offered data protection feature. KCL-ECO, SimaPro, and TEAM offered unit flexibility feature, but SimaPro is the only software tool requires the conversion of user-defined units to standard system-defined metric units. Once defined, unit convention must be maintained in KCL-ECO and TEAM.

The use of formulas offers a dynamic dimension to the LCA process. Formulas and variables are used in KCL-ECO and TEAM in a similar manner. Each tool is able to support uncertainty analysis as a result of formula and variable utilization. The ability to perform uncertainty analysis by the three identified software tools is quite different
A commonly accepted methodology for impact assessment is still under development within the LCA practitioners' community. Despite this lack of agreement, four of the five evaluated software tools support impact assessment capabilities: LCAiT, PEMS, SimaPro, and TEAM. Each tool supports the assessment of impact based on emission

loadings to common environmental parameters such as global warming, greenhouse gases, and solid waste. Comparison of results is supported by three of the five evaluated software tools. The graphical display of results is the last feature common among only a few software tools. LCAiT offers only a graphical depiction of the calculated inventory results. PEMS supports a wide range of user-defined graphical results that can also be viewed in tabular form. Finally, SimaPro presents characterization (classification), normalization, and valuation calculations in graphical form; graphical depiction of inventory results is not supported.

Though each software tool has common capabilities within the remaining criteria categories, the flexibility and functionality of these capabilities vary significantly from tool to tool. While completing the evaluation, overall impressions of each software tool's capabilities, limitations, and ease of use were formulated by the evaluators.

(Source: http://eerc.ra.utk.edu/clean/pdfs/LCAToolsEval.pdf)

**2.5 Limitation of LCA**

Life Cycle Assessment is one of the several environmental techniques (e.g. risk assessment, environmental performance evaluation and environmental auditing) and may not be the most appropriate techniques to use in all situations. The limitations in Life Cycle Assessment include the following:

1. The nature of choices and assumptions made in Life Cycle Assessment (e.g. system boundary setting, selection of data sources and impact categories) may be subjective.
2. Models used for inventory analysis or to assess environmental impacts are limited by their assumption, and may not be available for all potential impacts or applications.
3. Results of Life Cycle Assessment studies focused on global and regional issues may not be appropriate for local applications.
4. The accuracy of Life Cycle Assessment studies may be limited by accessibility or availability of relevant data or by data quality.
5. The lack of spatial and temporal dimensions in the inventory data used for impact assessment introduces uncertainty in impact results. This uncertainty varies with the spatial and temporal characteristics of each category.
6. The Life Cycle Assessment focuses on physical characteristics of the industrial activities and other economic process. It does not include market mechanisms or secondary effects on technological development.

### 2.6.0 Literature Review

The redevelopment of the Reservoir Civic Centre is a major capital works project of the City of Darebin, with a project budget of $4 million. The Centre will be home to a range of community organisations and Council services. The design, construction and operations of the Reservoir Civic Centre (RCC) will be a demonstration of Darebin Council's commitment to environmental sustainability and community wellbeing. Its design, construction and operations are based on principles of triple bottom line (social capital, environmental sustainability and financial responsibility). It will provide a fully operational example of environmental sustainability in a community building. Council has embraced this opportunity to demonstrate its commitment to reducing its impact on the environment, including greenhouse gas emissions The Reservoir Civic Centre made use of qualitative simplified modelling of the whole building life cycle. The modelling was based on making decision in conscious consideration of their material impacts, operational impacts and end of life. Guiding life cycle questions were used and these were answered in several ways – by using a detailed LCA tool (SimaPro), a thermal modelling (CSIRO tool - CHEMIX a combination of CHENATH, the simulation engine used in the NatHERS software, and MIX), expert opinion, literature and other similar projects.

### 2.6.1 Scope

The scope of the project was:

To produce a building which performed well in all environmental areas, while meeting budgetary, aesthetic, functional is the main goal and some social goals.

### 2.6.2 Aim and Objectives

The aims and objectives were:

1. maximise energy efficiency - perform better than a 5 star building
2. minimise waste - reduce construction waste by 80%
3. maximise water efficiency

4. optimise indoor air quality
5. minimise embodied energy
6. maximise the use of recycled, environmentally responsible materials

The audience for the results of the life cycle input was the architects and the project team. Data was used according to the need of the issue being investigated, Assessment software used was the Eco-Indicator 95 Australian model developed by the Centre for Design at RMIT.

### 2.6.3 Functional Unit

The functional unit was a community building encompassing a recording studio, Youth Resources area, Cafe, Customer service, Maternity and Health Centre, Function room, meeting rooms and UN room (area designated for the various community groups to write their newsletters, etc.) The life expectancy is 50 Years, it is 1.5 storeys, with 1,220 $m^2$ of floor space.

### 2.6.4 System boundary

Due to the use of the qualitative life cycle questions the boundaries were not formally determined. For the LCA's carried out on materials the boundaries were:

1. Impacts of energy production were taken into account but not of the infrastructure (capital equipment)
2. The system analysed included the manufacture of all building materials from resources in the ground, building site activities, construction equipment, repairs/maintenance, periodic refurbishment and finally, decommissioning
3. Disposal of material was included and any material recycled was credited
4. Transportation mode and distance were included

### 2.6.5 The Details

The redevelopment of the Reservoir Civic Centre has been based on the following environmentally sustainable principles:

| | |
|---|---|
| Waste not | Minimisation of wastage, maximum material reuse and recycling during construction and operation of the new Centre |
| Material smart | Selection of materials which are non-toxic, low in embodied energy, low impact, locally produced and sensitive to health concern as asthma |
| Energy smart | Minimisation of energy use and greenhouse emissions |
| Water smart | Minimisation of water use and use of rain water |
| Health | A healthy environment for work both in construction and use |
| Educational | A learning and educational building from which Darebin Council can influence future capital works and community understanding of environmental concerns |
| Quality | A quality building which fulfils its functional requirements |
| Beauty | An aesthetically pleasing building which echoes the vibrant Reservoir community |

**Table 2.5 Details of sustainable principles for Redevelopment Civic Center**

These principles have guided the design of the building and will be followed through in the construction and management of the building. In order to minimise the environment impact of the building and create a healthy working environment, the following initiatives were applied:

1. Thermal and natural ventilation modeling were carried out by CSIRO to determine optimum passive design for natural air flow
2. Specification of responsible materials – especially for wood
3. Energy use and water use modeling
4. Life cycle assessment (for the design process as well as to address specific questions for material selection
5. Development of an Environmental Management System (EMS)

### 2.6.6 Material of LCA

Material choice can be influences by issues such as the environmental impact over the life of the material apart from the use of the embodied energy. Three questions developed using the life cycle approach, literature, expert advice and some software based LCAs to support the decisions in the design process. Four different types of materials are discussed to illustrate the process:

1. Cladding,
2. Flooring,
3. Paints,
4. Insulation.

#### 2.6.6.1 Cladding

Parts of the building were designed to be clad externally for aesthetic reasons. This presented the problem of choosing a cladding material which performed aesthetically and environmentally well. A LCA based software; SimaPro was used for comparison of two cladding options. This required information from the supplies on the weight per meter square of the material used in the cladding system, data on each material was taken from the software database. This option performed better than the previously considered cladding system in environmental performance, while providing the required aesthetic and being lower in cost.

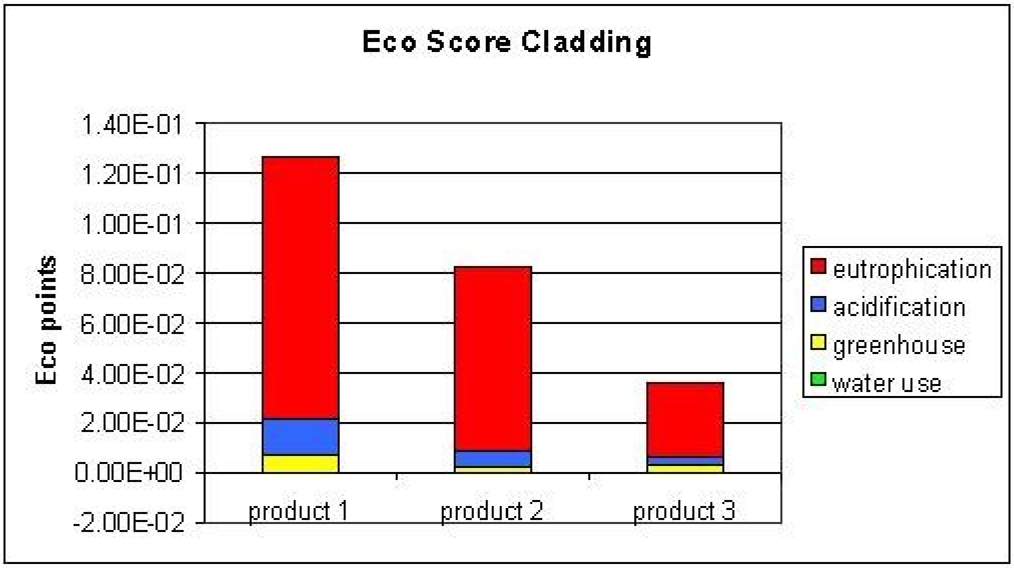



**Figure 2.1 Environmental Score for cladding system**

### 2.6.6.2 Function Hall Flooring

Inside the building there was a large function hall designed to be a sprung wooden floor. Life Cycle Approach was used to guide into the wood selection. The requirement of the material:

1. Should be from a renewable resources such as mixed plantation or bamboo
2. Should be treated with non harmful chemicals
3. Should be finished using a low emission material which met the German E1 Standard less than 0.01ppm of Formaldehyde
4. Should be from local source
5. Should be available in sizes appropriate to the function hall size
6. Should be durable, requiring little maintenance
7. Should be recyclable at the end of its life

The material chosen was a bamboo floor source from Queensland

#### 2.6.6.3 Paints

The building walls mostly will be painted. Indoor Air Quality (OHS) due to paint emissions, durability and waste minimization is the main life cycle issues after conducting Life Cycle approach. The paints with the features of non-toxic, low emission, contained no lead and were Australian made is chosen. Also the method of application of paint to minimise waste was specified. Information was readily available from paint manufacturers.

#### 2.6.6.4 Insulation

Insulation is very important to allow the building thermal performance to be optimised. Based on the CSIRO modelling insulation levels were set. Once these were set the materials needed to be chosen. A mix of software based LCA, literature, expert opinion and site requirements were used. Some of the wall cavities were only 50mm, this meant a material had to be sourced which was relatively thin but with a high R value. A recycled plastic bulk insulation and a thin, high density CO2 blown plastic combined with a recycled aluminium reflective sheet is chosen based on the tools used..

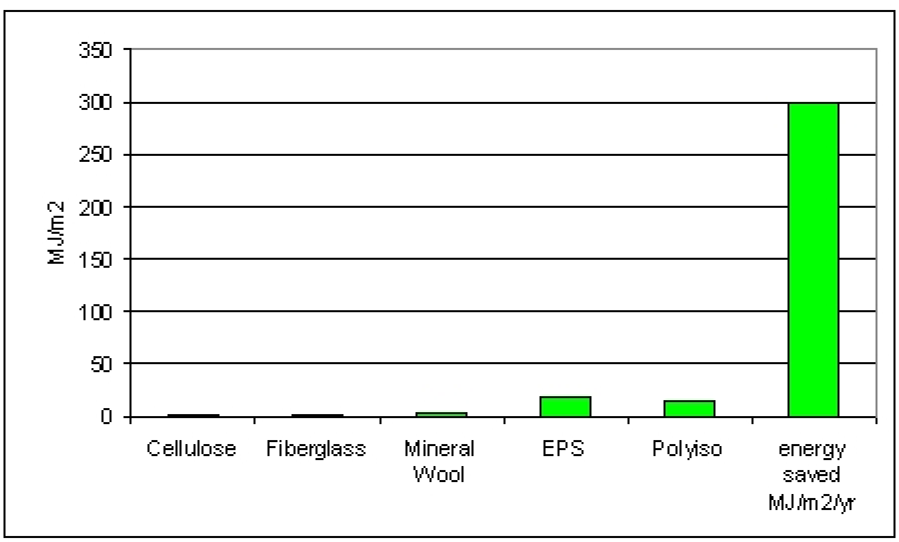



**Figure 2.2 Embodied energy in insulation (R2) compared to energy saved over 1 year**

As shown in figure 2.2, the designers did not need to sweat over the type of insulation because the relative energy impact of the insulation material was small compared with the energy saved

**2.6.6.5 Result of Embodied Energy and Operational modeling**

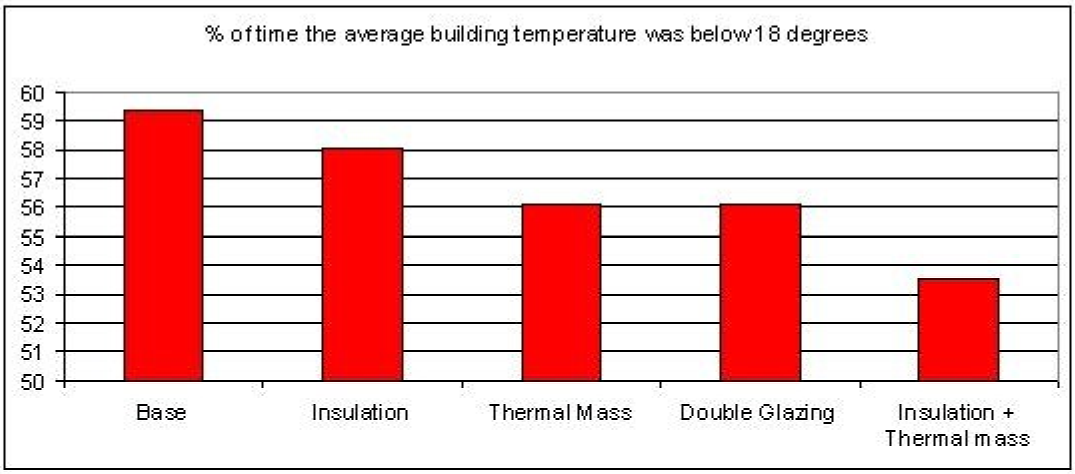



**Figure 2.3 Percentage of time the average building was below 18 degree**

**Winter results:**

1. The need of heat reduce by 10% as the result of insulation plus thermal, but the time the building would be under 18ºC.
2. The heating time decrease by 6% as the result of double glazing.
3. The heating time decrease by 6% as the thermal mass increase

Usage of the heater can be reduce as the increasing thermal mass and decreasing of heating by time of 6% It can be expected to conserve energy saving and eventually reduce the environment impact cause by the heater to the environment.

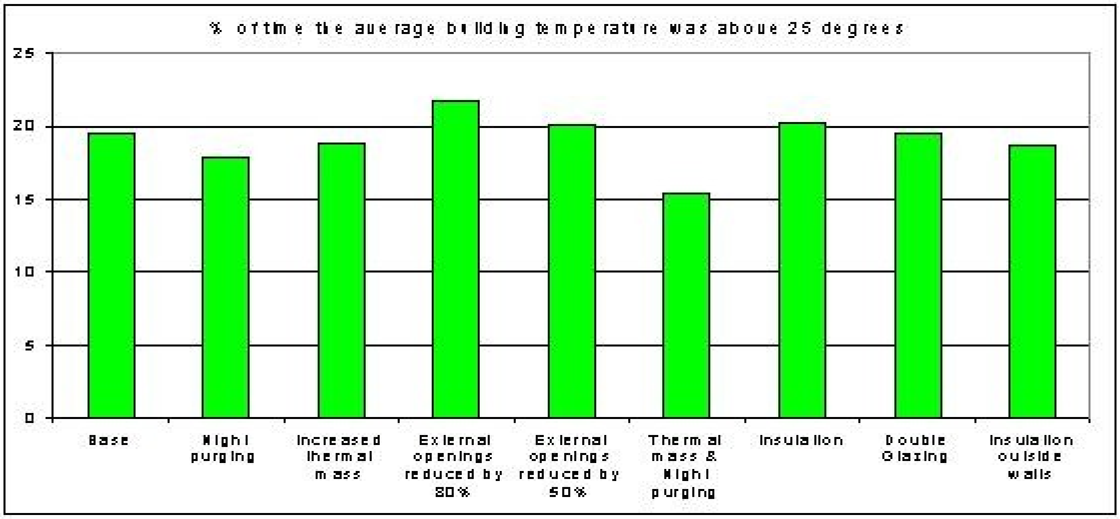



**Figure 2.4 Percentage of time the average building temperature was above 25 degree**

**Summer results:**

1. The base can be worsening due to decrease the number of openable window to 80 or 50%.
2. The need to cool can be reduce by 24% in increasing of thermal mass and night purging.
3. The effect of double glazing would be little
4. The need of cool would decrease by 10% by insulation on the outside thermal mass

Usage of the air conditioner can be reduce by 10% as the need to cool decrease by 10%. It can be expected to conserve energy saving by 10% and eventually reduce the environment impact cause by the air conditioner to the environment.

#### 2.6.6.6 Water

Water is a valuable commodity in Australia. The minimisation of its use was seen as a major goal for the Reservoir Civic Centre.

**Results**

The water use and potential for using rainwater was calculater using the Excel based modeling. The use of water saving fixtures was initially modeled (efficiency 1 – standard; efficiency 2 - top of the range water saving devices) and followed by the toilet flushing using rainwater. As the result it may had the potential of satisfying 66% of the building needs. In further, wastewater treatment through reuse for toilet flushing and irrigation would have allowed water use direct from mains supply to be almost negligible. Due to the cost and lack of support it is unfortunate that this option is not implemented

.

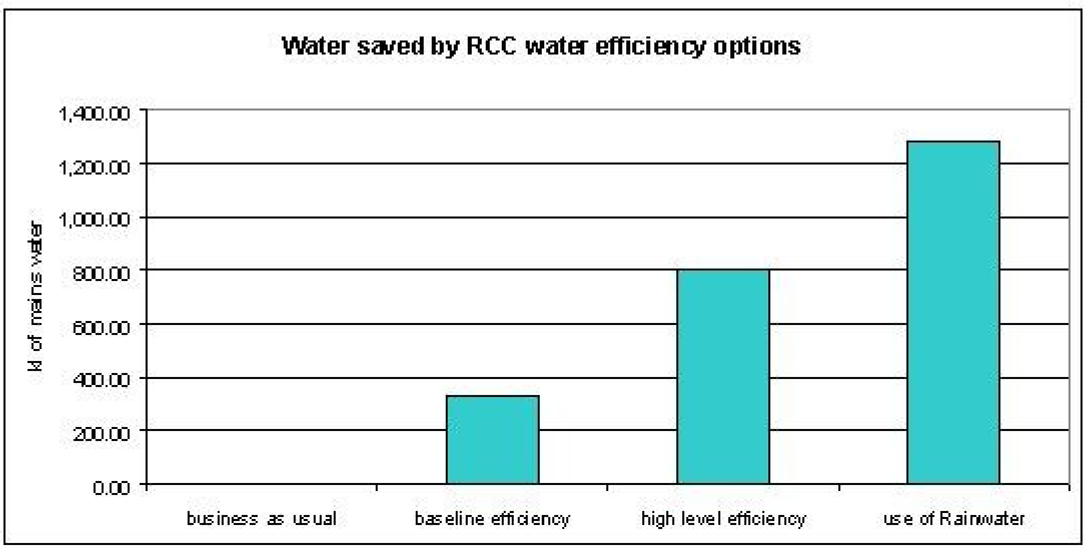



**Figure 2.5 Water saved by RCC water efficiency options**

### 2.6.7 The overall results

Through the integrated design process used for the design of the Reservoir Civic Centre, it is expected that the building will:

1. save 60-65% in energy over a comparable building,
2. have cooling and lighting which will perform over 75% better,
3. produce over 50% savings by using 5-star equipment.

In order for the City of Darebin to meet its zero climate change goal, energy supply as well as efficiency has been considered. As an investment for the future and a statement supporting the environmental features of the building the Reservoir Civic Centre will have a solar panel clad wall and roof structure on the north and northwest side. The array will produce approximately 40kWh a day providing nearly 25% of the building's energy needs. The remaining power required for the building will be from accredited GreenPower – saving almost 200 tonnes of $CO_2$ annually. The design has also incorporated a system for rainwater collection –over 600 kilolitres of water per year will be collected, minimising the need for the use of mains water. Further water efficiency will be achieved by using efficient water fittings, appliances and aerators. Through high efficiency and the use of rainwater collection tanks, the building will be saving over 1200 kilolitres annually. Through the smart use of materials in construction it is expected that 80% of waste will not end up in landfill compared to other similar building projects. This is expected to equal over 200 tonnes of waste.

### 2.6.8 The savings

**1. Energy**

Energy consumption reduced by 149 665 kWh per annum (this equates to annual savings of between $14,967 and $22, 450 depending on the price of energy remaining within $0.10 to $0.15 per kilowatt hour). In addition $250 per annum will be saved from reduced consumption of natural gas. The use of photovoltics will generate 38–40kW per annum, saving an additional $2,080-$2,200 in annual energy costs.

Estimated annual savings: $17,297 - $24,900

**2. Greenhouse**

The production of more than 200 tonnes of greenhouse emissions per annum has been avoided (the equivalent to taking 50 cars off the road1)

**3. Water**

Through the combination of high efficiency standards and rainwater collection, the City of Darebin will save more than $1,520 per annum by reducing the need to purchase 1.2 megalitres (or 27 average swimming pools) of water annually and the subsequent reduced sewerage costs.

