Portland cement: an application of life cycle assessment

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Abstract: This paper presents an application of the Life Cycle Assessment – LCA, which is an evaluative tool of the environmental impacts generated throughout the life cycle of a product and its results. The analysis shows that during the life cycle of Portland Cement; the industrial process harms to the environment, where the greenhouse effect, which is caused by the combustion of fossil fuels, was highlighted; there is air contamination by heavy metals due to the mining activities; and smog caused by the emissions of particulate matter. The current production and consumption model is an example of a situation that, in the near future, could culminate with the end of natural resources and a complete change in the world's environment. This situation can be avoided associating conscientious consumption and sustainable production. In order to modify the production system and its products, it is necessary to identify the most harmful production steps to the environment.

Keywords: life cycle assessment, Portland cement, environment aware, productive system.

1. Introduction

The world economic model of mass production and goods consumption is growing by the inclusion of the BRICs, especially Brazil, India and China, but also Thailand, South Africa, Turkey and others consumers in the global market. The search for technological development and economic growing are providing the generation of less durable goods and a market that strives to meet this demand without restrictions. This causes a cost that mainly includes the extinction of natural resources and environmental degradation. Such a situation thus requires modifications in the relationship between the industrial society and the nature before the occurrence of irreversible damages. Sustainable development constitutes a proposal that seeks to changes in the production system, supplying the needs of society and ensuring the preservation of natural resources (RODRIGUES; ALMEIDA, 2007). A change in the production system requires its analysis, highlighting the production steps that generate the greatest environmental impacts, followed by the recast these steps. The LCA (life cycle assessment) is one of the main methods used to evaluate the environmental impacts caused by industrial products.

1.1. Life cycle assessment history

Studies involving the life cycle of products were launched in the U.S. in the last century seventies. However, the environmental issue was taken as a priority only in the mid eighties which caused discussions about the level of environmental degradation generated in certain products manufacturing process. Consequently, several methods were proposed for measuring environmental impacts. The Society of Environmental Toxicology and Chemistry (SETAC) is the major institution responsible to develop these techniques. A remarkable growth in this area has been observed in the nineties, mainly in the U.S. and Europe. Since then, the terms "Life Cycle Analysis" and "Life Cycle Assessment" (LCA) have been extensively used.

The fact that the environmental impacts generated by economic and industrial society were seen as a growing problem, the ISO - International Organization for Standardization with the support of SETAC - Society of Environmental Toxicology and Chemistry created the Technical Committee TC 207 with the objective of developing standards involving environmental issues. This effort generated the ISO 14000 series with a mission to establish a standardization of processes that use natural resources or with high potential to generate any environmental damage. Nowadays, there is a new version (ISO 14040:26) including three subcommittees or Working Groups (Cycle assessment, Eco-efficiency assessment and Water footprint). The ISO 14040:2006 describes the principles and framework for life cycle assessment (LCA) including: definition of the goal and scope of the LCA, the life cycle inventory analysis (LCI) phase, the life cycle impact assessment (LCIA) phase, the life cycle interpretation phase, reporting and critical review of the LCA, limitations of the LCA, the relationship between the

LCA phases, and conditions for use of value choices and optional elements (INTERNATIONAL..., 2006).

1.2. Description of life cycle analysis

The analysis of the product life cycle evaluates the interaction between the "product life", from raw material extraction to final product disposal, and the environment, trying to characterize the impacts imposed to the environment. In a LCA study on a product, process or service, all extractions of resources and emissions from/to the environment are determined, when possible, in quantitative values throughout the life cycle from "cradle to grave". The LCA analysis has to be based on these data and evaluates the potential impacts on natural resources, environment and human health (FERREIRA, 2004). Figure 1 illustrates the stages of the life cycle of a product, highlighting the possible inputs and outputs involved in the system.

1.3. Phases of LCA

According to ISO 14040 (ASSOCIAÇÃO..., 2001) the LCA is composed of the following steps:

a) ISO 14040: Principles and structure;
b) ISO 14041: Definitions and scope of the inventory analysis;
c) ISO 14042: Measurement the impact of life cycle;
d) ISO 14043: Interpretation of the life cycle.