Estimated annual savings: $1,520

**4. Waste**

By recycling bricks from the existing the building, the Council was able to save more than $11,500 in capital expenses by not having to purchase new bricks as well as an additional $6,525 in disposal and landfilling costs by diverting more than 217 m3 with a mass of 200 tonnes (or approximately 30 trucks of waste1)

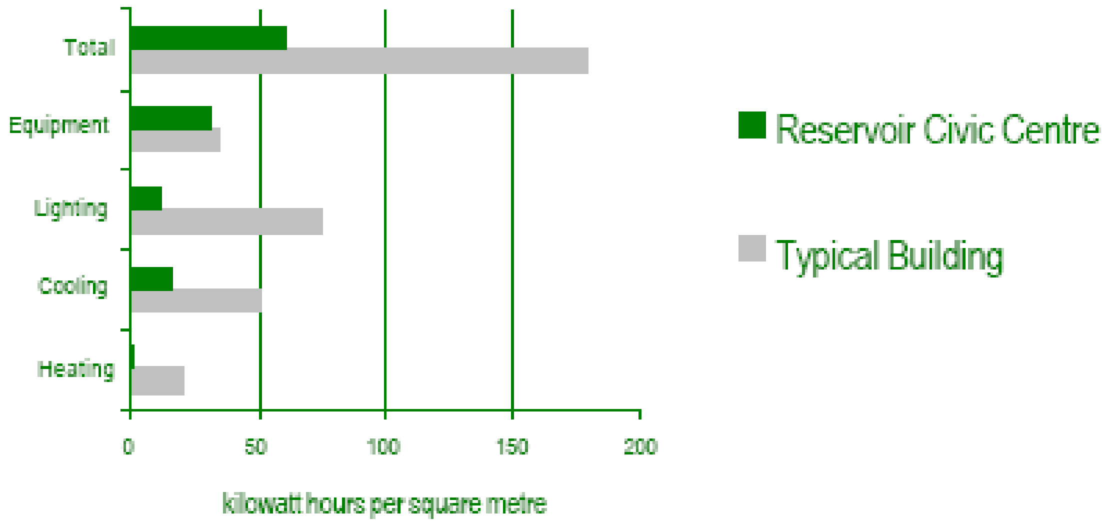



**Figure 2.6: comparison of energy consumption per square metre**

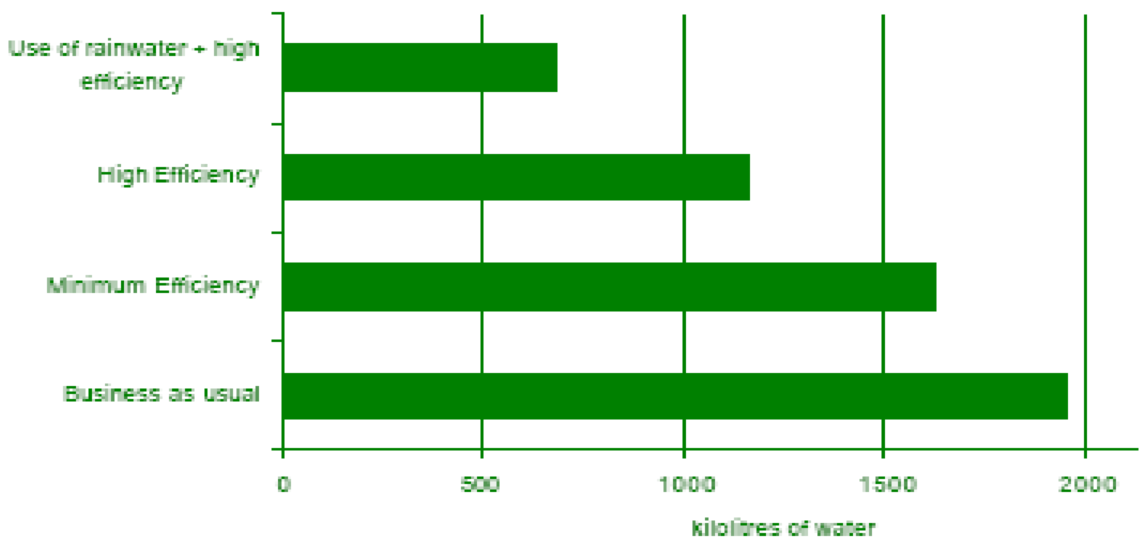



**Figure 2.7: comparison of water options**

Source http://buildlca.rmit.edu.au/ (Assessed 14th April 2007)

http://buildlca.rmit.edu.au/menu9.html (Assessed 14th April 2007)

# *Chapter 3*

**3.0 Phase 1 - Goal Definition**

In goal and scope definition the specific objectives of the assessment and the assumption under which all subsequent analysis is done. The objectives of Life Cycle Assessment can be classified broadly into system improvement studies, while the goal is to identify the opportunities for reducing the environmental effects of an existing system or process from a number of alternatives available. Scope definition involves specifying system boundaries, functional unit, allocation assumptions, inventory parameters, and impact categories that will be used. Based on the scope and objectives, it may not be necessary for an LCA to have all four components. In some cases, for example, a simple inventory assessment may be sufficient.

The Chapter 3 is the beginnings of the whole Life Cycle Assessment on cement manufacturing where the goal and scope of the project will be define. The main goal of this research project is to produce an outline of the Life Cycle Assessment to analyse the impact of the cement production to the environment in Malaysia. The scope of this project is to comprise the production of Ordinary Portland cement in Malaysia such as proportioning, blending, grinding, preheater tower, kiln, clinker cooler and finishing. Before the goal of the project is defined we need to understand more about the cement manufacturing process in Malaysia. A detail process flow chart is .

## 3.1 A brief history on cement

Cement of the Early Days

Cement can vaguely be defined as any compound that can be used to bind two materials together e.g. wood, bricks etc. Today the term is generally synonymous with Portland Cement, which is one of several types produced. The first recorded use of cement was by the Egyptians, who used it to build their pyramids, about 5,000 years ago. The cement used during that period was made from lime and gypsum. In the later periods of civilization, volcanic materials were ground with lime and sand to produce better cement. During the rise of the Roman Empire this technology spread throughout Europe. In December 1755 in Plymouth, England, a wooden lighthouse was razed to the ground. The job of rebuilding this lighthouse was given to John Smeaton. In an effort to construct a fire resistant building he experimented with many types of building materials, cement being one of the materials being studied. He discovered that siliceous limestone produced superior cement, he thus used limestone and volcanic lime to build the now famous "Eddystone Lighthouse". In 1818 Louis Joseph Vicat discovered that burnt clay when mixed with lime also resulted in cement. These were the first steps in the manufacture of Portland cement.

## 3.2 Cement Industry in Malaysia

The first cement factory in Malaysia was started by Mr Loke Yew sometime in 1906 at Batu Caves, using steam for power. The manufacture method is not clear but it did not meet with much success. During WWII Japan did build a cement factory in Batu Caves but these ceased operations after the war.

In 1952 the Blue Circle group of England built a plant in Rawang; this was a wet process kiln. Production could not meet the demand so extension was built to increase its production to 300,000 tonnes per year. There were many other plants built over the years and to date the following cement manufacturers/grinding plants as shown in Table 3.1 are in operation.

In Malaysia, infrastructural projects using cement as a building material (for example airports, highways, dams and office buildings) are the foundation of our future growth. Below are some examples:

| Company | Plant Type | Clinker Production Capacity ('000 tonnes) | Cement Grinding Capacity ('000 tonnes) |
|---|---|---|---|
| Associated Pan Malaysian Cement | Integrated | 4,600 | 6,060 |
| Cement Industries of Malaysia Berhad | Integrated | 1,600 | 2,000 |
| Cement Industries (Sabah) Sdn Bhd | Grinding | - | 900 |
| CMS Cement Sdn Bhd | Grinding | - | 1,750 |
| Holcim (Malaysia) Sdn Bhd | Grinding | - | 1,300 |
| Kedah Cement Holdings Bhd | Integrated | 3,300 | 6,120 |
| Negeri Sembilan Cement Industries Sdn Bhd | Integrated | 1,200 | 1,400 |
| Pahang Cement Sdn Bhd | Integrated | 1,200 | 1,300 |
| Perak-Hanjoong Simen Sdn Bhd | Integrated | 3,000 | 3,400 |
| Sarawak Clinker Sdn Bhd | Clinker | 600 | - |
| Slag Cement Sdn Bhd | Grinding | - | 1,000 |
| Southern Cement Industries Sdn Bhd | Grinding | - | 770 |
| Tasek Corporation Berhad | Integrated | 2,300 | 2,300 |
| **Total** | - | | 28,300 |
| White Cement | | | |
| Aalborg RCI White Cement | Integrated | 190 | 210 |
| **Grand Total** | | 17,990 | 28,510 |

**Table 3.1: Installed Capacities of Cement Plants by Company (2007)**

**Source: Cement and Concrete Association of Malaysia**

The raw materials required for the production of cement are abundantly distributed throughout Malaysia. The limestone mined locally is of a crystalline nature, chalk is the form more commonly found in Europe. There are 3 main methods for the manufacture of cement they being the wet process, semi-dry process and dry process. All the integrated cement manufacturers located in Malaysia use the dry process and are currently the most cost effective method of production.

| Country | Production Capacity (million tones) | Actual Production (million tonnes) | Consumption (million tonnes) |
|---|---|---|---|
| **Brunei** | 0.55 | 0.23 | 0.24 |
| **Indonesia** | 47.57 | 31.10 | 25.70 |
| **Malaysia** | 28.30 | 14.06 | 11.80 |
| **Philippines** | 26.78 | 11.38 | 11.71 |
| **Singapore** | 7.50 | - | 4.20 |
| **Thailand** | 55.34 | 25.54 | 18.34 |
| **Vietnam** | 20.62 | 16.37 | 16.37 |
| **Total** | 186.67 | 98.68 | 88.37 |

**Table 3.2: ASEAN Cement Production Capacities (2001)**

| Country | Production Capacity (million tones) | Actual Production (million tonnes) | Consumption (million tonnes) |
|---|---|---|---|
| **Brazil** | - | 40.00 | - |
| **China** | - | 595.00 | - |
| **France** | - | 21.00 | - |
| **Germany** | - | 40.00 | - |
| **India** | - | 100.00 | - |
| **Italy** | - | 36-00 | - |
| **Japan** | 83.31 | 79.46 | 68.64 |
| **South Korea** | 61.88 | 53.66 | 50.06 |
| **Spain** | - | 30.00 | - |
| **Taiwan** | 28.24 | 18.01 | 16.70 |
| **UK** | - | 11.85 | - |
| **USA** | 105.00 | 89.60 | 114.00 |

**Table 3.3: World's Leading Cement Producing Countries (2001)**

**Source: 1) Asean Federation of Cement Manufacturers**

**2) U.S. Geological Survey (Mineral Commodity Summaries, January 2002)**

### 3.3 Raw Materials Preparation

The raw materials used in the manufacture of cement are limestone, clay and iron ore, typical chemical compositions of which are given in table 3.4. Limestone makes up approximately 80% of the raw material requirements, composes of mainly calcium carbonate with small intrusions of magnesium carbonate. Quarrying operations are geared to minimizing the intrusions. The limestone is crushed to less than 75mm. MgO in the cement, if present in sufficient quantities will cause expansion upon hydration thus resulting in unsoundness in the concrete.

| Component | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | CaO | MgO | $SO_3$ | $K_2O$ | $Na_2O$ | LOI |
|---|---|---|---|---|---|---|---|---|---|
| **Limestone** | 2.68 | 0.62 | 0.46 | 51.85 | 1.94 | 0.03 | 0.05 | 0.02 | 42.52 |
| **Sandy clay** | 81.56 | 11.29 | 1.79 | 0.12 | 0.09 | 0.05 | 0.14 | 0.03 | 4.91 |
| **Clay** | 65.18 | 21.91 | 3.36 | 0.11 | 0.08 | 0.06 | 0.19 | 0.04 | 9.11 |
| **Iron ore** | 14.88 | 16.79 | 57.74 | 0.12 | 0.56 | 0.04 | 0.04 | 0.03 | 9.87 |
| **Shale** | 61.10 | 16.42 | 7.01 | 1.02 | 2.34 | 0.01 | 4.12 | 1.65 | 3.71 |
| **Sand** | 94.70 | 2.90 | 0.24 | 0.35 | 0.13 | 0.01 | 0.60 | 0.21 | 0.91 |
| **Bauxite** | 3.11 | 57.59 | 15.74 | 4.16 | 0.16 | 0.29 | 0.08 | 0.08 | 15.40 |
| **Gypsum** | 4.31 | 0.34 | 0.14 | 31.19 | 0.11 | 43.88 | - | - | 19.39 |
| **Fuel Ash** | 57.20 | 17.36 | 9.11 | 3.95 | 1.80 | 3.40 | 0.78 | 2.5 | - |

**Table 3.4: Typical Composition of some raw materials**

Due to the variable nature of these three components, they are pre-blended prior to their use. In Tasek, limestone is crushed and stored in a covered circular storage dome, utilizing the chevron pile stacking method. In this method, stacking takes place at one end of the pile. At the other end of the pile the limestone is reclaimed and then stored in a silo. Clay and iron ore are crushed in a crusher and are then stored in a storage hall. Prior to use the two components are reclaimed and stored in intermediate silos.

**Figure 3.1: Limestone pre-homogenisation pile being built by a boom stacker**

**Figure 3.2: A completed limestone pre-homogenisation pile**

### 3.4 Raw Materials Proportioning & Grinding

A rawmill is the equipment used to grind raw materials into "rawmix" during the manufacture of cement. Rawmix is then fed to a cement kiln, which transforms it into clinker, which is then ground to make cement. The rawmilling stage of the process effectively defines the chemistry (and therefore physical properties) of the finished cement, and has a large effect upon the efficiency of the whole manufacturing process.

The rawmix is formulated to a very tight chemical specification. Typically, the content of individual components in the rawmix must be controlled within 0.1% or better. Calcium and silicon are present in order to form the strength-producing calcium silicates. Aluminium and iron are used in order to produce liquid ("flux") in the kiln burning zone. The liquid acts as a solvent for the silicate-forming reactions, and allows these to occur at an economically low temperature. Insufficient aluminium and iron lead to difficult burning of the clinker, while excessive amounts lead to low strength due to dilution of the silicates by aluminates and ferrites. Very small changes in calcium content lead to large changes in the ratio of alite to belite in the clinker, and to corresponding changes in the cement's strength-growth characteristics. The relative amounts of each oxide are therefore kept constant in order to maintain steady conditions in the kiln, and to maintain constant product properties. In practice, the rawmix is controlled by frequent chemical analysis (hourly by X-Ray fluorescence analysis, or every 3 minutes by prompt gamma neutron activation analysis). The analysis data is used to make automatic adjustments to raw material feed rates. Remaining chemical variation is minimized by passing the raw mix through a blending system that homogenizes up to a day's supply of rawmix (15,000 tonnes in the case of a large kiln).

In Tasek, the raw materials are extracted from the storage silos via weigh-feeders. The materials are conveyed to the grinding mill and are ground to a suitable fineness, called raw meal at this stage. This is then stored in a blending silo and blended to ensure homogeneity. The proportions of the 3 components are controlled by the continuous sampling and testing of this raw meal. The raw meal chemical composition is determined by the use of an x-ray fluorescence analyzer. This is linked to the computer which will automatically adjust the weigh-feeders, so that the resultant raw meal stored in the blending silo meets the preset parameters. After blending this material is then discharged into the storage silos ready for the next phase of production.

The parameters used in the control of the raw meal are lime saturation factor, silica modulus and iron modulus. These are actually proportions of the various chemical component is which are desired in the resultant clinker. The formulae being:

$$LSF = \frac{CaO}{2.8SiO_2 + 1.18Al_2O_3 + 0.65Fe_2O_3} = 0.90 - 0.96$$

$$SM = \frac{SiO_2}{Al_2O_3 + Fe_2O_3} = 2.0 - 2.8$$

$$IM = \frac{Al_2O_3}{Fe_2O_3} = 1.3 - 2.2$$

As coal is used as a fuel the coal ash, a combustion product of the coal, has to be treated as an individual raw material component and the appropriate corrections made at the weigh-feeder stage.

### 3.5 Clinker Burning

The kiln is a long cylinder lined with refractory materials and supported on rollers such that it can rotate on it's own axis and erected with a slight inclination from the horizontal. The raw meal now called kiln feed enters the kiln system at the top of the pre-heater. This is essentially a counter current heat exchanger with the hot gasses rising and kiln feed falling. The heat source is located at the lower end of the kiln. The kiln is essentially made up of four sections, drying, calcining, sintering and cooling. As the kiln feed moves towards the lower end of the kiln it undergoes successive reactions as shown in table 3.5

| Temperature Deg C | Reactions | Thermal Change | Clinker Compounds Formed |
|---|---|---|---|
| 100 | Evaporation of free water from raw meal | Endothermic | |
| 500+ | Evolution of combined water from clay | Endothermic | |
| 800+ | $CaCO_3 = CaO + CO_2$ | Endothermic | |
| 800-900 | $CaO + SiO_2 = CaO.SiO_2$ | Exothermic | CS |
| 900-950 | $5CaO + 3Al_2O_3 = 5CaO.3Al_2O_3$ | Exothermic | C5A3 |
| 950-1200 | $2CaO + SiO_2 = 2CaO.SiO_2$<br><br>$2CaO + Fe_2O_3 = 2CaO.Fe_2O_3$ | Exothermic<br><br>Exothermic | C2S<br><br>C2F |
| 1200-1300 | $3CaO + Al_2O_3 = 3CaO.Al_2O_3$ | Exothermic | C3A, C4AF |
| 1250-1280 | Beginning of liquid formation | Exothermic | Molten |
| 1260-1450 | $3CaO + SiO_2 = 3CaO.SiO_2$ | Endothermic | C3S |

**Table 3.5: Reactions in the Kiln**

The principal chemical compounds in the clinker are tricalcium silicate, C3S (40-60%) , dicalcium silicate, C2S (16-30%), tricalcium aluminate, C3A (7-15%) and tetracalcium aluminoferrite, C4AF (7-12%). The cooling zone in the kiln is actually quite short but it is in this zone that nodulisation of the melt occurs. The red hot clinker is then discharged into the cooler, where it is quenched cooled to around 100 degrees centigrade. The heat dissipated by the clinker is used as secondary air for the combustion in the calciner. This hot gas is also used in the dryers at the raw materials preparation stage. Rapid cooling of the clinker is essential as this hampers the formation of crystals , causing part of the liquid phase to solidify as glass. The faster the clinker cooling the smaller the crystals will be when emerging from the liquid phase. Table 3.6 provides a summary of the principal compounds of Portland cement and their characteristics.

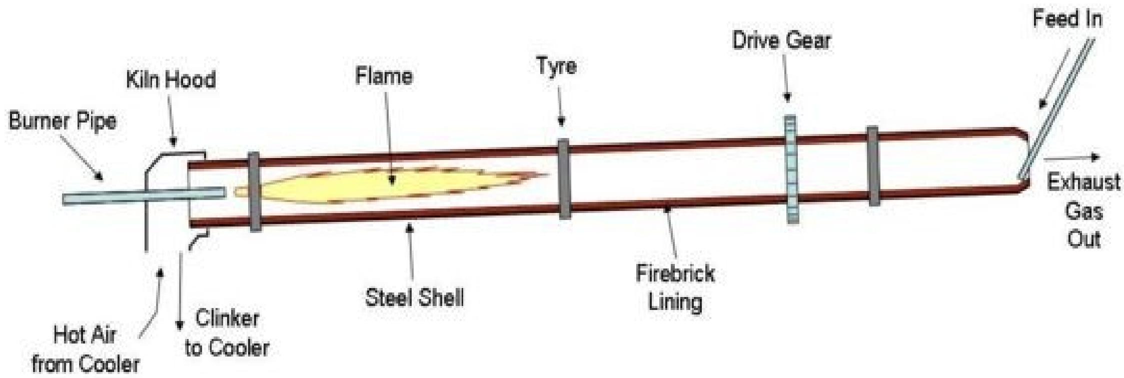



**Figure 3.3: General Layout of a Rotary Kiln**

**Figure 3.4: Hot end of medium sized modern cement kiln, showing tyres, rollers and drive gear**

### 3.6 Cement Grinding

The cooled clinker is fed into the finish grinding mill (which is a tube mill) and ground to a fine powder. At this stage a small quantity of gypsum (3-5%) is added to control the setting time of cement produced. A cement mill is the equipment used to grind the hard, nodular clinker into the fine grey powder that is cement. Most cement is currently ground in ball mills.

| ITEM | $CaO.SiO_2$ | $2CaO.SiO_2$ | $3CaO.Al_2O_3$ | $4CaO.Al_2O_3.Fe_2O_3$ |
|---|---|---|---|---|
| **Abbreviated formula** | C35 | C25 | C3A | C4AF |
| **Common Name** | Alite | Belite | - | - |
| **Principal impurities** | MgO, $Al_2O_3$ , $Fe_2O_3$ | MgO, $Al_2O_3$ , $Fe_2O_3$ | $SiO_2$, MgO , alkalies | Ferrite phase , $SiO_2$ , MgO |
| **Common crystalline form** | Monoclinic | Monoclinic | Cubic, Orthorhombic | Ferrite phase , $SiO_2$ , MgO |
| **Range present (%)** | 40-60 | 16-30 | 7-15 | 7-12 |
| **Average in OPC (%)** | 50 | 25 | 8 | 8 |
| **Reaction with water** | Medium | Slow | Fast | Medium |
| **Contribution to strength** | | | | |
| **Early** | Good | Poor | Good | Good |
| **Ultimate** | Good | Excellent | Medium | Medium |
| **Heat of Hydration** | Medium | Low | Medium | Medium |
| **(cal/g)** | 120 | 60 | 320 | 100 |

**Table 3.6: Principal Compounds of OPC and their characteristics**

In order to achieve the desired setting qualities in the finished product, a quantity (2-8%, but typically 5%) of calcium sulfate (usually gypsum or anhydrite) is added to the clinker and the mixture is finely ground to form the finished cement powder. This is achieved in a cement mill. The grinding process is controlled to obtain a powder with a broad particle size range, in which typically 15% by mass consists of particles below 5 µm diameter, and 5% of particles above 45 µm. The measure of fineness usually used is the "specific surface", which is the total particle surface area of a unit mass of cement. The rate of initial reaction (up to 24 hours) of the cement on addition of water is directly proportional to the specific surface. Typical values are 320-380 $m^2.kg^{-1}$ for general purpose cements, and 450-650 $m^2.kg^{-1}$ for "rapid hardening" cements. The cement is conveyed by belt or powder pump to a silo for storage. Cement plants normally have sufficient silo space for

1-20 weeks production, depending upon local demand cycles. The cement is delivered to end-users either in bags or as bulk powder blown from a pressure vehicle into the customer's silo. In developed countries, 80% or more of cement is delivered in bulk, and many cement plants have no bag-packing facility. In developing countries, bags are the normal mode of delivery.

**Figure 3.5 cement mill**

### 3.7 Cement Storage & Despatch

From the mill the cement is pumped to the storage silos. When needed cement from the silos is packed into bags or loaded into road tankers and rail wagons for despatch.

### 3.8 Cement Quality

Portland cement quality is defined by Malaysian Standard MS 522, which is basically based on the British standard BS 12. This is however now superseded by EN 196, which is the European Union standard. These standards specify a series of test for which the cement will have to conform to. The most common being:

a) fineness - blaine method

b) chemical composition

c) strength - mortar / concrete cubes

d) setting time - vicat method

e) soundness - Le'Chatelier method

A typical chemical composition of clinker and cement is provided in table 3.7.

| Item | Clinker % | Cement % |
|---|---|---|
| **Oxide Composition** | | |
| $SiO_2$ | 21.66 | 21.28 |
| $Al_2O_3$ | 5.80 | 5.60 |
| $Fe_2O_3$ | 3.68 | 3.36 |
| CaO | 65.19 | 64.64 |
| MgO | 2.86 | 2.06 |
| $SO_3$ | 0.20 | 2.14 |
| Total Alkalis | 0.07 | 0.05 |
| Insoluble Residue | 0.10 | 0.22 |
| Loss on Ignition | 0.27 | 0.64 |
| **Modulus** | | |
| Lime Saturation Factor | 0.93 | 0.92 |
| Silica Modulus | 2.28 | 2.38 |
| Iron Modulus | 1.58 | 1.67 |
| **Mineral Composition %** | | |
| C3S | 55.90 | 52.82 |
| C2S | 20.02 | 21.25 |
| C3A | 9.15 | 9.16 |
| C4AF | 11.19 | 10.21 |
| Free CaO (lime) | 1.35 | - |

**Table 3.7: Chemical composition of Clinker & Cement**

**Source (**http://www.tasekcement.com/index4.htm)

# Chapter 4

**4.0 Phase 2 - Inventory analysis**

In Inventory analysis, it involves the quantification of environmentally relevant material and energy flows of a system using various sources of data. Essentially, an accounting of system inputs and outputs is performed. The data used may come from a variety of sources, including direct measurements, theoretical material and energy balances, and statistics from databases and publications. In this chapter, it will show the input of the data and the data collected from Tasek Corporation Sdn Bhd. The assumption, functional unit and SimaPro setting made will state in this chapter. The functional unit in this project is defined as the production of one kilogram of cement. The particular functional unit chosen was the best option because most people can easily quantify one kilogram of cement. This functional unit is much better compared to other studies that use large figures which in turn is difficult to quantify

**4.1 Life Cycle Inventory**

The average input details of materials and energy consumed annually in Tasek Corporarion Sdn Bhd for manufacturing of cement is given as follows. The yearly total production of cement is 1.6 million tonnes. The average limestone used annually is approximately 2.1 million tonnes. The limestone is from the quarry site located one kilometer from the plant. The quarry is owned by Tasek Corporation Sdn Bhd. The average clay and iron ore used annually is approximately 400,000 tonnes and 150,000 tonnes. The clay and iron ore is purchased and the site of the clay is located approximately 30 kilometers from the plant and the iron ore site is located 40 kilometer from the plant. In return distance it will be 2*30 and 2*0 respectively. Beside clay and iron ore, Tasek purchased coal for the fuel of kiln and gypsum as the addictive of the cement. The average annually used is approximately $1.84 * 10^9$ Kcal of coal and 80,000 tonnes of gypsum.The annually average water usage is approximately about 200,000 $m^3$

and much of the water is for cooling purpose. The annually average of electricity used is $1 * 10^{9}$ kWh. The electricity is used in the plant and office premises.

**Input details**

Ratio of raw material to cement

1.6:1

Therefore 1 tonne of cement require 1.6 tonne of raw material

Proportion of each raw material:

80% of the raw material is limestone

15% of the raw material is clay

5% of the raw material is iron ore

Additional 5% of gypsum is added in cement mill

The coal usage is about 800kcal per kg of clinker

Utilities usage at plant:

The water consumption for cooling is about 0.1 cubic meters per tonne of cement

The electricity consumption is about 100 kWH per tonne of cement

| Material/energy source | Quantity |
|---|---|
| Limestone | 1.28 tonne |
| Clay | 0.24 tonne |
| Iron Ore | 0.08 tonne |
| Gypsum | 0.05 tonne |
| Coal | 800 kcal/kg clinker |
| Water | 100 L |
| Electricity | 100 kwh |

**Table 4.1 Input materials required for the manufacture of one tonne cement**

| Location | Percentage of usage % |
|---|---|
| Preparation of raw material | 3.3 |
| Raw mill | 27.6 |
| Kiln | 27.7 |
| Cooling | 5 |
| Cement Grinding | 31.2 |
| Office / Utilities | 5.2 |
| Total | 100 |

**Table 4.2 Percentage usage of electrical at each location**

| Location | Percentage of usage (kWH) |
|---|---|
| Preparation of raw material | 3.3 |
| Raw mill | 27.6 |
| Kiln | 27.7 |
| Cooling | 5 |
| Cement Grinding | 31.2 |
| Office / Utilities | 5.2 |
| Total | 100 |

**Table 4.3 Total electricity usage for 1 tonne of cement**

| Material/energy source | Quantity |
|---|---|
| Limestone | 2,100,000 tonne |
| Clay | 400,00 tonne |
| Iron Ore | 150,000 tonne |
| Gypsum | 100,000 tonne |
| Coal | 800 kcal/kg clinker |
| Water | 1.6 million $m^3$ |
| Electricity | $1.6*10^9$ kwh |

**Table 4.4 Average annually input for Tasek Corporation Sdn Bhd**

### 4.2 Simapro Setting and Data

A basic model incorporating the major inputs and outputs is created using SmaPo. Tasek Corporation Sdn Bhd, a cement manufacturing plant based in Ipoh, Perak is selected. The data is collected from the division manager of Tasek Corporation Sdn Bhd. The version of the software used for the project is SimaPo 5.1. The SimaPo method Eco-indicator 99 (H) is used to perform impact assessment. Eco-indicators are "damage oriented" impact assessment methods for LCA. This means that the environmental impacts are assessed by damages to ecosystem quality. In SimaPro5.1 the damages are expressed as the percentage of species disappearing in a certain area due to the environmental load. The eco-indicator used depends on the impact categories wanting to be assessed. Therefore, the reasons for assessment and the system being assessed in this life cycle assessment determine the eco-indicator used since they also define the impact categories. The indicators can assess categories in the following areas:

Human health Radiation, Smog, Carcinogens, Climate Change, Ozone Layer, noise

Eco System Quality Acidification, Eutrophication, Eco-toxicity, Land Use

Resources Minerals, Fossil Fuels

#### 4.2.1 Project goals and details

| Preliminary goal and scope | |
|---|---|
| Goal: | ➢ Identify the use of SimaPro to conduct life cycle assessment of cement manufacturing,<br>➢ Identify the environmental impact of cement manufacturing processes,<br>➢ Identify the hot spots for potential improvements, |
| Target Group: | ➢ Tasek Corporation Sdn Bhd |
| Question answered: | ➢ What are the most significant environmental impacts of cement manufacturing?<br>➢ What are the eco-efficiency opportunities available to reduce overall life cycle impacts in cement manufacturing? |

| | |
|---|---|
| Functional unit: | ➢ One tonne of cement |
| Life cycle stages studied: | ➢ Raw material preparation<br>➢ Raw mill<br>➢ Clinker<br>➢ Cooling<br>➢ Cement mill |
| Study boundaries: | ➢ Raw material transport to the cement plant.<br>➢ All unit processes in the manufacturing process |
| Items excluded from the study: | ➢ Transportation of purchased coal and gypsum<br>➢ Electricity usage in the office premises of the plant.<br>➢ Cradle to grave analysis |
| Impact categories considered: | ➢ Single score assessment<br>➢ Damage assessment<br>➢ Normalization<br>➢ Impact indicator Climate change |
| Interpretation | ➢ Data quality assessment<br>➢ Sensitivity analysis of LCA results |

**Table 4.5 Preliminary goal and scope**

#### 4.2.2 Libraries

The libraries data chosen are

- BUWAL 250,
- Data Archive,
- Industry data
- Methods

### 4.2.3 Data Quality Indicator Requirement

The data quality requirements indicate the relevant data to the specific projects requirement. The available options for selection are geography, type, allocation and system boundaries. The selected options for this project are:

**Time Period:**

- 2000-2001
- 2005-2009

**Geography:**

- Asia, South East
- Mixed

**Type**

Technology (DQI weighting 3):

- Mixed data,
- Average technology ,
- Modern Technology

Representativeness (DQI weighting 3):

- Mixed Data,
- Data from a specific process and company,
- Average from a specific process,
- Average from processes with similar outputs,
- Average of all suppliers
- Theoretical calculations.

Allocation:

Multiple output allocation (DQI weighting = 11):

- not applicable,

- physical causality,
- socio economic causality

Substitution allocation:

- Not applicable,
- Actual substitution,
- substitution by close proxy (similar process),
- substitution by distant proxy (different process)

Waste treatment allocation (DQI weighting =11):

- Not applicable,
- Closed loop assumption,
- Full substitution by close proxy (similar process),
- Full substitution by distant proxy (different process)

**System Boundaries:**

Cut-off rules (DQI weighting = 3)

- Unspecified
- Unknown
- Not applicable
- Less than 1% (physical criteria)
- Less than 1% (socio economic)
- Less than 1% (environmental relevance)

System boundary (DQI weighting = 4)

- Second order (material, energy flows including operations)

Boundary with nature (DQI weighting = 11)