In the stage (a) "Principles and Structure" it should be clearly described the purpose of the study containing justifications, its scope and its functional unit. In step (b) "Definitions and Scope of the Inventory Analysis" the product has to be characterized, its manufacturing process described and included the inputs used in their manufacture and also the technologies involved. Certain systems and their boundaries delimiting the steps in the productive process have to be defined and included in the study. The systems are divided into subsystems interconnected by flows of materials, energy and environmental discharges. The data included in this study are placed according to the functional unit that provides a reference input-output system. The aspects and environmental impact categories adopted in the study are established in the final stage of scoping. The environmental aspects are associated with the natural resources consumption, secondary materials and energy and the emission of waste, vibration, radiation, odour and liquid effluents (VALT, 2004). The inventory analysis constitutes the collection and quantification of the data or variables involved in the system. This step determines the material flow, i.e., the inputs and outputs of materials into the system. Thus, the quality of work varies according to data quality.

The step (c) "Measurement the Impact of Life cycle" determines the extension to which environmental issues generated during the life cycle of the product affect the environment. Then, the data are sorted and grouped according to specific categories and are assigned values according with a scale of importance as defined previously. There is no consensus on the allocation of values or weights to the environmental impacts. The last phase of the LCA is the (d) "Interpretation of the Life cycle" stage, when the results obtained in previous phases are evaluated according to the objectives proposed at the beginning of the analysis. According to the ISO14043 this phase defines a systematic procedure to identify, qualify, check and evaluate the information, the results of the inventory life cycle inventory and assessment of the life cycle, facilitating the interpretation of the life cycle to create a base where the conclusions and recommendations are embodied in the Final Report.

The Life Cycle Analysis gives support to decision of manufacturing processes and materials or choice of considering the impacts to the environment. Provides an overview of the real manufacturing impact of the product and also determines the critical stages of production that provide high environmental discharge or consume large amounts of natural resources. Thus LCA allows the comparison between two products or processes and it assess the best option. Moreover, the product Life Cycle Analysis requires resources and time so that certain studies become practically unfeasible varying its application according to

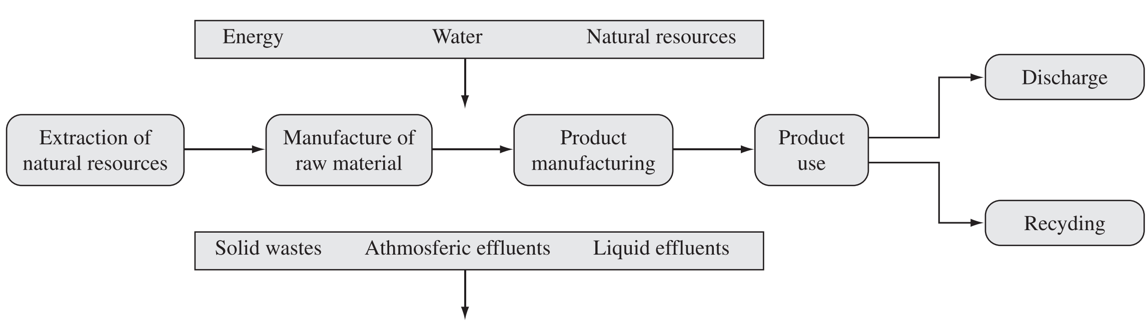

Figure 1. Stages of life cycle and possible entries and exits in the system.

the cost benefit analysis of each. Moreover, LCA serves as decision support, because it can help to determine which is the best product or process and the associated costs.

1.4. Researches involving LCA in the cement industry.

Various studies using the LCA methodology have been developed in the context of the cement industry (HUNTZINGER; EATMON, 2008; JOSA et al., 2007; NAVIA et al., 2006, LEE; PARK, 2004). Eatmon and Huntzinger (2008) evaluated the environmental impacts of four different configurations of process using LCA methodology: (1) the conventional process for production of cement, (2) cement blends (natural pozzolans), (3) where 100% of the cement powder residual furnace was recycled and re-entered the process and (4) Portland cement produced when the particulate material from the furnace was used to remove a portion of the CO_2 emitted. The studies and research using the LCA enable a comprehensive analysis of the process and quantifying the impacts associated with the process, focusing from the use of natural resources by the end of life of cement products. However, the results can not be extrapolated from one area to another, and each co-processed waste must be studied, since their physical and chemical characteristics may alter the results.