- Not applicable
- Agricultural production is part of production system

### *Step 1 Raw material preparation*

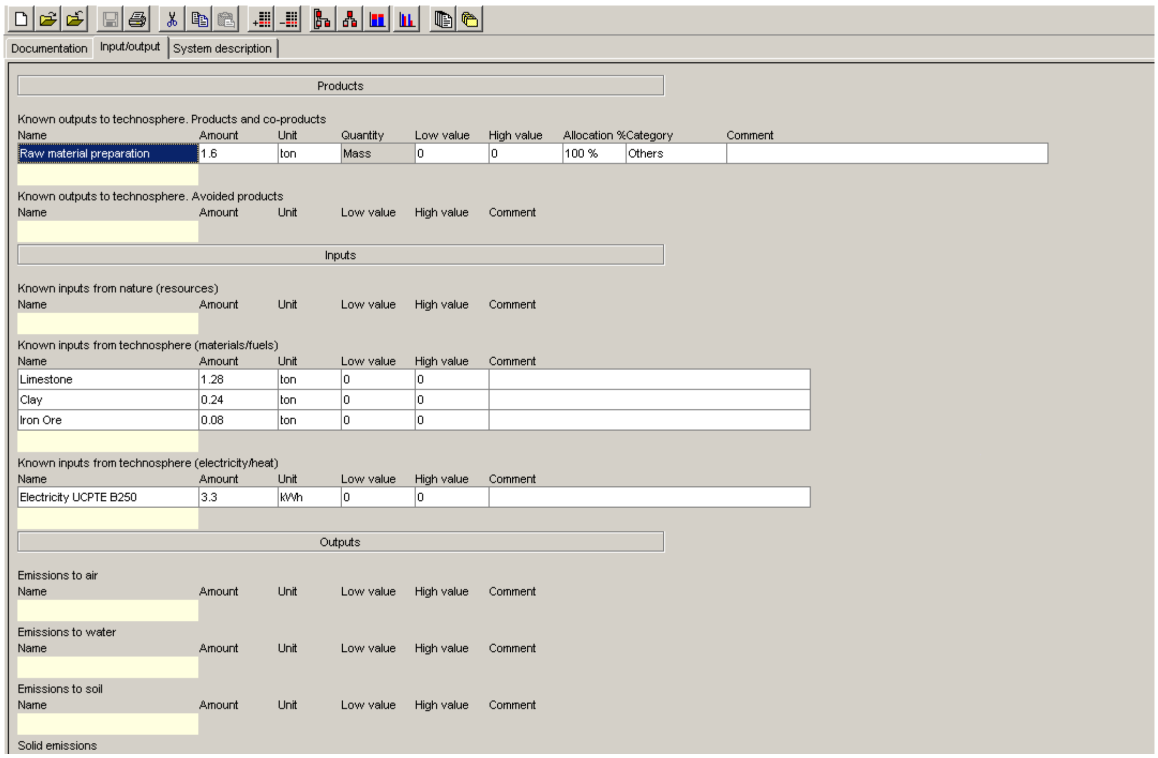



**Figure 4.1 Life cycle Inventory Input/Output screen for unit process Raw material preparation**

**Tree analyse for the process of Raw material preparation.**

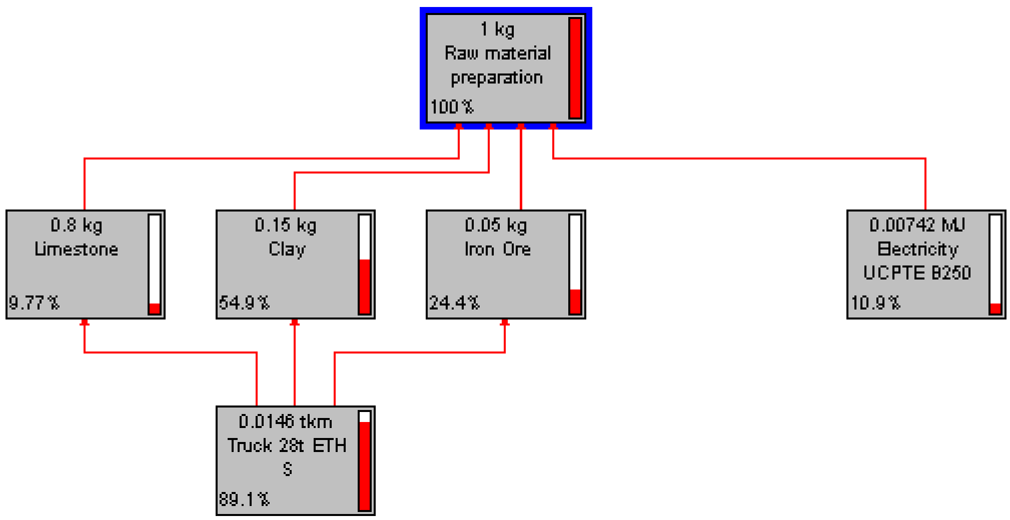



**Figure 4.2 Life cycle Inventory for unit process Raw material preparation**

***Step 2 Raw materials grinding and proportioning***

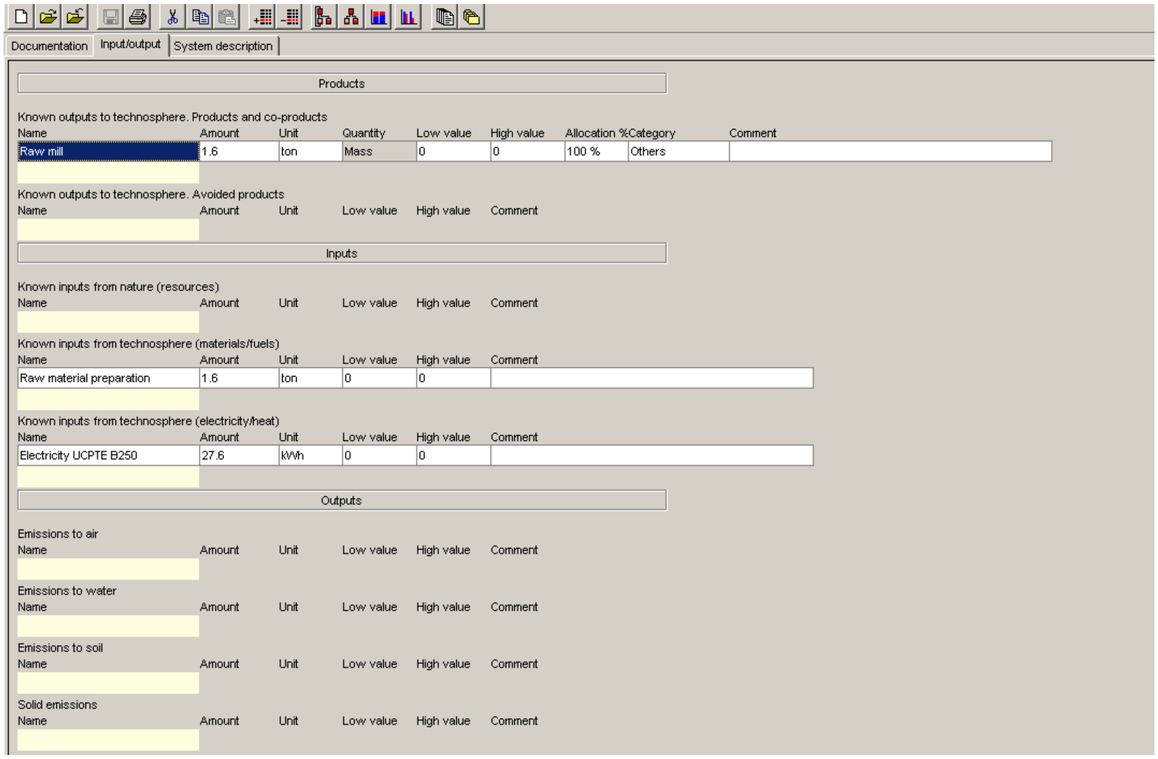



**Figure 4.3 Life cycle Inventory Input/Output screen for unit process of Raw materials grinding and proportioning**

**Tree analyse for the process of Raw materials grinding and proportioning**

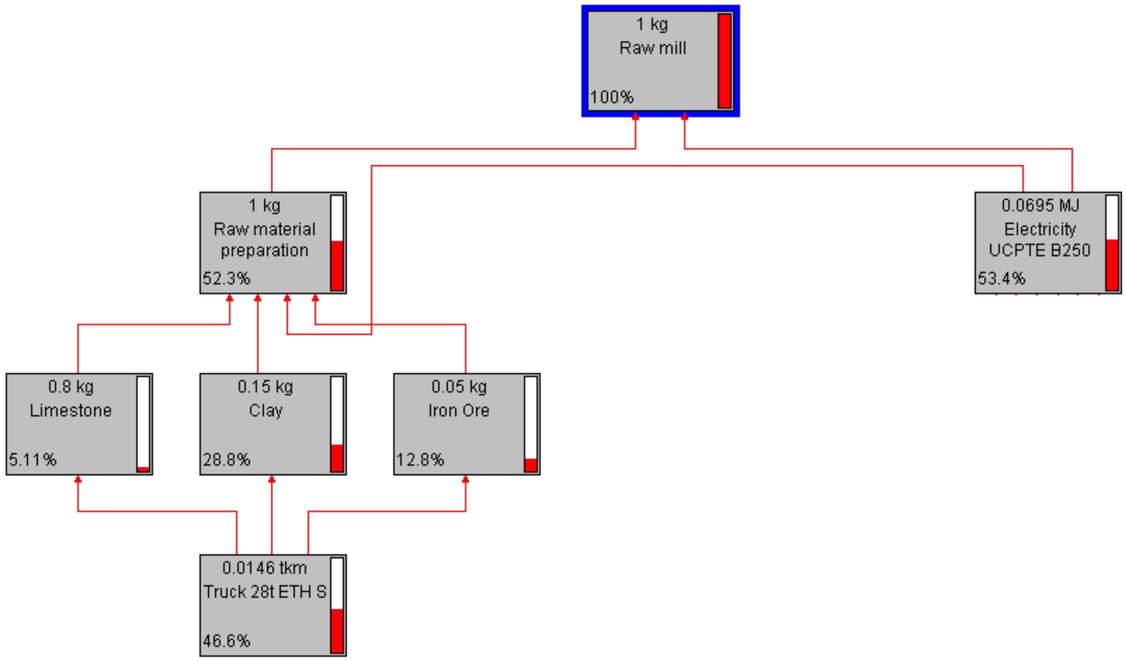



**Figure 4.4 Life cycle Inventory for unit process of Raw materials grinding and proportioning**

***Step 3: Kiln burning***

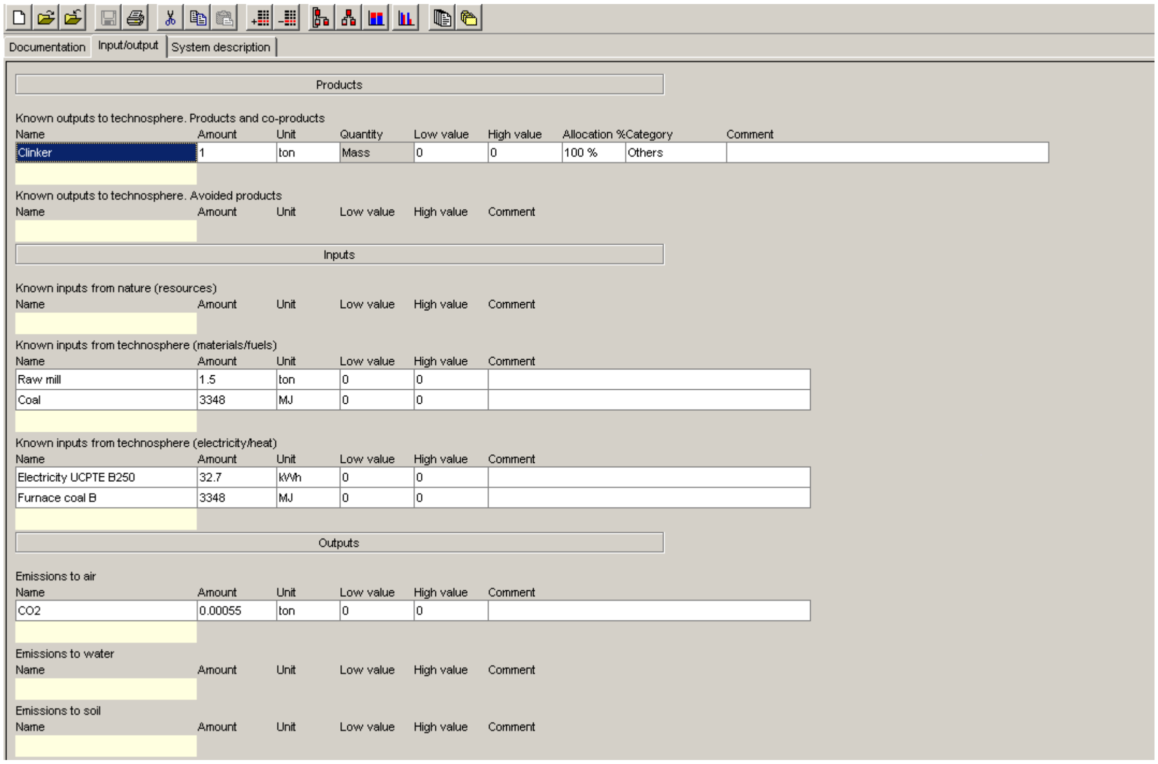



**Figure 4.5 Life cycle Inventory Input/Output screen for unit process of kiln burning**

## Tree analyse for the process of kiln burning

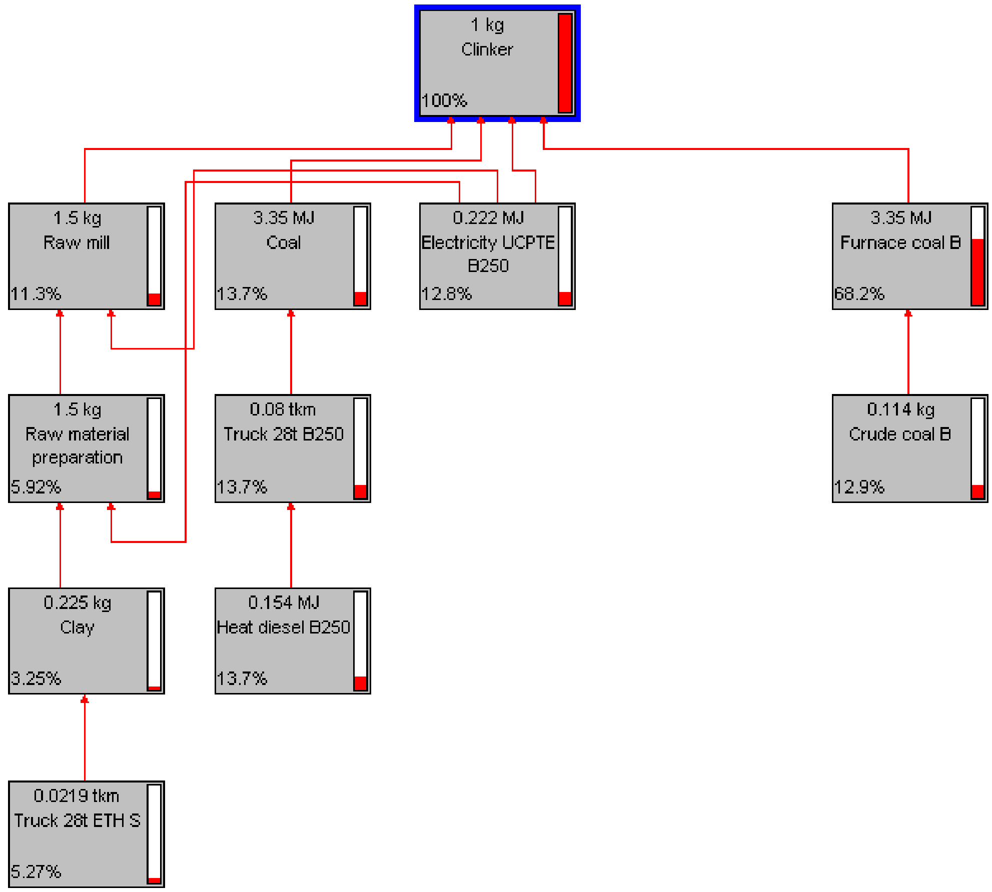



**Figure 4.6 Life cycle Inventory for unit process of kiln burning**

### *Step 4: Clinker cooling*

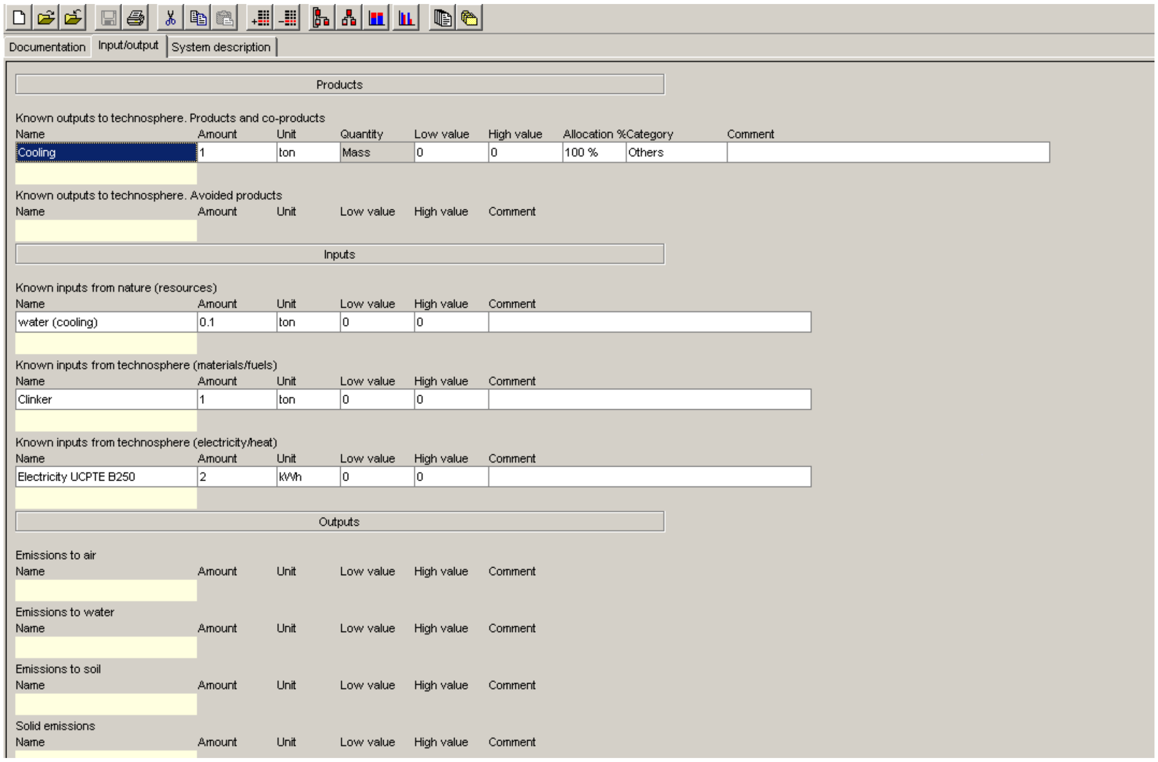



**Figure 4.7 Life cycle Inventory Input/Output screen for unit process of clinker cooling**

**Tree analyse for the process of clinker cooling**

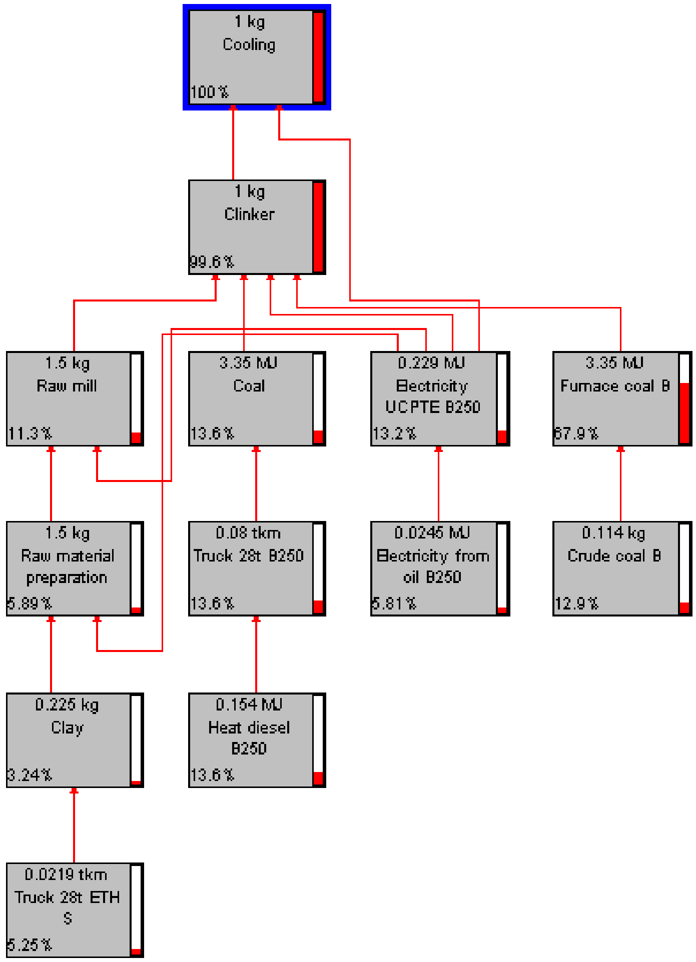



**Figure 4.8 Life cycle Inventory for unit process of clinker cooling**

*Step 5: Clinker grinding*

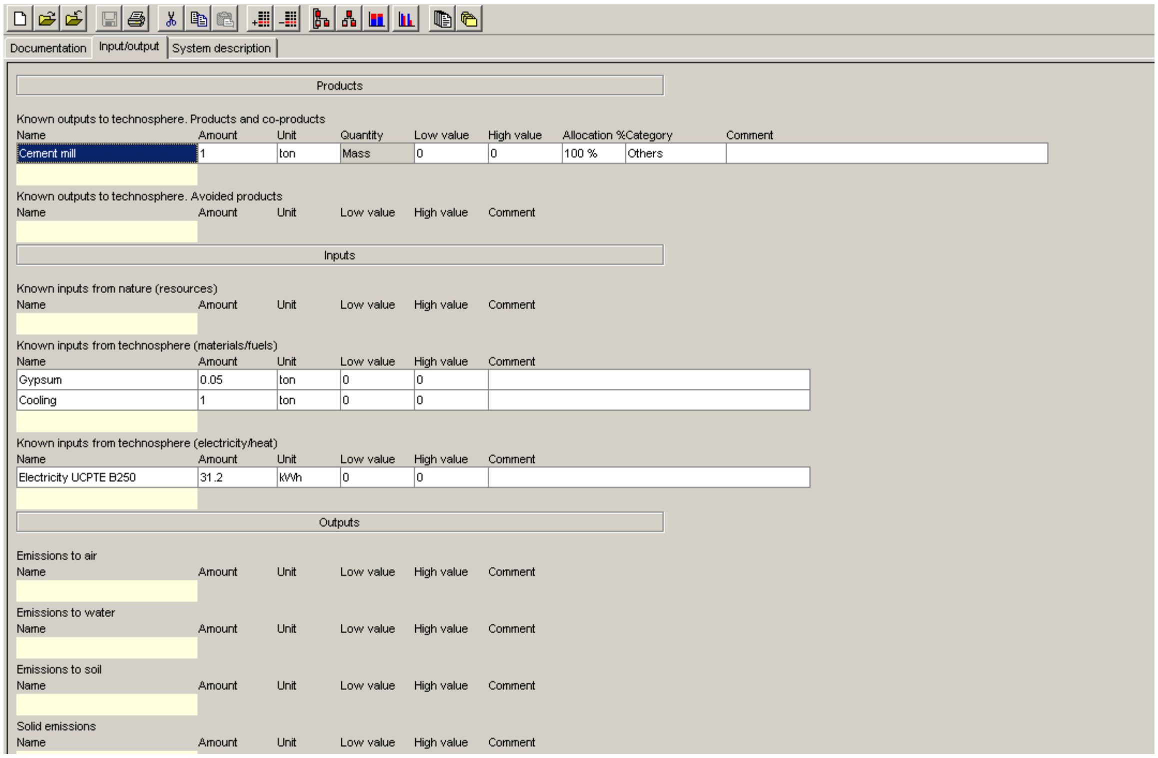



**Figure 4.9 Life cycle Inventory Input/Output screen for unit process of clinker grinding**

**Tree analyse for the process of clinker grinding**

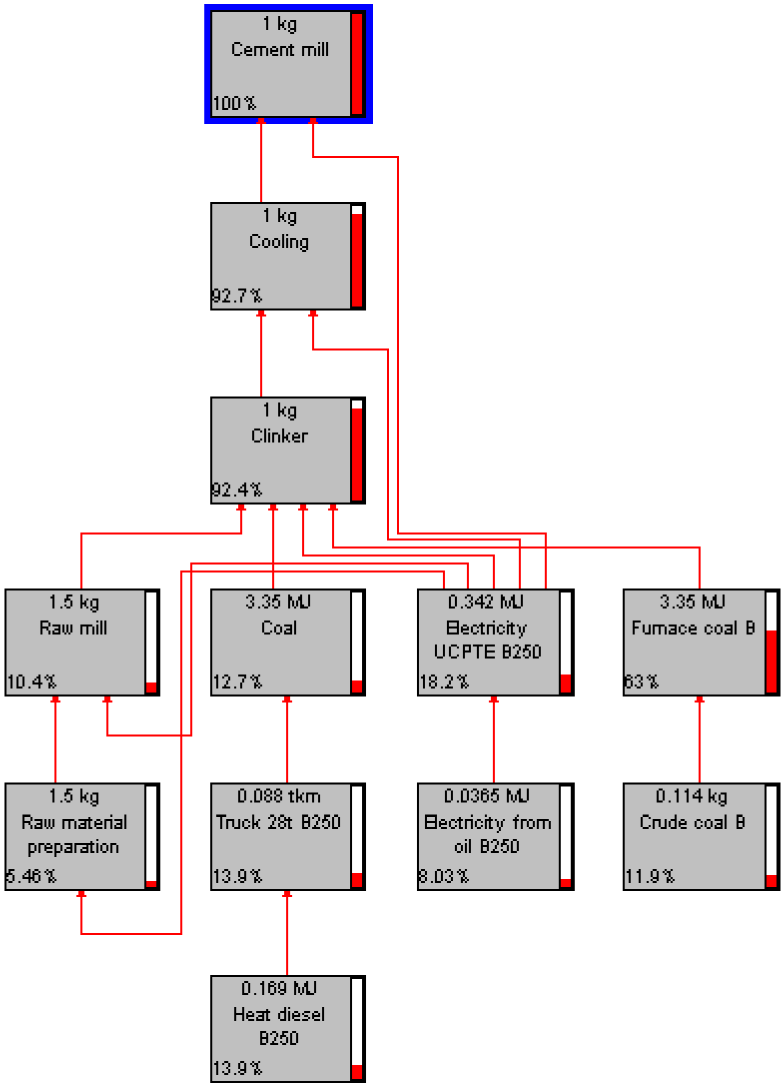



**Figure 4.10 Life cycle Inventory for unit process of clinker grinding**

# ***Chapter 5***

**5.0 Phase 3 – Impact Assessment**

In impact assessment, the environmental burdens associated with the material and energy flows determined in the previous phase is analyzes and compared. The conventional approach is to classify the inventory flows into specific impact categories (e.g., global warming, resource depletion, ecotoxicity). Normalization and weighting (or valuation) of the impacts is also included in this stage. If necessary, the individual impacts can then be aggregated into a single composite environmental index. In this chapter the output of the data will be analyse and compared. The environmental impact categories can be broadly classified under:

1. Resource depletion and degradation
2. Human health impact
3. Ecosystem health impact

The environmental impact will be assessing using single score, normalization and characterization. Single score is the total impact of each process and analyzed by comparing with other environmental impact categories of the eco-indicator. Normalization is the calculated total impact on each impact category from each process showing on one scale. Characterization is the calculated percentage share each process has out of the total impact shown by each impact category of the eco-indicator used.

### 5.1 Raw materials preparation

Single score

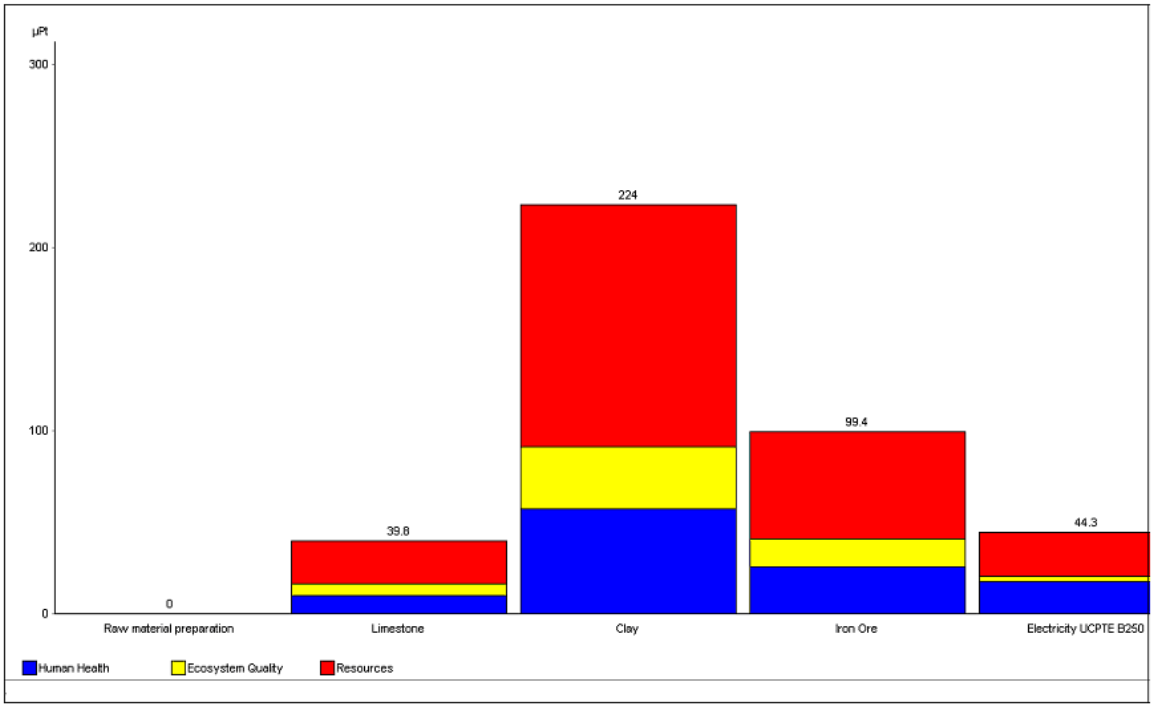



**Figure 5.1 Single score output for raw materials preparation**

| Impact category | Human Health | Ecosystem Quality | Resources |
|---|---|---|---|
| **Limestone** | 10.2 µpt | 6.07 µpt | 23.5 µpt |
| **Clay** | 57.4 µpt | 34.1 µpt | 132 µpt |
| **Iron ore** | 25.5 µpt | 34.1 µpt | 58.7 µpt |
| **Electricity** | 17.7 µpt | 3 µpt | 23.6 µpt |

**Table 5.1 Single score output for raw materials preparation**

Based on the single score analysis of life cycle impact assessment, clay causes the most damage in resources and human health follows by iron ore, electricity and limestone. This is due to the wide land use and long distance transportation of clay to the plant which used up higher amount of fossil fuel.

Normalization

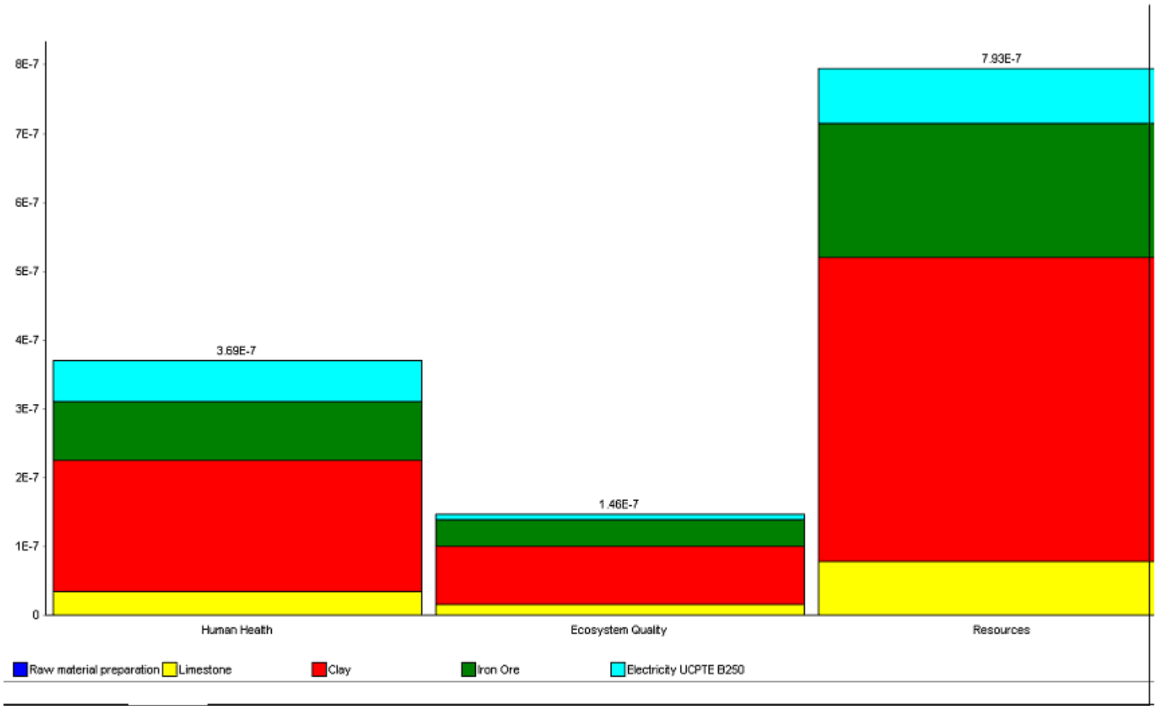



**Figure 5.2 Normalization output for raw materials preparation**

| Impact category | Human Health | Ecosystem Quality | Resources |
|---|---|---|---|
| **Limestone** | 3.4 E-8 | 1.52 E-8 | 7.83 E-8 |
| **Clay** | 1.91 E-7 | 8.53 E-8 | 4.41 E-7 |
| **Iron ore** | 8.5 E-8 | 3.79 E-8 | 1.96 E-7 |
| **Electricity** | 5.91 E-8 | 7.49 E-9 | 7.86 E-8 |

**Table 5.2 Normalization output for raw materials preparation**

Based on the normalization analysis, the graph shown that, resources have the highest impact follows by human health and ecosystem quality. As the result of long distance transportation which due to high consumption of fossil fuel and wide land use makes clay has the highest environment impact and follows by iron ore, electricity and limestone.