Due to the large impact generated by the cement life cycle, studies have been conducted in order to mitigate them. In Brazil, studies show that the use of agricultural residues can decrease the use of cement and thus reduce the emission of CO_2. The ashes of sugarcane bagasse, rice hulls and residues of the ceramic industry are entering candidates for the preparation of concrete and decrease the presence of the cement in the preparation of this product. Moreover, the Brazilian ceramic industry produces about 5 to 6 million tons of waste in the production of tiles, bricks and floors. This material, after calcination and grinding, can replace up to 20% of total cement (SETOR RECICLAGEM, 2009). Another way to mitigate the environmental impact is the use of slag as aggregate for cement. Zordan (1997) report the rubble use for paving urban roads and closing graves.

2. Case study

2.1. Principles and structure

Portland cement is one of the essential raw materials of modern society. It is part of our life and is present in virtually all buildings developed by man. It is difficult to imagine the society without the use of cement in a view of the dimensions of its application. Based on the importance of cement for society as well as the impact to the environment during its production cycle, this product was chosen as LCA case study.

Cement is the main material used in construction as binding. It is a ceramic material that, in contact with water, undergoes an exothermic reaction due to crystallization of hydrated products and thereby gaining strength. Cement is the final product of clinker grinding and receives additions of gypsum, slag, clay and limestone. In the present work 1 (one) tonne of product or twenty bags of 50 kg of cement was adopted as reference value for the LCA of Cement production.

2.2. Definitions and scope of the inventory analysis

The Portland cement life cycle is presented in the block diagram (Figure 2), since the raw materials extraction from nature until its final disposal.

2.3. Portland cement life cycle

2.3.1 Manufacturing

The Portland cement manufacturing process starts with the extraction of limestone and clay deposits which in Brazil is generally carried out in open pit mines. The

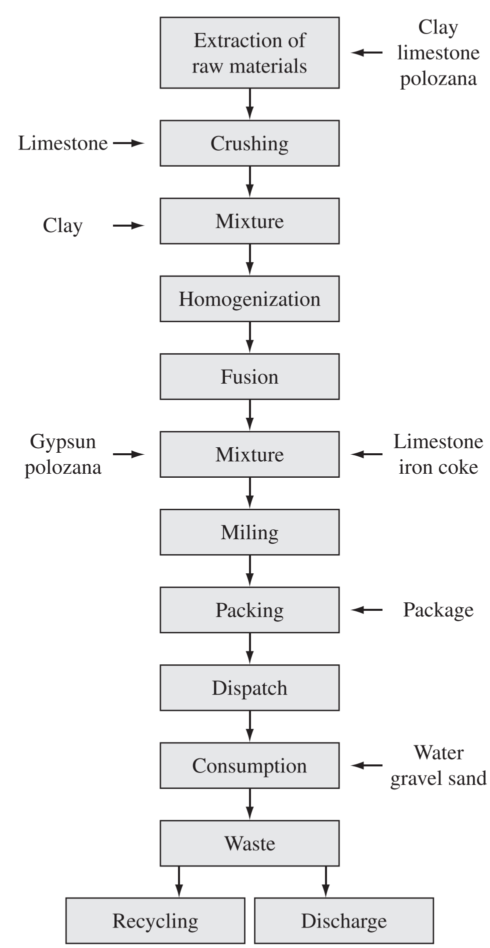

Figure 2. Schematic Flow chart of cement life cycle.

mined limestone is crushed to acquire an appropriate size for the industrial process. The clay particle size has become quite adequate and does not require further comminution step. The limestone and clay are stored separately, sampled to undergo quality tests and sent later for the stage of pre-homogenization. A mixture of 90% limestone and 10% clay is prepared and fed to the raw mill, to obtain a product of average size equal to 0.050 mm. The mixture (called flour) passes through a process of homogenization and goes to the furnace. The flour is introduced into the furnace after to be pre-heated with the combustion gases which promote its initial heating. In the furnace flour suffers decarbonation reactions being further melted, and consequently the clinker is generated due to various reactions in liquid phase. After cooling, dark pellets are formed. The temperature is decreased to 80 °C in order to complete the step of clinker formation that determines the cement characteristics. Additives such as gypsum, blast furnace slag, pozzolana, and limestone are added to the clinker, giving origin to Portland cement type. The mixture is dry milled in ball mills resulting into cement. The cement is stored, analyzed, and goes to the step of packaging and shipping (ASSOCIAÇÃO..., 2009).

2.3.2 Transportation

The transport of raw materials and also of the finished product is made, mostly in Brazil, by roads, using diesel trucks, allowing the emission of CO_2 to the atmosphere and contributing to the greenhouse effect.

2.3.3 Use

During its use and handling, in the civil construction sector, there are still emissions of particulate matter which may cause respiratory problems, skin and eye irritations in the workers.

2.3.4 Disposal / end of life

At the end of life of the cement, when it is already incorporated into the bricks, mortar and other materials, it is discharged in the form of debris in landfills or unsuitable sites. A part of this material has been used for paving roads and ditches covering. The debris can also be reprocessed and used as aggregate for cement.

2.4. Data presentation

Table 1 presents data from a study in the cement industry in the United States. The data were estimated considering a production rate of one ton of cement. The energy sources considered in this study are coal used (70%), fuel oil (15%), and natural gas (15%). These figures may vary according to the procedure used.

3. Impact assessment of life cycle

3.1. Assessment of environmental impacts according to the Eco-indicator 95 method

One of the methods used to evaluate the results obtained by LCA is the adoption of environmental impact categories like global warming, eutrophication, acidification, photochemical effect and others. This method, called Eco-indicator 95, quantifies the environmental performance associated with the product or process throughout its life cycle. The evaluation is carried out by multiplying each data normalized by a weighting factor determined according to the damage that each category of impact can cause to the environment. This method allows the comparison between the life cycle of products or processes that meet similar situations, quantifying its environmental impact. Table 2 shows weight factors considered for the impact categories and adopted in the method Eco-indicator 95.

3.2. Overview of environmental impacts between categories and their contributing agents

Global warming is the result of the greenhouse effect, a process that occurs when part of the solar radiation

Table 1. Emissions and energy inventory in the cement manufacturing process (Adapted from HUNTZINGER and EATMON, 2008).

Energy and emission inventory elements for the traditional cement manufacturing process. The energy inputs and emissions are divided among the three major processing steps.		
Crushing, grinding, and blending	**Unit**	**Input or emission**
Energy (electricity)		
Coal	GJ	0.224
Fuel oil	GJ	0.048
Natural gas	GJ	0.048
Emissions		
Particulate matter	lbs	0.011
Preheating and kiln		
Energy (heat)		
Coal	GJ	3.230
Fuel oil	GJ	0.693
Natural gas	GJ	0.693
Emissions		
Particulate matter	kg	0.02
Carbon dioxide (process related)	ton	0.51
Cement kiln dust	ton	0.10
Finish grinding and blending		
Energy (electricity)		
Coal	GJ	0.322
Fuel oil	GJ	0.069
Natural gas	GJ	0.069
Emissions		
Particulate matter	lbs	0.012

Table 2. Factors valuation method in accordance with the Eco-indicator 95.

Method Eco-indicator 95	
Environmental impact category	**Weighting factor**
Greenhouse effect	2.5
Acidification	10
Eutrophication	5
Smog	5
Heavy metals	5
Carcinogenic substances	10

Adapted from Goedkoop (1995).