Damage assessment

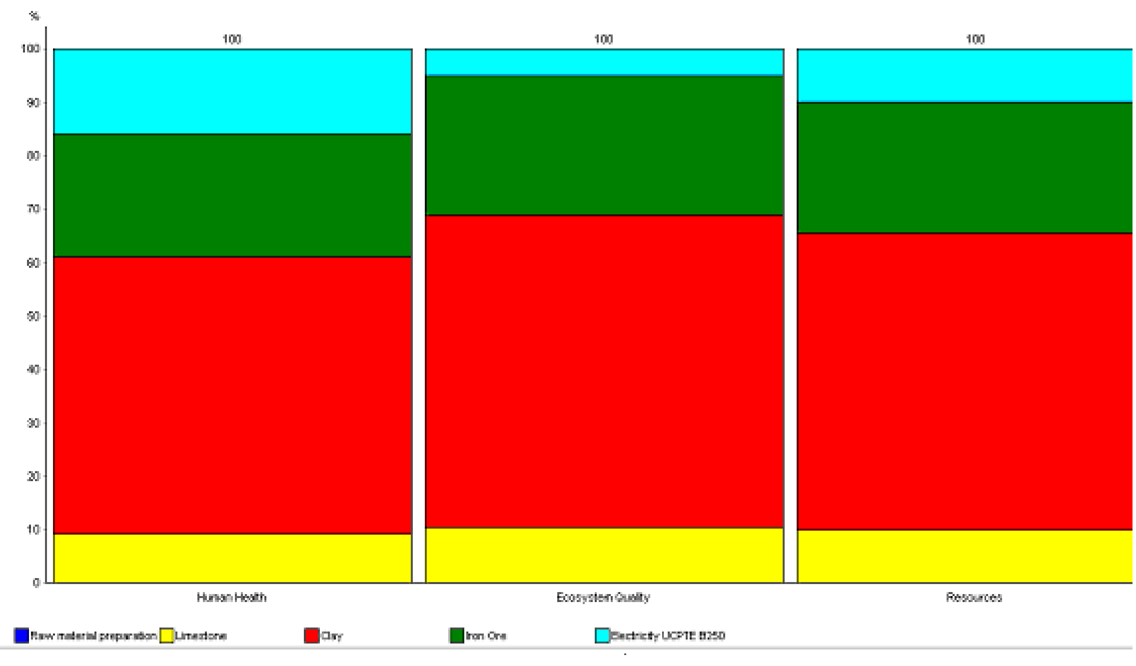



**Figure 5.3 Damage assessment output for raw materials preparation**

| Impact category | Human Health | Ecosystem Quality | Resources |
|---|---|---|---|
| **Limestone** | 5.94 E-10 DALY | 3.84 E-5 PDF*m2yr | 0.000658 MJ |
| **Clay** | 2.94 E-9 DALY | 0.000194 PDF*m2yr | 0.0037 MJ |
| **Iron ore** | 1.31 E-9 DALY | 0.000438 PDF*m2yr | 0.00165 MJ |
| **Electricity** | 9.08 E-10 DALY | 7.78 E-5 PDF*m2yr | 0.000661 MJ |

**Table 5.3 Damage assessment output for raw materials preparation**

Based on the graph, resources have the highest impact follows by human health and ecosystem quality. As the result of long distance transportation and high consumption of fossil fuel clay again is the highest impact among all follow by iron ore, electricity and limestone.

Tree impact indicator

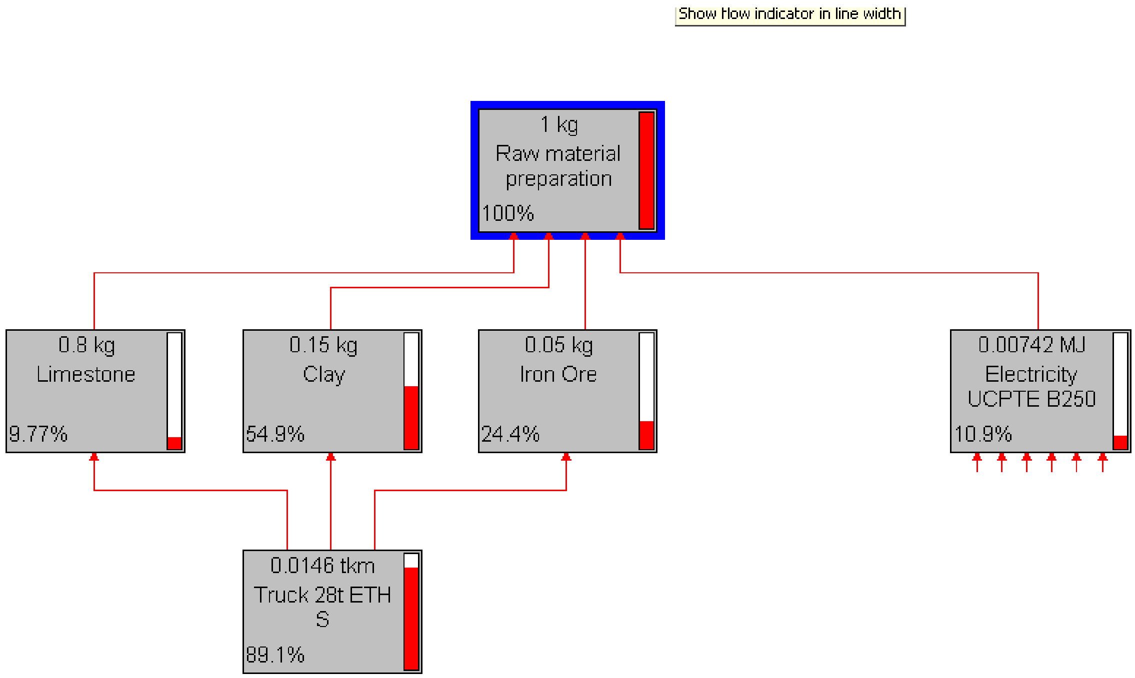



**Figure 5.4 Analysation by impact indicator 'Climate Change' for raw materials preparation process**

Clay transsportation by truck is the major contributor for the impact indicator 'Climate change' because of the greenhouse gas releases from this process.

**5.2 Raw materials grinding and proportioning**

<u>Single score</u>

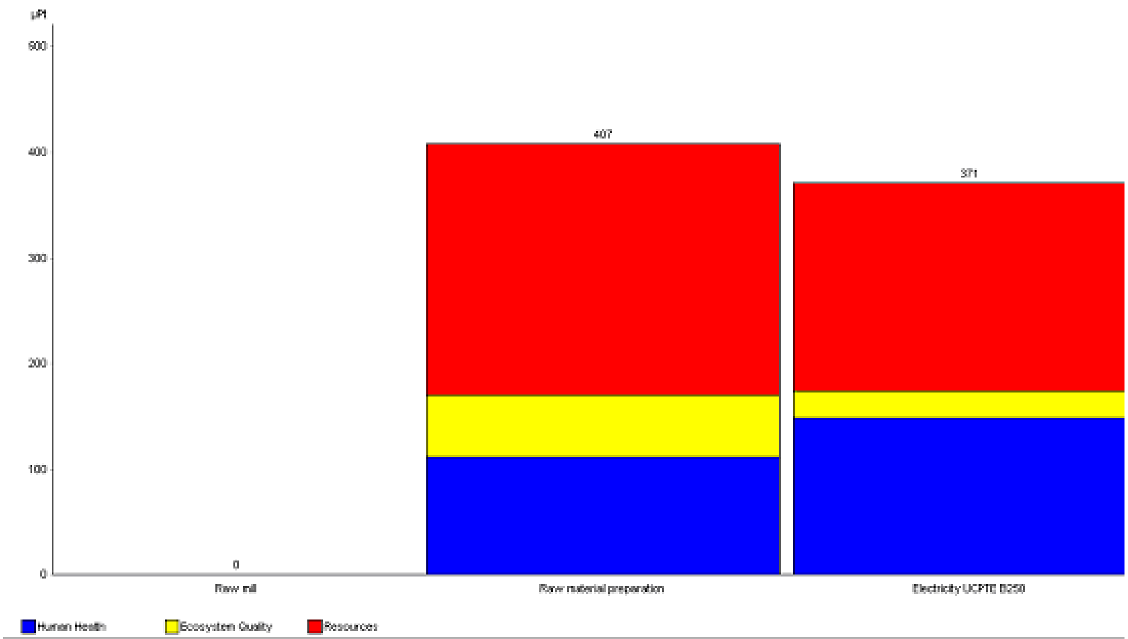



**Figure 5.5 Single score output for raw materials grinding and proportioning**

| Impact category | Human health | Ecosystem Quality | Resources |
|---|---|---|---|
| **Electricity** | 148 µpt | 25 µpt | 197 µpt |
| **Raw material preparation** | 111 µpt | 58.4 µpt | 238 µpt |

**Table 5.4 Single score output for raw materials grinding and proportioning**

Based on the graph, electricity causes the most impact on resources fllow by human health and ecosystem quality

<u>Normalization</u>

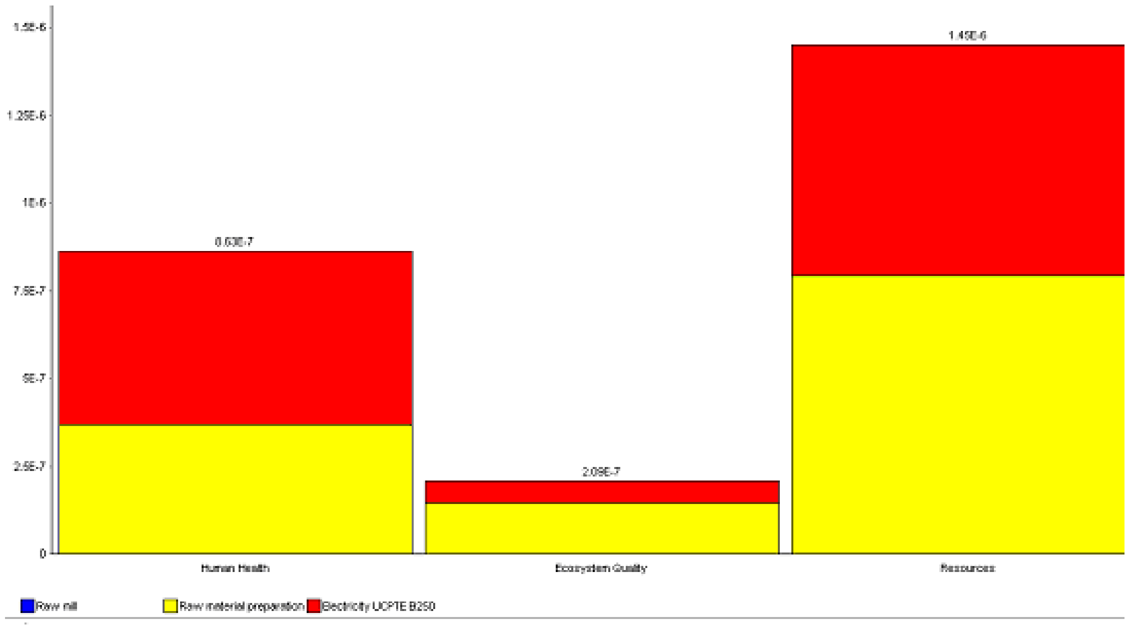



**Figure 5.6 Normalization output for raw materials grinding and proportioning**

| Impact category | Human health | Ecosystem Quality | Resources |
|---|---|---|---|
| **Electricity** | 4.94 E-7 | 6.26 E-8 | 6.58 E-7 |
| **Raw material preparation** | 3.69 E-7 | 1.46 E-7 | 7.93 E-7 |

**Table 5.5 Normalization output for raw materials grinding and proportioning**

Based on the graph, the result indicated the electricity has major influence on human health, resources and lastly ecosystem

Damage assessment

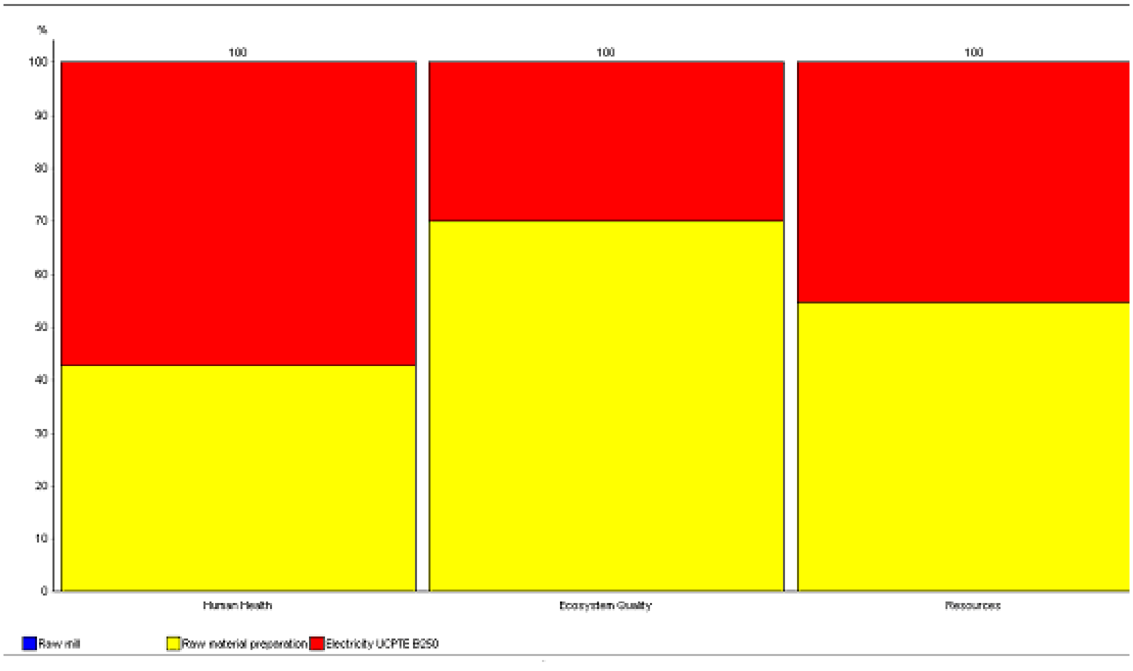



**Figure 5.7 Damage assessment output raw materials grinding and proportioning**

| Impact category | Human health | Ecosystem Quality | Resources |
|---|---|---|---|
| **Electricity** | 7.59 E-9 DALY | 0.000321 PDF*m2yr | 0.0053 MJ |
| **Raw material preparation** | 5.67 E-9 DALY | 0.000748 PDF*m2yr | 0.00667 MJ |

**Table 5.7 Damage assessment output for raw materials grinding and proportioning**

Based on the graph, electricity is the sole and the only major contributor to human health, resources and ecosystem quality.

Tree impact indicator

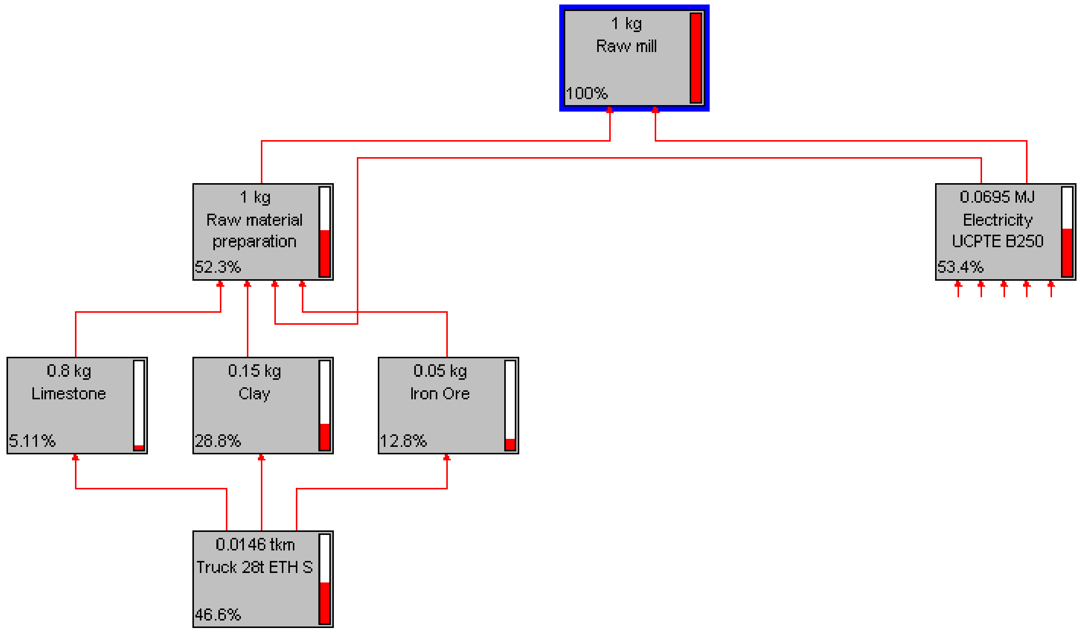



**Figure 5.8 Analysation by impact indicator 'Climate Change' for raw materials grinding and proportioning process**

The electricity flow in this process is distributed at 53.4% and the remaining 52.7% is distributed to raw materials preparation.

### 5.3 Kiln burning

<u>Single score</u>

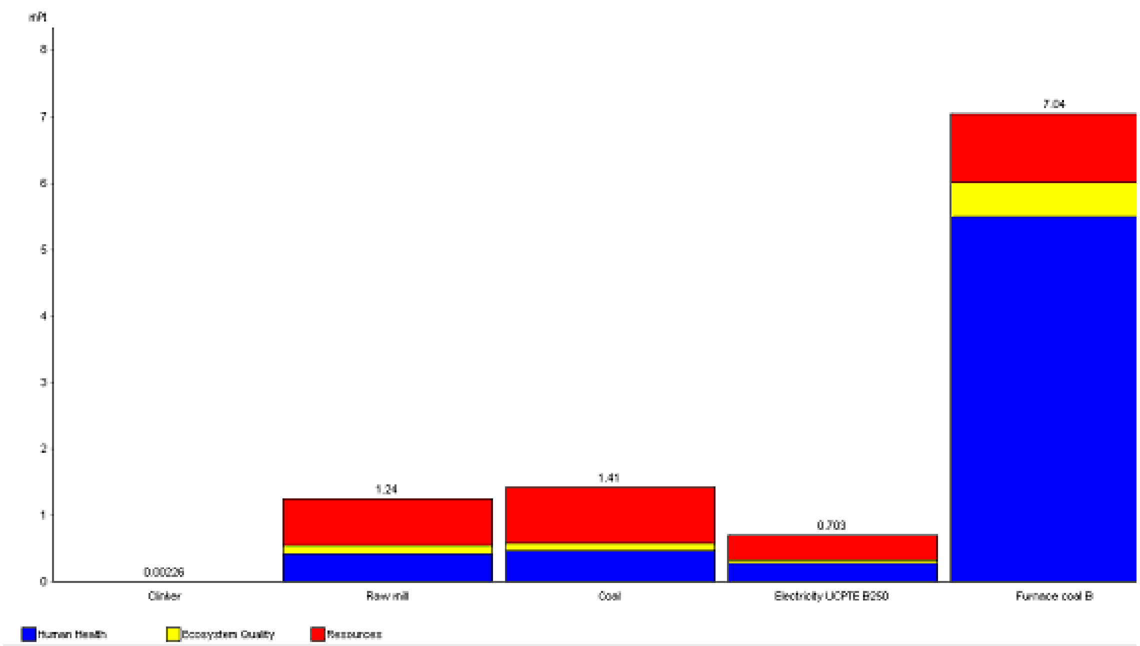



**Figure 5.9 Single score output for kiln burning**

| Impact category | Human health | Ecosystem Quality | Resources |
|---|---|---|---|
| **Raw mill** | 0.414 mpt | 0.133 mpt | 0.697 mpt |
| **Coal** | 0.468 mpt | 0.104 mpt | 0.842 mpt |
| **Electricity** | 0.281 mpt | 0.0475 mpt | 0.374 mpt |
| **Furnace** | 5.49 mpt | 0.521 mpt | 1.03 mpt |

**Table 5.7 Single score output for kiln burning**

Based on the graph, furnace has the highest impact follows by coal and electricity. This is due to high amount emission of airborne pollution in the form of dust and gases into the air.

Normalization

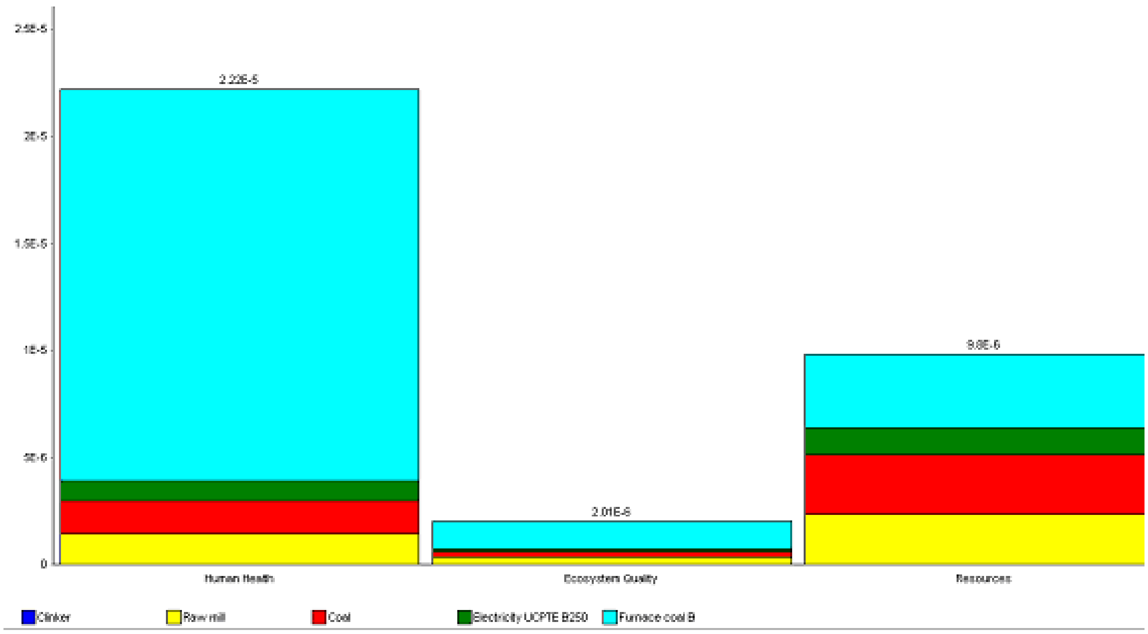



**Figure 5.10 Normalization output for kiln burning**

| Impact category | Human health | Ecosystem Quality | Resources |
|---|---|---|---|
| **Raw mill** | 1.38 E-6 | 3.34 E-7 | 2.32 E-6 |
| **Coal** | 1.56 E-6 | 2.6 E-7 | 2.81 E-6 |
| **Electricity** | 9.37 E-7 | 1.19 E-7 | 1.25 E-6 |
| **Furnace** | 1.83 E-5 | 1.3 E-6 | 3.43 E-6 |

**Table 5.8 Normalization output for kiln burning**

The figure 5.10 indicate the major influence of furnace on the human health, resources and ecosystem quality

Damage assessment

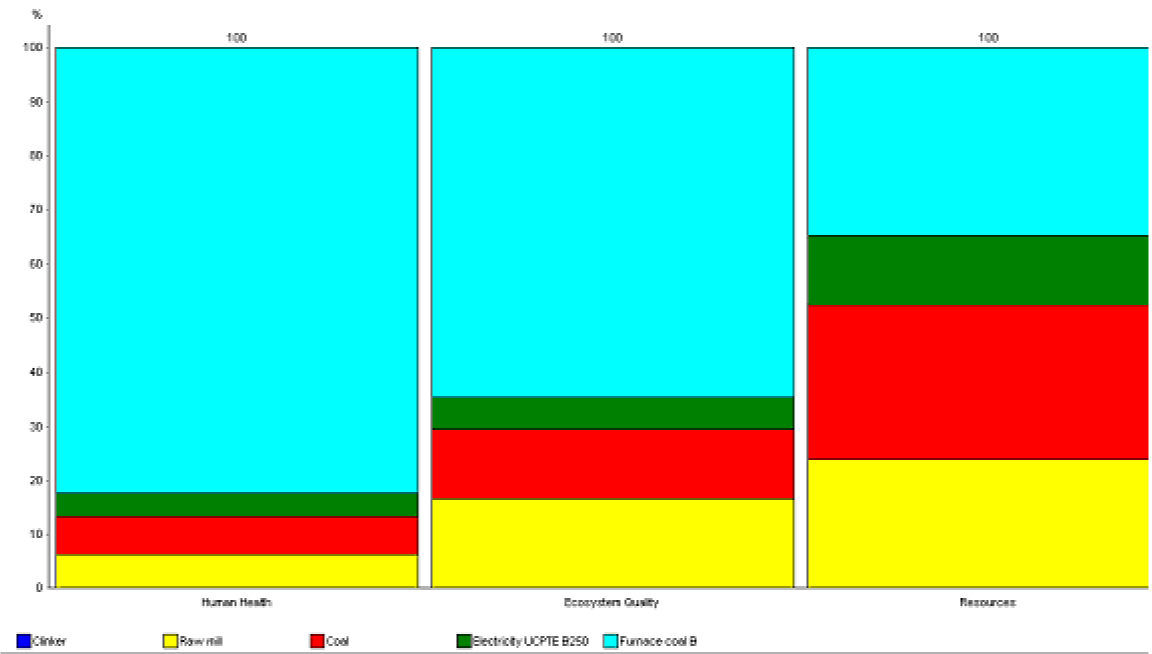



**Figure 5.11 Damage assessment output kiln burning**

| Impact category | Human health | Ecosystem Quality | Resources |
|---|---|---|---|
| **Raw mill** | 2.12 E-8 DALY | 0.00171 PDF*m2yr | 0.0195 MJ |
| **Coal** | 2.4 E-8 DALY | 0.00133 PDF*m2yr | 0.0236 MJ |
| **Electricity** | 1.44 E-8 DALY | 0.000609 PDF*m2yr | 0.0105 MJ |
| **Furnace** | 2.81 E-7 DALY | 0.00668 PDF*m2yr | 0.0288 MJ |

**Table 5.9 Damage assessment output kiln burning**

Based on the graph, resources furnace is the major contributors for human health, ecosystem quality and resources damages.

Tree impact indicator

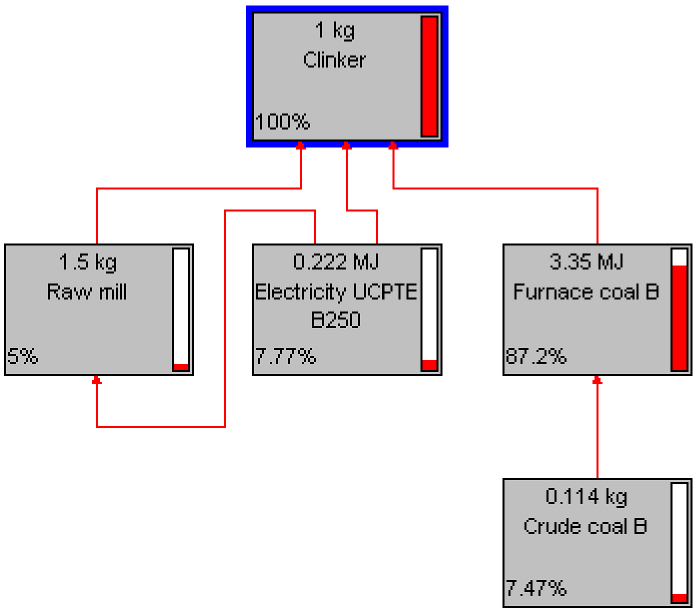



**Figure 5.12 Analysation by impact indicator 'Climate Change' for kiln burning process**

Furnace is the major contributor for climate change with 87.2% follows by the electricity usage 7.77%

### 5.4 Clinker cooling

<u>Single score</u>

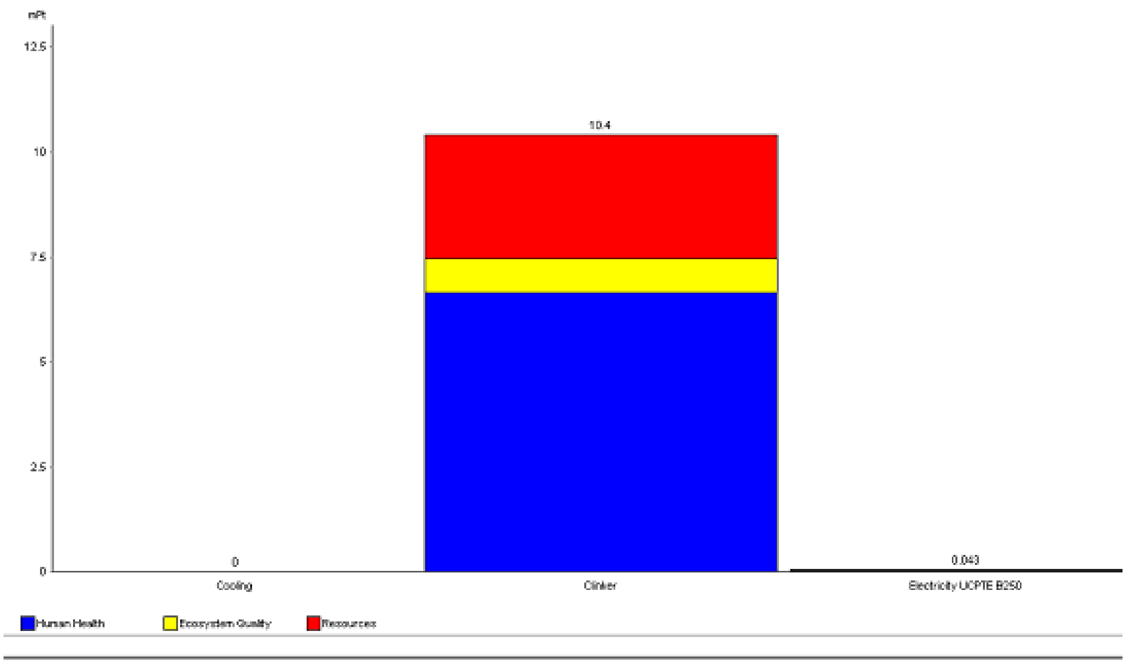



**Figure 5.13 Single score output for clinker cooling**

| Impact category | Human health | Ecosystem Quality | Resources |
|---|---|---|---|
| **Clinker** | 6.65 mpt | 0.806 mpt | 2.94 mpt |
| **Electricity** | 0.0172 mpt | 0.0029 mpt | 0.0229 mpt |

**Table 5.10 Single score output for clinker cooling**

Based on the graph, electricity is the only in the cooling processes.

Normalization

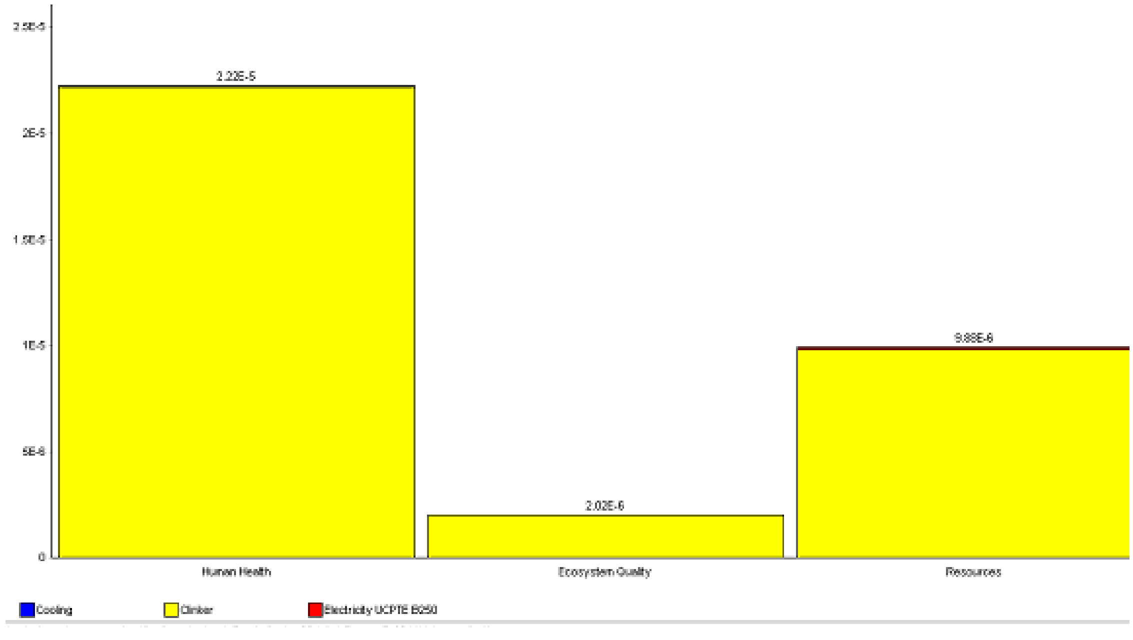



**Figure 5.14 Normalization output for clinker cooling**

| Impact category | Human health | Ecosystem Quality | Resources |
|---|---|---|---|
| **Clinker** | 2.22 E-5 | 2.01 E-4 | 9.8 E-6 |
| **Electricity** | 5.73 E-8 | 0.01 E-4 | 0.08 E-6 |

**Table 5.11 Normalization output for clinker cooling**

Figure 5.14 indicate electricity has a little impact on the human health, ecosystem and resources.

Damage assessment

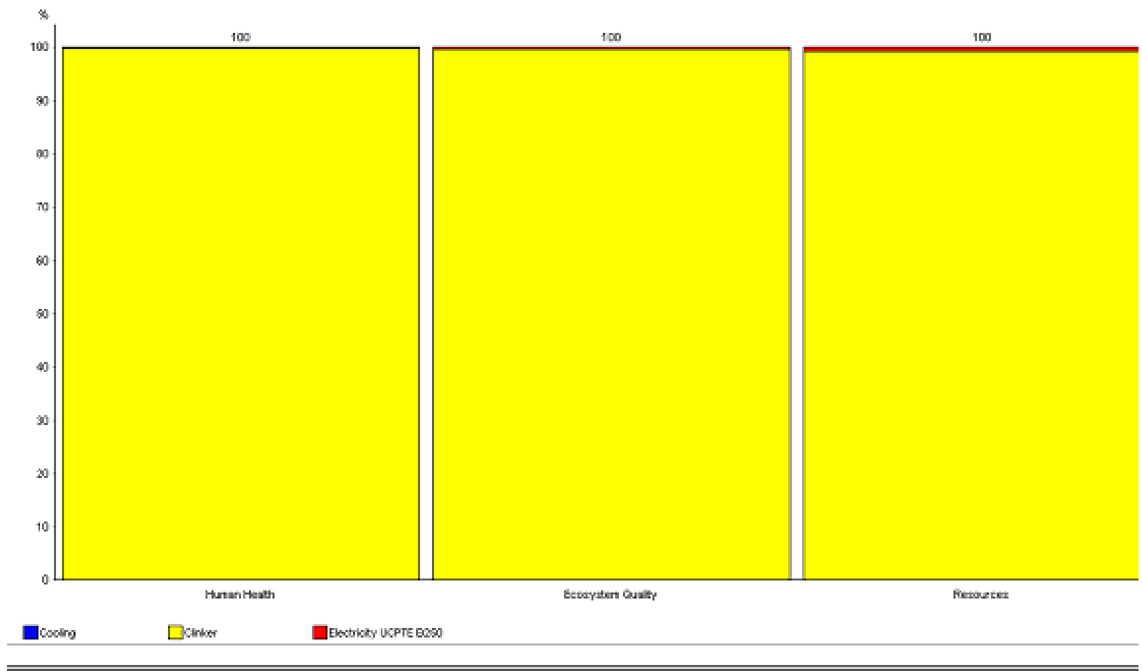



**Figure 5.15 Damage assessment output for clinker cooling**

| Impact category | Human health | Ecosystem Quality | Resources |
|---|---|---|---|
| **Clinker** | 3.41 E-7 DALY | 0.0103 PDF*m2yr | 0.0824 MJ |
| **Electricity** | 8.8 E-10 DALY | 3.72 E-5 PDF*m2yr | 0.000641 MJ |

**Table 5.12 Damage assessment output for clinker cooling**

Based on figure 5.15 damage is due to electricity to human health, ecosystem quality and resources.

Tree impact indicator

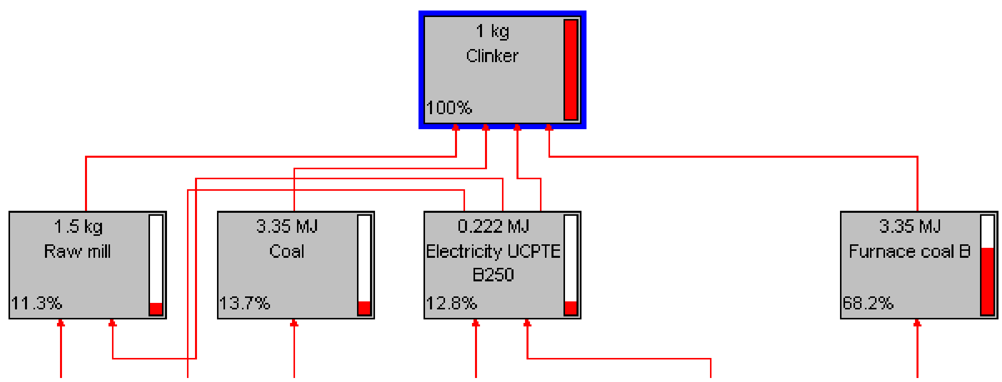



**Figure 5.16 Analysation by impact indicator 'Climate Change' for clinker cooling process**

The impact of climate change in the clinker process is caused by furnace (68.2 %), Electricity (12.8) and coal (13.7)

## 5.5 Clinker grinding

<u>Single score</u>

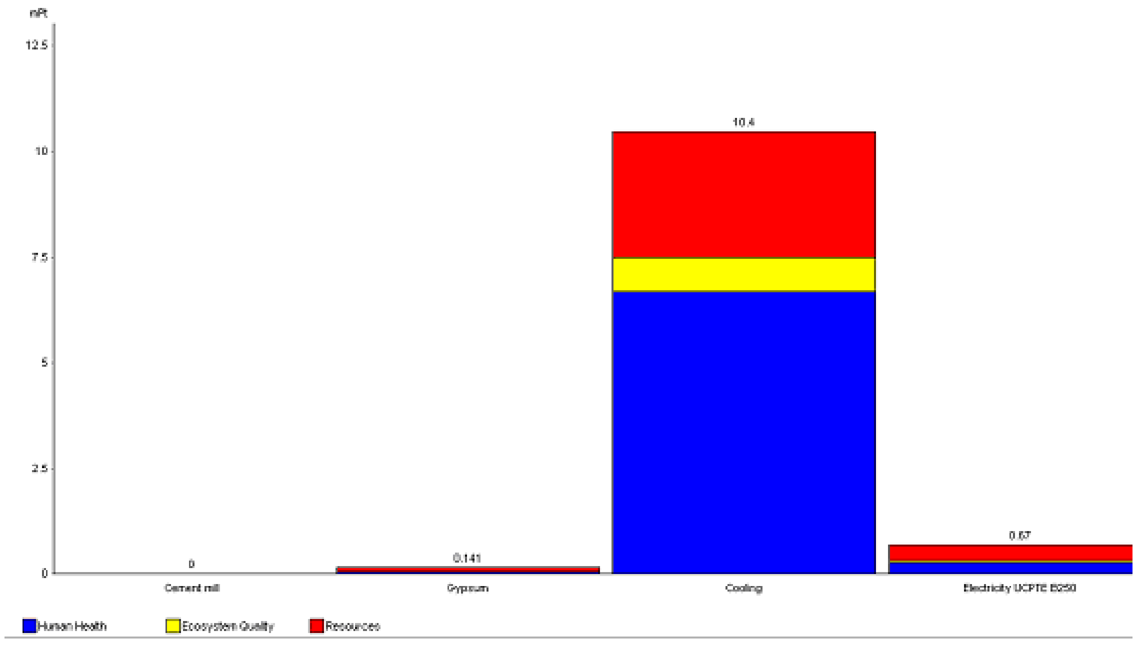



**Figure 5.17 Single score output for clinker grinding**

| Impact category | Human health | Ecosystem Quality | Resources |
|---|---|---|---|
| **Gypsum** | 0.0468 mpt | 0.01 mpt | 0.0842 mpt |
| **Cooling** | 6.67 mpt | 0.809 mpt | 2.96 mpt |
| **Electricity** | 0.268 mpt | 0.0453 mpt | 0.357 mpt |

**Table 5.13 Single score output for clinker grinding**

Based on the graph, electricity has higher impact compare to gypsum. Ecosystem has the lowest impact among the impact category.

Normalization

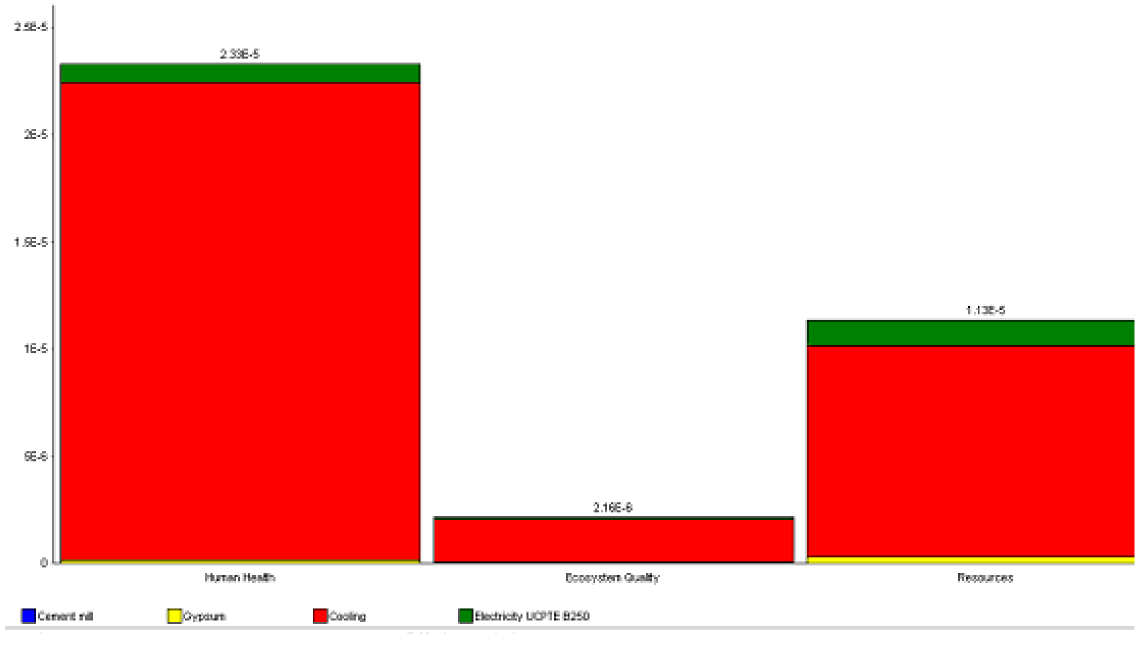



**Figure 5.18 Normalization output for clinker grinding**

| Impact category | Human health | Ecosystem Quality | Resources |
|---|---|---|---|
| **Gypsum** | 1.56 E-7 | 2.6 E-8 | 1.19 E-6 |
| **Cooling** | 2.22 E-5 | 2.02 E-6 | 9.88 E-6 |
| **Electricity** | 8.94 E-7 | 1.13 E-7 | 1.19 E-6 |

**Table 5.15 Normalization output for clinker grinding**

Figure 5.18 indicate electricity is the higher impact to human health, ecosystem and resources. While the gypsum only has lower impact due to low amount consumed.

Damage assessment

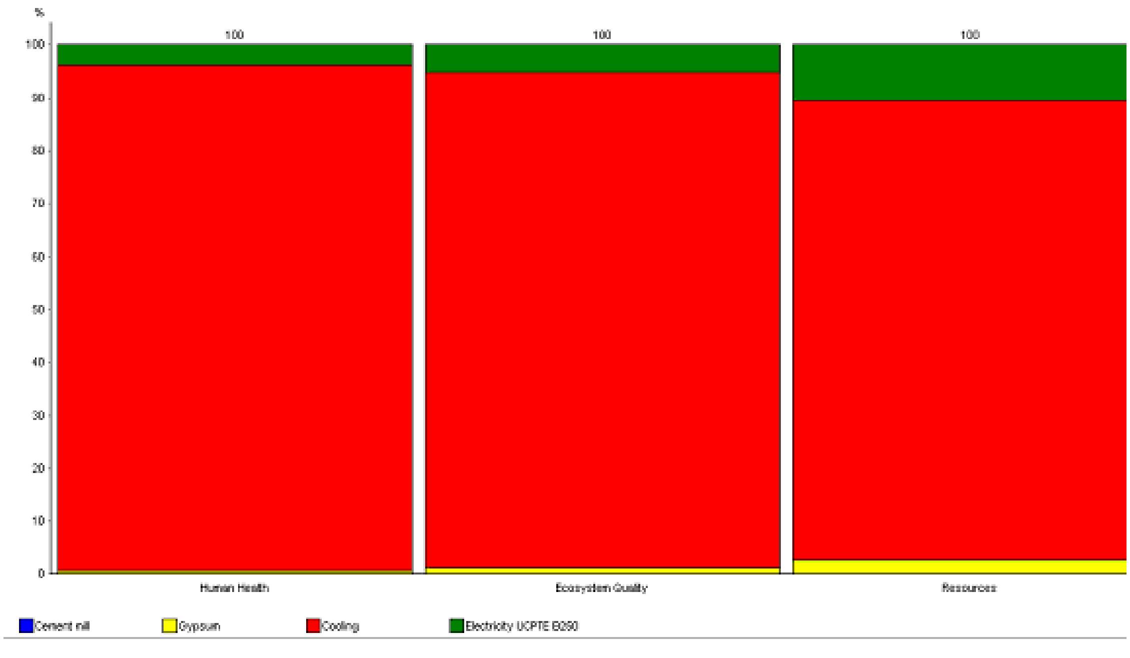



**Figure 5.19 Damage assessment output for clinker grinding**

| Impact category | Human health | Ecosystem Quality | Resources |
|---|---|---|---|
| **Gypsum** | 2.4 E-9 DALY | 0.000133 PDF*m2yr | 0.01 MJ |
| **Cooling** | 3.42 E-7 DALY | 0.0104 PDF*m2yr | 0.083 MJ |
| **Electricity** | 1.37 E-8 DALY | 0.000581 PDF*m2yr | 0.00236 MJ |

**Table 5.15 Damage assessment output for clinker grinding**

Based on the graph, electricity is major contributor to human health, ecosystem quality and resources. Gypsum has higher impact to resources follow by ecosystem quality and human health.