reflected by the Earth's surface is absorbed by certain gases in the atmosphere. As a result, the heat is retained, not being released into space. The increased greenhouse effect is caused by the emission of gases such as carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), CFCs (CF_xCl_x) into the atmosphere. The smog is a phenomenon characterized as the mixture of gases, smoke and water vapour form a large mass of air. This is produced by nitrogen oxides (NO_x), volatile organic compounds (VOC), sulphur dioxide, acid aerosols and gases. The effect is caused by photochemical reaction between the volatile organic compounds (VOC´s) and other substances in the atmosphere, producing compounds that are photochemical oxidants. As a result, an increasing in respiratory diseases has been observed in the world. Another environmental phenomenon, Eutrophication, occurs due to excessive nutrient enrichment of collections of water followed by the degradation of aquatic systems, usually driven directly or indirectly by human activities. Among the main substances responsible for water eutrophication are nitrogen (N), phosphorus (P), ammonia (NH_3), nitrogen compounds, phosphates, oxides of nitrogen (NO_x), oils and fats. On the other hand, Acidification is the increased acidity of the medium resulted resulting from the volatilization of compounds such as sulphur dioxide (SO_2) and nitrogen oxides (NO_x) that are dissolved in rainwater, combining with other elements to form acids. When the acids, reach the earth surface, the chemical composition of soil and water is altered which causes damages to metal structures and buildings. Another impact, due to heavy metal contamination is measured by the maximum permissible concentration of substances or materials multiplied by the issue thereof. The carcinogenicity is the increased presence of substances classified as carcinogens in the environment.

4. Environmental impacts generated during the Portland cement life cycle

Cement process production can generate local environmental impacts such as noise, reduced air quality, changes in the local ecosystem due to extraction of raw materials such as clay, limestone, and others. Regionally it can cause acid rain due to emission of sulphur dioxide (SO_2) and nitrogen oxides (NO_x) among others. Already the burning of fossil fuels like oil, coal and natural gas may cause climate changes worldwide. According to the International Energy Agency (IEA) cement production generates a global average CO_2 emission of 0.81 $kg.kg^{-1}$ of cement produced. On average, about one ton of concrete is produced each year for all human beings around the world.

It is estimated that about 5% of global CO_2 emissions come from the manufacture of cement. Besides the generation of CO_2 in the process of manufacturing cement, are produced millions of tons of waste (particulate matter from the cement kiln) each year that contribute to pollution and respiratory health risks. The calcination process of obtaining CaO from $CaCO_3$ generates CO_2 and contributes to about half the CO_2 emitted, while the rest comes from energy consumption during the production process.

According to Santi and Seva (2004) due to the characteristics of the technological process and the physico-chemical and toxicological properties of raw materials and inputs used in the cement manufacturing, clinker and cement itself, the cement plants cause a risk to the health of workers, public health and the environment. They are mainly associated with exposure to particulate matter that permeates the entire chain of production and emissions of pollutants that occur continuously and that even in small concentrations, characterizing the chronic risk.

It can be observed in Table 1 that all stages of cement manufacturing generate impacts to the environment. It is also noted that much of the energy used in the process focuses on the step of using kilns and the consequent emission of particulate matter into air. During the raw material extraction environmental impacts arise as the removal of vegetation for the local mining activity and a possible contamination of groundwater due to particulate matter generated in the extraction, among others. During the crushing, grinding and mixing, as well as virtually the entire manufacturing process is the emission of particulate matter and volatile substances to the desktop and into the atmosphere can cause several health problems.

In the stage of using the kiln or fusion step is consuming more energy and therefore has the greatest environmental impact. This is due not only to the burning of fossil fuel that releases heavy metals as well as CO_2 and SO_2, but also by the calcination process. Additionally it small size solid particles are emitted to the environment (cement kiln dust). Due to its caustic nature dust may cause irritation to skin, eyes, and cause respiratory problems. After the blending step, the emission of particulate matter in the mixing, grinding, packaging and shipping steps has also to be taken into account. The stage also provides the use of solid waste issue.

Table 3. Impact values generated in the manufacture of cement according to Eco-indicator 95 method.

Environmental impact by category (Method Eco-indicator 95)	
Greenhouse effect	0.088
Acidification	0.043
Eutrophication	0.006
Heavy metals	0.204
Carcinogenic substances	0.003
Smog	0.039

Considering the life of the cement in the construction industry (or in the building life), in general, there are no particulate emissions, greenhouse gases or pollutants. However, its disposal in the form of debris constitutes the most important problem. With the rise in cities and a reduced useful life of buildings, the generation of debris has become increasingly larger and often complex, since it has been done improperly. Thus, vacant city areas have served as places to dispose those wastes, causing visual pollution, population growth and spread of insect infection.

Finally, Table 3 presents the results obtained through the use of Eco-indicator 95 method. The values obtained during the manufacturing process of cement by this method shows that actually the cement manufacturing process contributes to harm to the environment where it is highlighted the greenhouse effect, caused by burning fossil fuels, pollution by heavy metals due to mining activities and smog caused by emissions of particulate matter. However, it is important to consider that this material is essential for the expansion of development. So, the environmental impacts have to be minimized by environmental efficient processes, materials recycling, atmospheric effluent treatment and also the recovery of depredated mining areas, with reforestation.

5. References

ASSOCIAÇÃO BRASILEIRA DE CIMENTO PORTLAND – ABCP. **Portal**. Disponível em: <http://www.abcp.org.br/home.shtml> Acesso em: mar. 2009.

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS – ABNT. **NBR ISO 14040**. Gestão Ambiental - Avaliação do ciclo de vida - Princípios e estrutura. São Paulo: ABNT, 2001. 10p.

FERREIRA, J. V. R. **Gestão Ambiental** - Análise do ciclo de vida dos produtos. Viseu: Instituto Politécnico de Viseu - ESTV/IPV, 2004.

GOEDKOOP, M. **Eco-indicador 95**. Printerweg, The Netherlands: Pré Consultants, 1995. Disponível em: <http://www.pre.nl/eco-indicator95/eco-indicator95.htm#100scores>.

HUNTZINGER, D. N.; EATMON, T. D. A life-cycle assessment of Portland cement manufacturing: comparing the traditional process with alternative technologies. **Journal of Cleaner Production**, p. 1-8, 2009.

INTERNATIONAL ORGANIZATION FOR STANDARDIZATION - ISO. **ISO 14040:2006** - Environmental management - Life cycle Assessment - Principles and framework. ISO, 2006. Disponível em: <http://www.iso.org/iso/catalogue_detail?csnumber=37456>. Acesso em: 25 jul. 2010.

JOSA, A. et al. Comparative analysis of the life cycle impact assessment of available cement inventories in the EU. **Cement and Concrete Research**, v. 3, p. 781-788, 2007.

LEE, K-M.; PARK, P-J. Estimation of the environmental credit for the recycling of granulated blast furnace slag on LCA. **Resources, Conservation and Recycling**, v. 44, p. 139-151, 2005.

NAVIA, B. et al. Recycling contaminated soil as alternative raw material in cement facilities: life cycle assessment. **Resources Conservation and Recycling**, v. 48, p. 339-356, 2006.

RODRIGUES, A. J. M.; ALMEIDA, C. M. V. B. A contabilidade ambiental na metodologia do ecodesign: utilizando a emergia como uma medida quantitativa de avaliação de carga ambiental. O caso das embalagens PET. In: CONFERÊNCIA PAULISTA DE PRODUÇÃO MAIS LIMPA, 4., 2007, São Paulo. **Anais**...

SANTI, A. M. M.; SEVÁ FILHO, A. O. Combustíveis e riscos ambientais na fabricação de cimento; casos na Região do Calcário ao Norte de Belo Horizonte e possíveis generalizações. In: ENCONTRO NACIONAL DE PÓS-GRADUAÇÃO E PESQUISA EM AMBIENTE E SOCIEDADE – ANPPAS, 2., 2004, Campinas. **Anais**...

SETOR RECICLAGEM. **Portal.** Disponível em: <http://www.setorreciclagem.com.br/modules.php?name=NewsANDfile=printANDsid=665>. Acesso em: mar. 2009.

VALT, R. B. G. **Análise do ciclo de vida de embalagens pet, de alumínio e de vidro para refrigerantes no Brasil variando a taxa de reciclagem dos materiais**. 2004. 193 f. Dissertação (Mestrado em Engenharia)-Universidade Federal do Paraná, Curitiba, 2004.

ZORDAN, S. E. **A utilização do entulho como agregado na confecção do concreto**. 1997. 140 f. Dissertação (Mestrado em Engenharia Civil)-Universidade Estadual de Campinas, Capminas, 1997.