Tree impact indicator

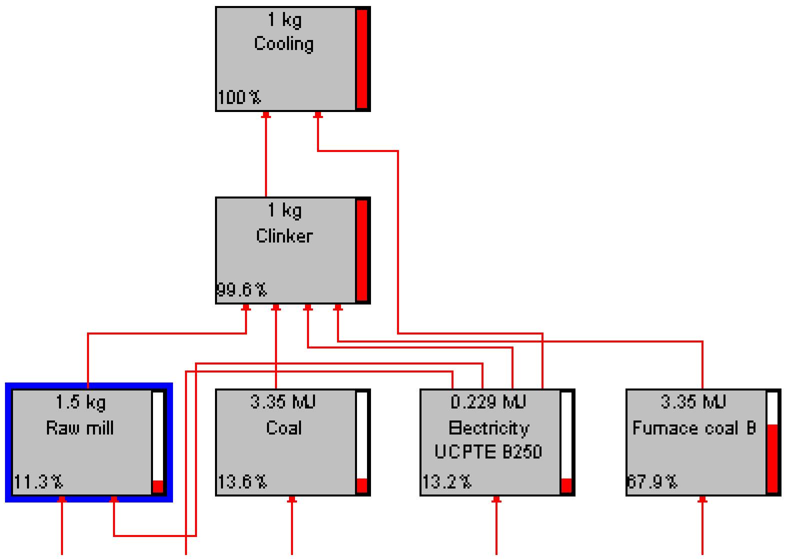



**Figure 5.20 Analysation by impact indicator 'Climate Change' for clinker grinding process**

The impact of climate change in cooling is caused by usage of electricity

**Analysation 'Electricity' in cement (Cement) process mill by Single product flow of energy source.**

The Electricity distribution of electricity on each process up to the last unit process in the cement manufacturing process is tabulated in table below

| Unit Process Name | Distribution (%) |
|---|---|
| Raw materials preparation | 3.26 |
| Raw mill | 27.3 |
| Clinker | 34.5 |
| Clinker cooling | 2.11 |
| Cement mill | 32.9 |

**Table 5.16 Electricity distribution between each unit process in the whole cement manufacturing system**

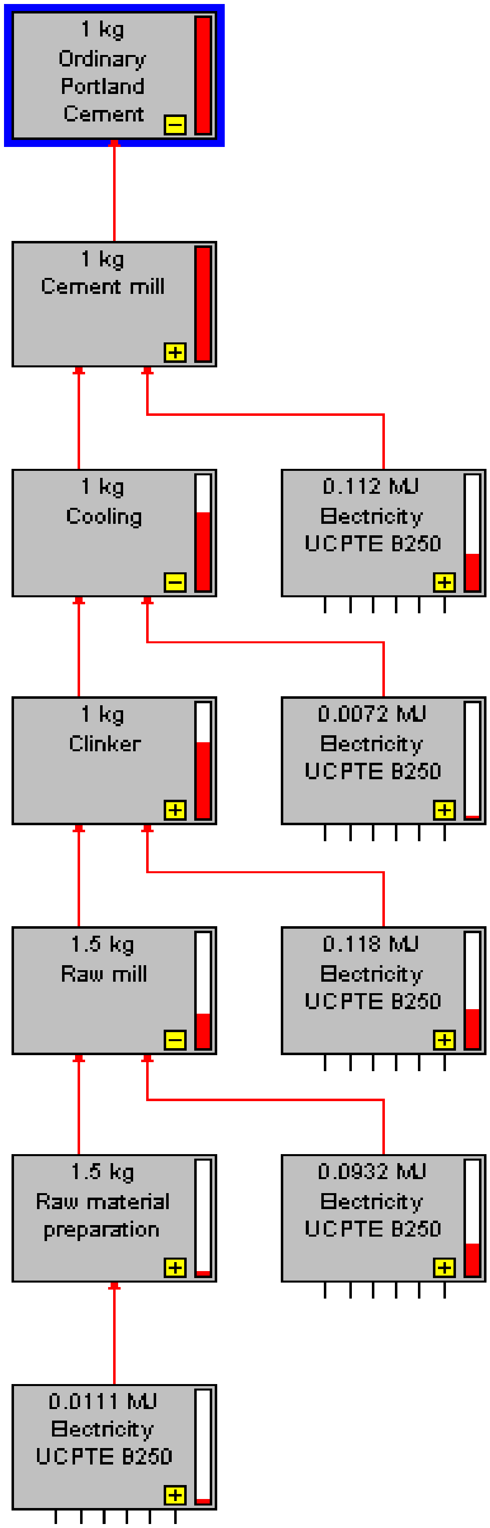



**Figure 5.21 Single product flow of energy source 'Electricity' in the Cement mill (cement) process**

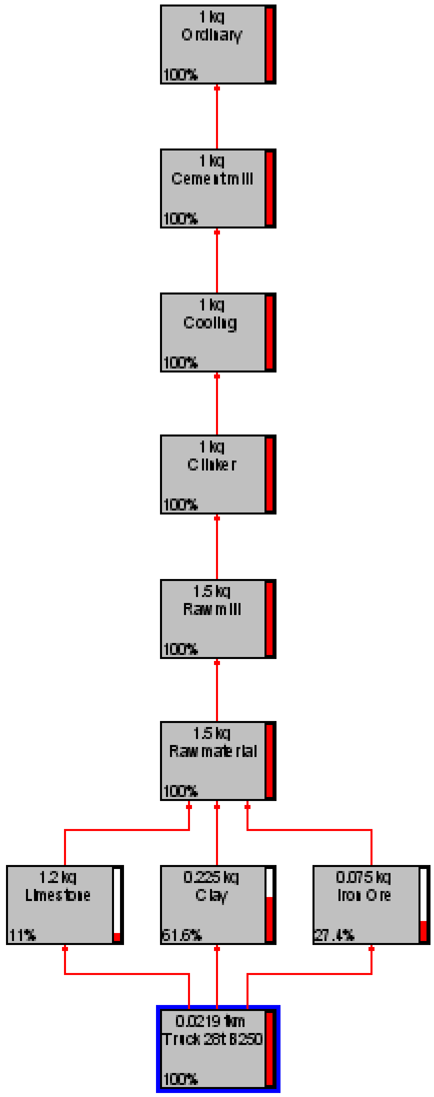
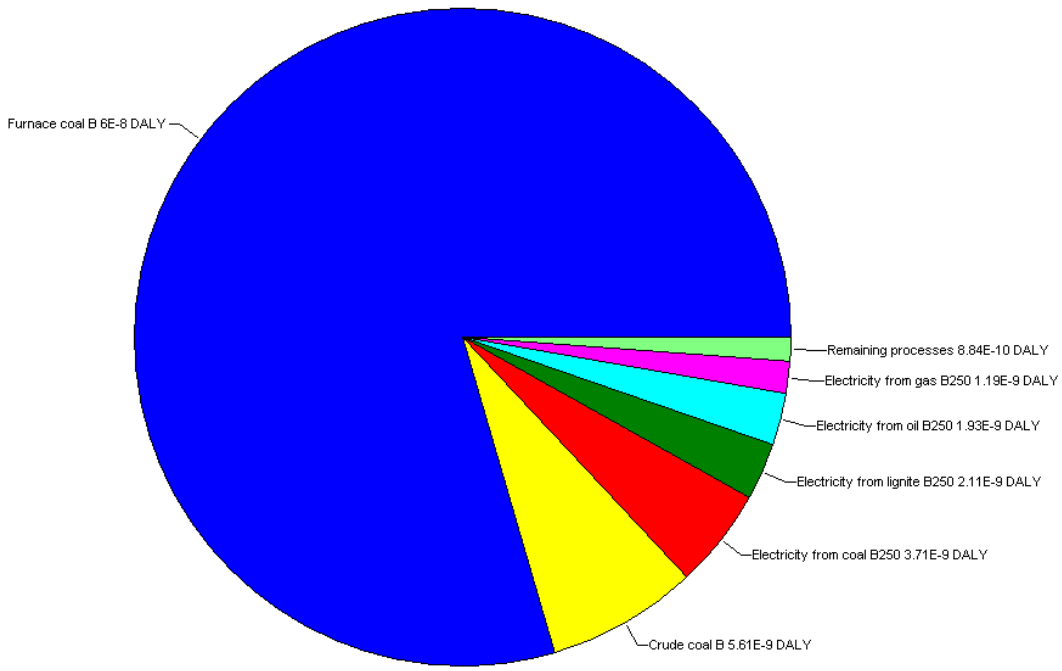



**Figure 5.22 Single product flow of energy source 'Truck 28T B250' in the Cement mill (cement) process.**

### 5.6 Analysing the whole cement manufacturing system by impact indicator 'climate change' DALY




.**Figure 5.23 Whole cement manufacturing system by impact indicator 'climate change' DALY**

The furnace has the highest impact to climate change due to high emission of gas.

# ***Chapter 6***

**6.0 Phase 4 - Improvement assessment/ Interpretation**

Life Cycle improvement of assessment or interpretation is the final step of the Life Cycle Assessment. It utilizes the results of the preceding stages to meet the specified objectives. In this phase it will typically generate a decision or plan of action. For diagnostic LCAs, the data is used to identify critical segments or "hot spots" in the life cycle which contribute disproportionately to the total system environmental impact. These problem areas can then be eliminated or reduced through system modifications. In the case of comparative LCAs, the competing system life cycles are ranked based on environmental performance and the optimal alternative is selected.

In this chapter the hot spots will be identified using the results of the previous chapter. The interpretation includes the identification of hot spots for the whole manufacturing process. The hot spots are the area with high environmental impact, after identify the critical path the next step is to look for possible of improvement. Although the hot spots is identified but it does not guaranteed there will be room of improvement.

The highest contributors for environmental impacts in the cement manufacturing process are clinker, followed by cement mill, raw materials preparation, raw mill and cooling. Based on the result, clinker is identified as the critical path of the cement manufacturing process. To make an improvement we need to understand 'what is clinker and how does it made?' Clinker is produced by heating the "rawmix" in oxidising conditions to around 1400-1450°C, at which temperature partial melting (sintering) takes place, producing hard spherical nodules around 5-20 mm in diameter.

**6.1 Option for possible improvement**

The environmental impact is due to the high energy requirements and the release of significant amounts of carbon dioxide. There are 2 options available with the possibility for improvement. The options are:-

**Option 1: To replace the existing kiln fuel with other available alternatives fuel.**

In this option the existing coal fuel will be replace with two alternative options available. The alternatives fuel used are gas fuel and oil fuel. The replaced fuel will compare with the existing coal fuel to identify which fuel has lower impact to the environment.

**Option 2: To reduce the usage of clinker in cement production.**

In this option two type of cement with relative low percentage of clinker will be used to compare with Ordinary Portland Cement. The cements used for comparison are Cement Blast Furnace and Cement Mortar. The comparison is to show the effect of clinker to the environment.

### 6.2 Option 1

Fuels that have been used for primary firing include coal, petroleum coke, heavy fuel oil, natural gas, landfill off-gas and oil refinery flare gas. High carbon fuels such as coal are preferred for kiln firing, because they yield a luminous flame. In this option two type of fuel will be used for comparison; heavy fuel oil and natural gas.

#### 6.2.1 Oil fuel VS Coal fuel

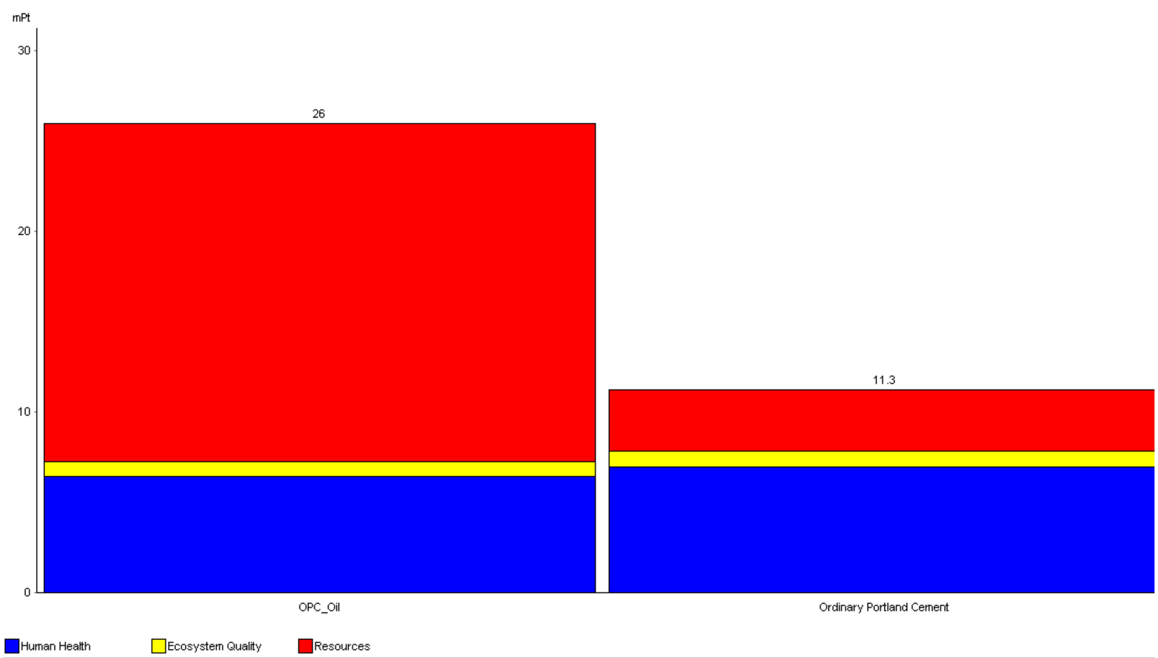



**Figure 6.1 Comparison using single score between Ordinary Portland Cement_ Oil fuel Vs Ordinary Portland Cement**

The results show that, oil base fuel ordinary Portland cement has higher impact to resources but lower impact to human health and ecosystem quality compare to coal base fuel ordinary portland cement. In overall the oil base fuel ordinary Portland cement has higher impact to the environment.

### 6.2.2 Gas fuel VS Coal fuel

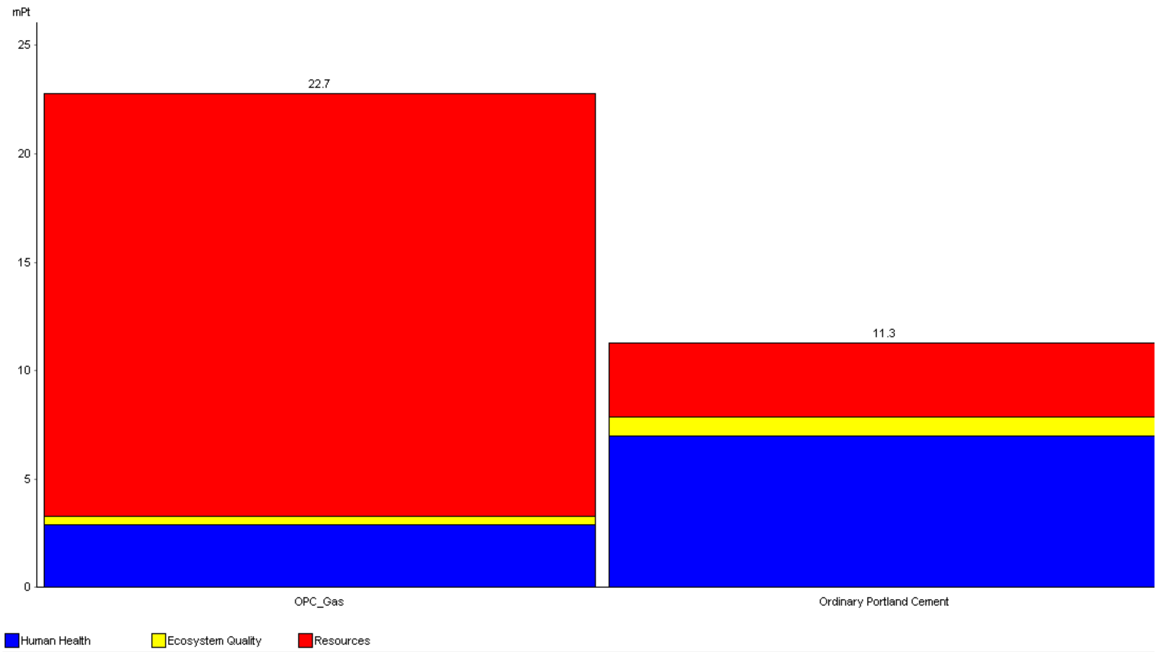



**Figure 6.2 Comparison using single score between Ordinary Portland Cement_ Gas fuel Vs Ordinary Portland Cement**

The results show that, gas base fuel ordinary Portland cement has higher impact to resources but lower impact to human health and ecosystem quality compare to coal base fuel ordinary Portland cement. In overall the gas base fuel ordinary Portland cement has higher impact to the environment.

## 6.3 *Option 2*

Cement Blast Furnace

In this option the clinker is replace with ground granulated blast furnace slag. Ground granulated blast furnace slag (GGBS or GGBFS) is obtained by quenching molten iron slag (a by-product of iron and steel making) from a blast furnace in water or stream, to produce a glassy granular product that is then dried and ground into a fine powder. The cement is known as Portland Blast Furnace Cement, it may contain up to 70% ground granulated blast furnace slag with the rest Portland clinker and a little gypsum.

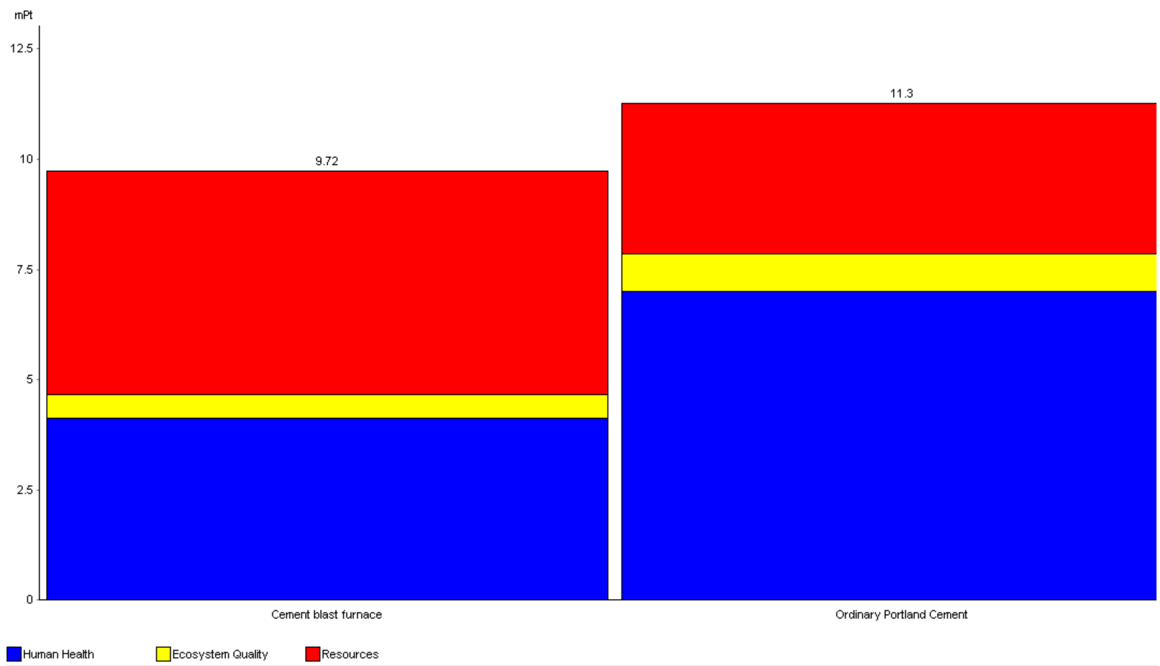



**Figure 6.3 Comparison using single score between Cement Blast Furnace VS Ordinary Portland Cement**

The results show that, the cement blast furnace has lower impact to human health and ecosystem quality but higher impact to resources compare to ordinary portland cement. In overall the cement blast furnace has lower impact to the environment.

Cement Mortar

Cement mortar is also known as masonry Cement. It is used for preparing bricklaying mortars and stuccos, and must not be used in concrete. They are usually complex proprietary formulations containing Portland clinker and a number of other ingredients that may include limestone, hydrated lime, air entrainers, retarders, waterproofers and coloring agents. They are formulated to yield workable mortars that allow rapid and consistent masonry work

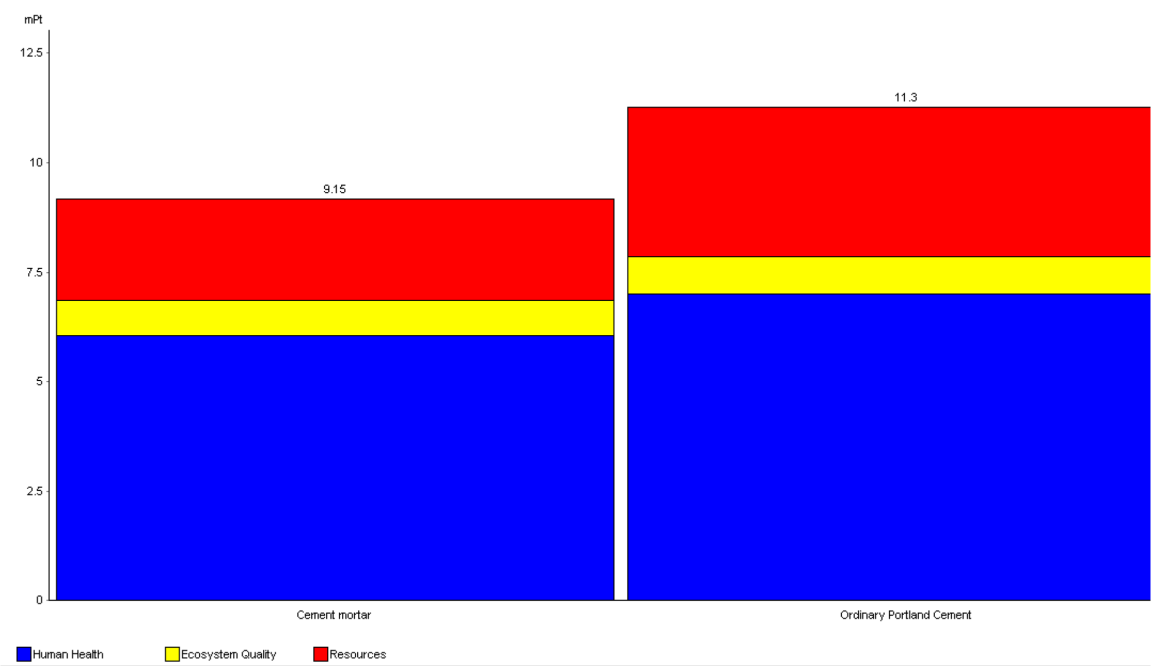



**Figure 6.4 Comparison using single score between Cement Mortar VS Ordinary Portland Cement**

The results show that, the cement mortar has lower impact in human health, ecosystem quality and resources. In overall the cement mortar has lower impact to the environment.

### 6.4 Sensitivity Analysis Result

The following results are the comparison of three different scenarios of Ordinary Portland Cement model, Oil Fuel Cement model and Gas Fuel Cement model.

**The Ordinary Portland Cement model using single score (Airborne emissions)**

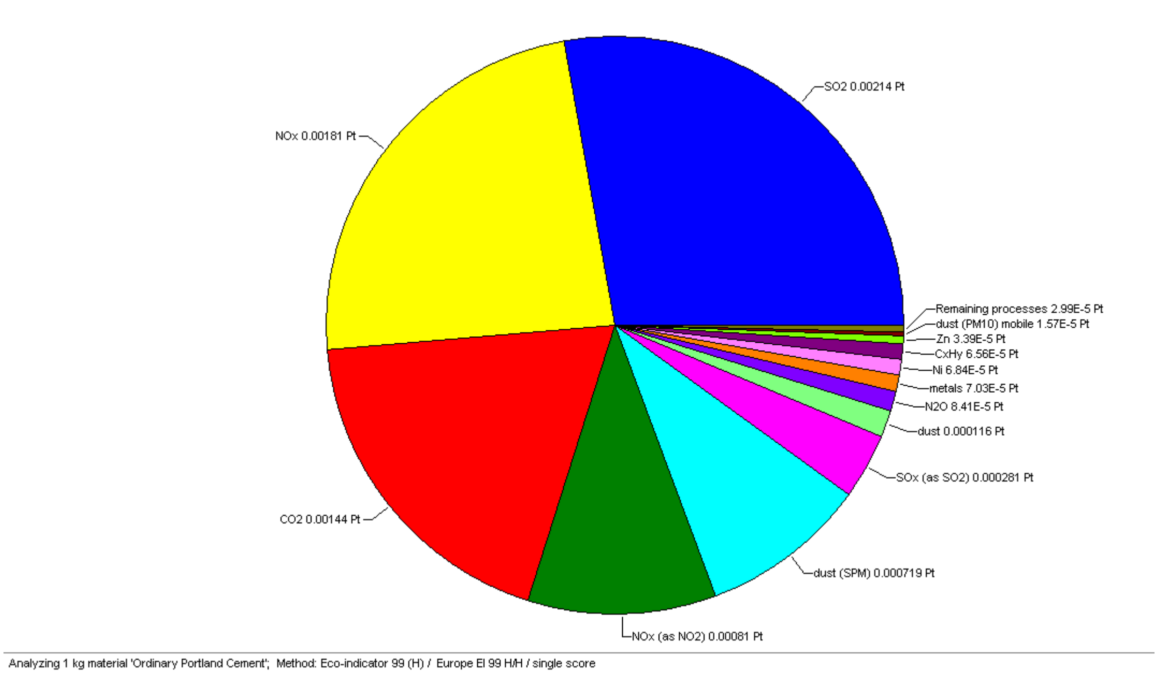



**Figure 6.5 Ordinary Portland Cement model using single score (Airborne emissions)**

The result shown, sulfur oxide, nitrogen oxide and carbon dioxide is the dominant of air emission

**The original plywood model using single score (compare processes)**

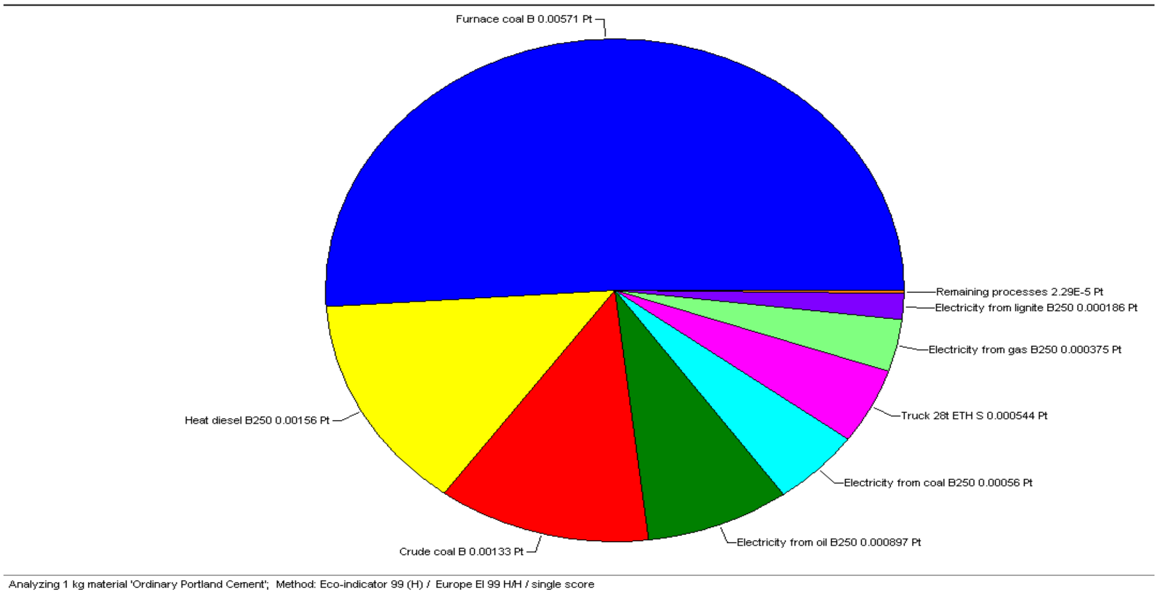



**Figure 6.6 Output for Ordinary Portland Cement model compared to the three scenarios**

The result shown in figure 6.6 indicates the furnace is the dominant of the process.

**The Cement Oil fuel using single score (Airborne emissions)**

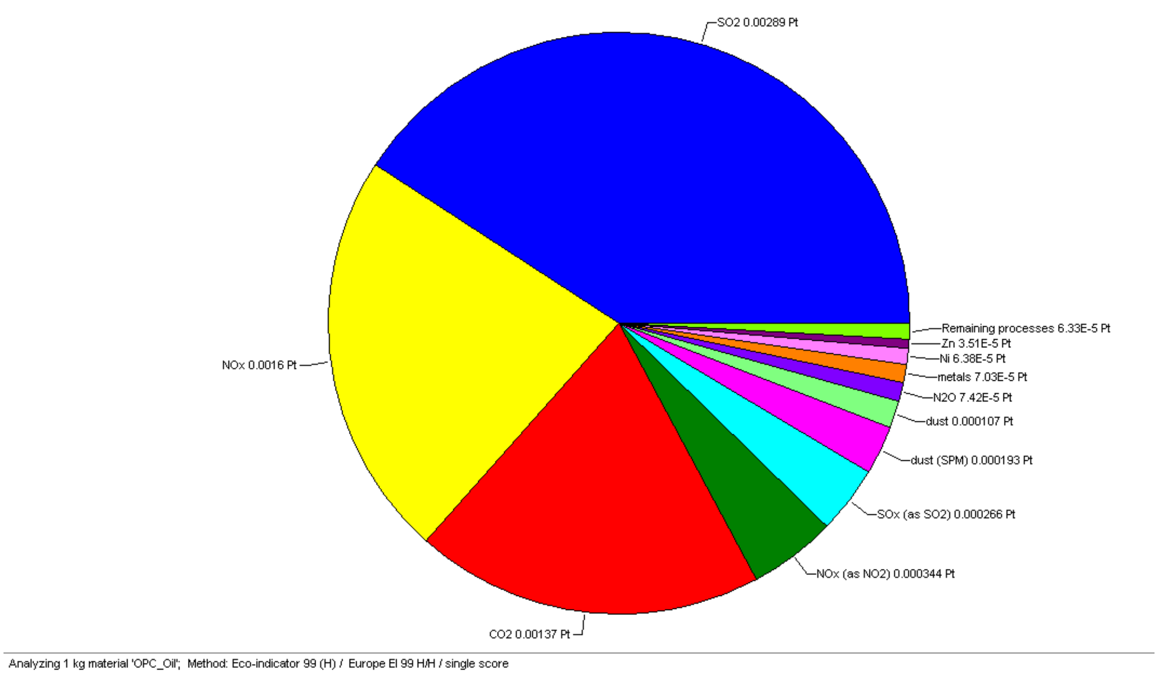



**Figure 6.7 Cement oil fuel model using single score (Airborne emissions)**

The result shown in figure 6.7 indicate sulfur oxide, nitrogen oxide and carbon dioxide is the dominant of air emission

**The Cement oil fuel model using single score (compare processes)**

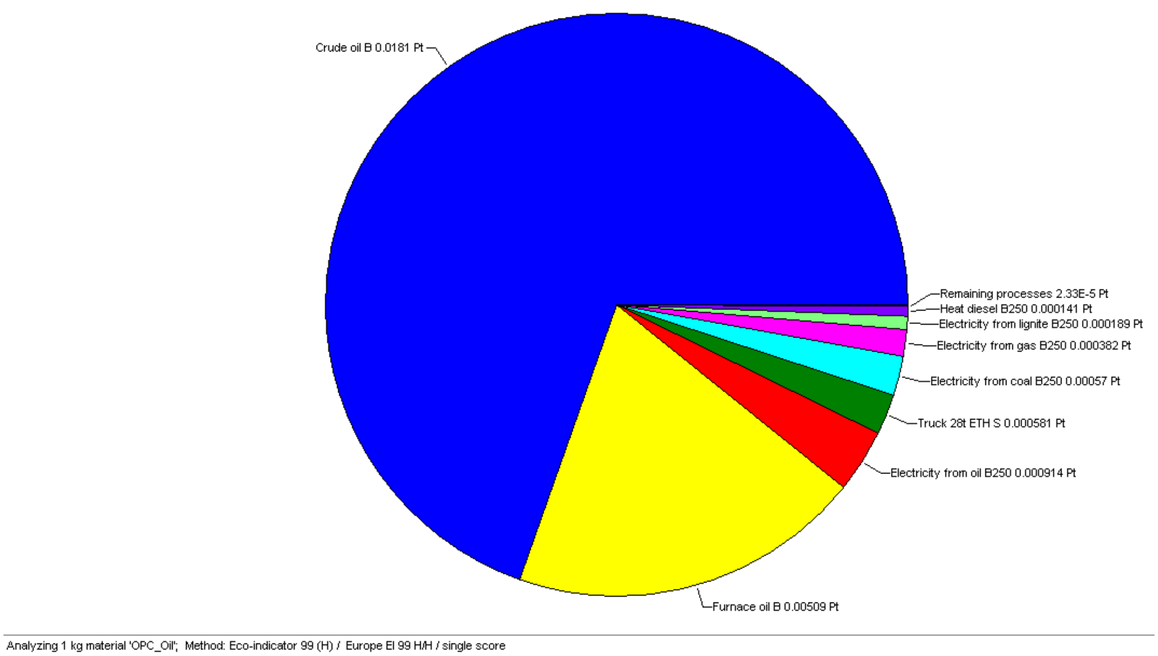



**Figure 6.8 Output for cement oil fuel model compared to the three scenarios**

The result shown in figure 6.8 indicate crude oil is the dominant of the process

**The cement gas fuel model using single score (Airborne emissions)**

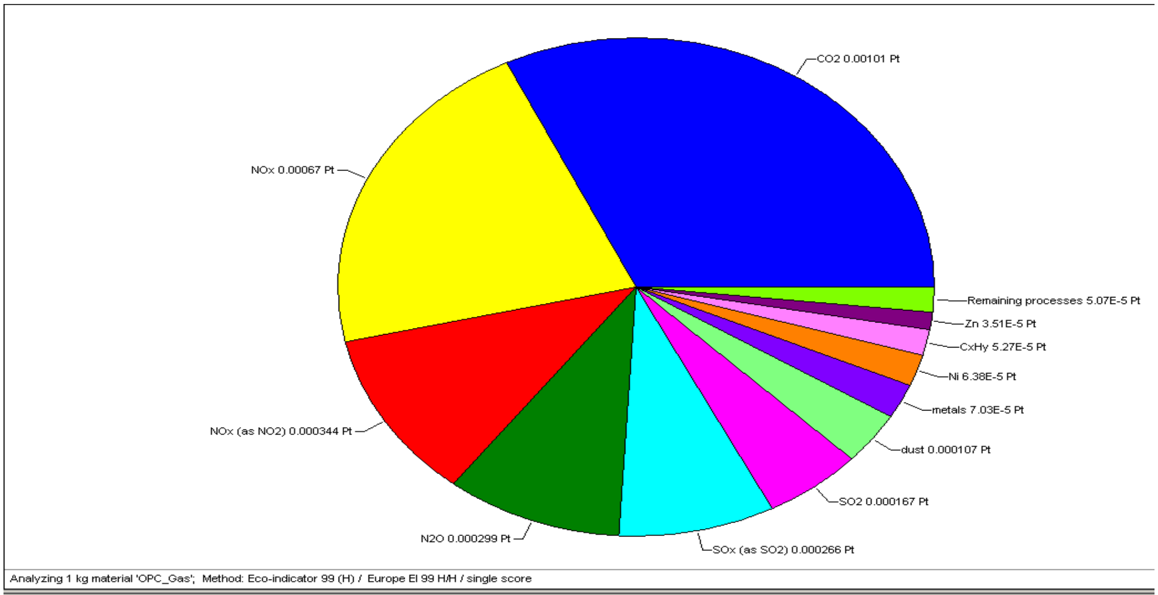



**Figure 6.9 Cement gas fuel model using single score (Airborne emissions)**

The result shown in figure 6.9 indicate sulfur oxide, nitrogen oxide and carbon dioxide is the dominant of air emission

**The cement gas fuel using single score (compare processes)**

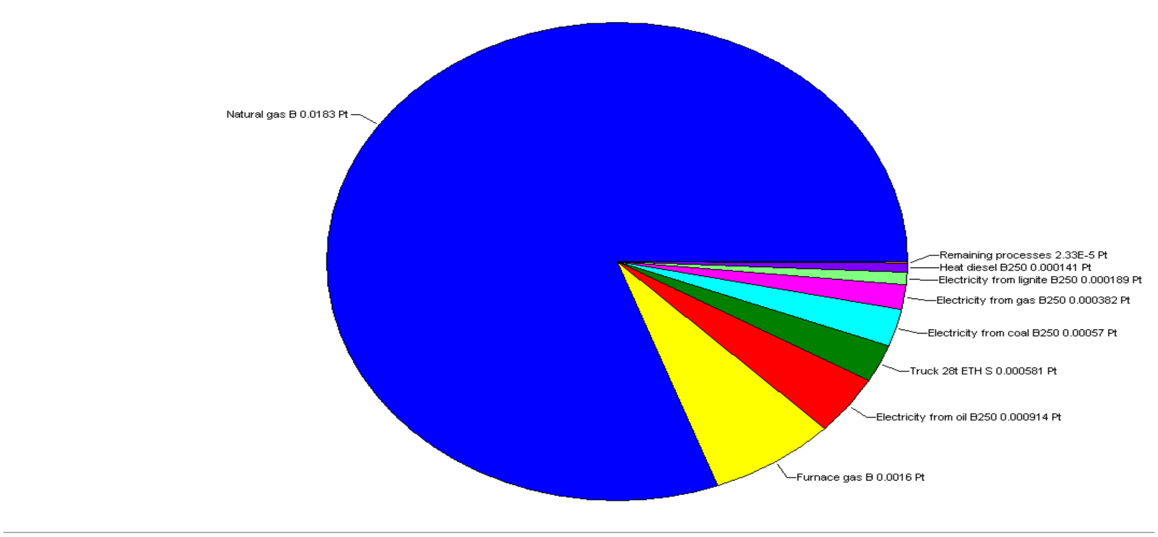



**Figure 6.10 Output for cement gas fuel compared to the three scenarios**

The result above indicate the Natural gas is the dominant of the process

# ***Chapter 7***

## 7.0 Conclusion

Life Cycle Assessment is very important in creating a sustainable environment in the future. The Life Cycle Assessment project of Redevelopment Civic Centre shows a building can serve the community well with minimum impact to the environment. It is one of the many successful projects of Life Cycle Assessment. The Life Cycle Assessment is not limited to building materials only it can be use for most of product or processes. This project has selected cement to conduct Life Cycle Assessment. Cement production is one major contributor of carbon dioxide emission in the world.

The outline of Life Cycle Assessment to analyse the cement production to the environment is produced. The result obtained from SimaPro software in phase 3 of Life Cycle Assessment shown that the clinker has the greatest impact to the environment among other processes. Two alternative options had been interpreted in phase 4 of Life Cycle Assessment. Option one is to comparing existing coal fuel with oil fuel and gas fuel. Option number two is to reduce the percentage of clinker in cement. Option one showed the existing coal fuel has the lowest impact. In reducing the percentage of clinker in option two showed a positive result of lower environmental impact.

Although Life Cycle Assessment is a very useful but there is also some limitation encountered during the project. These limitations are:

1. Electricity used in the office building premises and South East Asia
2. Transportation impact of purchased coal and gypsum
3. The specific type of oil fuel and gas fuel in the data.
4. Purchased coal from Kalimantan, Indonesia is excluded from the study
5. Purchased gypsum transport from Thailand is excluded from the study
6. No available option or similar option of waste treatment for cement to perform cradle to grave analysis.

## 7.1 Recommendations

In the phase 4 of Life Cycle Assessment two options had discussed for a possible improvement in cement manufacturing processes. A few recommendations had been made as follow for a possible improvement for the whole system.

As stated in the result the high amount emission of gas in the clinker is the major impact of the whole processes. One of the reasons of high emission is due to the type of fuel used for burning. The comparison between coal fuel, gas fuel and oil fuel shows that the coal fuel is the ideal type of fuel. One of the recommendations is to use waste materials in cement kilns as a fuel supplement. By doing this it can substantially reduce the usage of the primary fuel for burning. The recommended waste materials can be as follows:

1. Car and truck tires; steel belts are easily tolerated in the kilns,
2. Waste solvents and lubricants.,
3. Hazardous waste; cement kilns completely destroy hazardous organic compounds,
4. Bone meal; slaughter house waste,
5. Waste plastics,
6. Sewage sludge,
7. Rice shells,
8. Sugar cane waste.

It is also recommended to reduce the usage of clinker in producing cement. The mixture with some industrial waste is highly recommended. Portland cement manufacture has the potential to remove industrial byproducts from the waste-stream, effectively sequestering some environmentally damaging wastes. These include:

1. Slag
2. Fly ash (from power plant)
3. Silica fume (from steel mills)
4. Synthetic gypsum (From desulphurisation)

Raw materials transportation from the production site to the manufacturing site is also contributing to the environmental impact. The usage of fuel efficient trucks will reduce the usage of fuel and resulting in less environmental impact. It is also recommended to purchase raw materials from somewhere nearest to the manufacturing site to reduce the transportation impact.Advancement of technology in the future may able to invent a more environment friendly materials in replace of the cement or a more environment friendly kiln is invented for the cement plant.

The above recommendations may substantially improve the overall impact of the cement production to the environment.

## 7.2 Future work

The Life Cycle Assessment is very useful and effective as shown in the Redevelopment Civic Center. The only thing is concerned is the various kind of Life Cycle Assessment software tools. Standardization is needed among the tools as it is very important for the Life Cycle Assessment development in the future. ISO (the International Organization for Standardization) is a world wide private organization, including national bodies from both industrialized and developing countries, which aims to standardize a wide range of products and activities. Therefore the future development of Life Cycle Assessment should base on the ISO standard.

For cement production, promoting the usage of blended cement such as fly ash from coal-fired power stations, blast furnace slag from iron production, or other materials are inter-ground with clinker as it can reduce both fuel-related and process-related emissions. In the future it can achieve balance in economic prosperity, social responsibility and environmental stewardship in the future.

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# *Appendix A*

University of Southern Queensland

FACULTY OF ENGINEERING AND SURVEYING

**ENG 4111/4112 Research Project**

**PROJECT SPECIFICATION**

FOR: Ong Chin How

TOPIC: Environmental Life Cycle Analysis of Construction Material (Cement)

SUPERVISORS: Dr Guangnan Chen

SPONSORSHIP: Cemex, Malaysia

PROJECT AIM: The project aims to produce an outline of the Life Cycle Assessment to analyse the impact of the cement production to the environment in Malaysia.

**PROGRAMME:**

1. Review previous studies of Life Cycle Assessment on cement production
2. Research the Life Cycle Assessment methodology and the software used for the project research.
3. Collect and analyze the data collected for the Life Cycle Assessment.
4. Set up a basic model to characterize the environmental impact of cement production to the environmental. The model should include the environmental loads from the transport, materials for production, and the production processes. The model should also produce sensible results in comparison with other studies.

***As time permits:***

5. Carry out model sensitivity analyses and compare the whole-of-life environmental performance of alternative types of construction materials
6. Identify and evaluate the opportunities for further improvements.

AGREED

_________________ (Student) __________________, ________________(Supervisors)

___/___/___ ___/___/___ ___/___/___