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PROCESS MAPPING AND PRELIMINARY ASSESSMENT OF LIFE CYCLE IMPACT IN INDIAN CEMENT PLANTS

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Abstract
The Indian cement industry is the second largest in the world with an annual production of about 280 million tonnes. Though the environmental impact is significant, little has been done on process mapping, and associated accounting of the energy consumption and emissions in the cement plants. The salient features of cement production in India that distinguish it from other scenarios are highlighted. The present work proposes a framework and sets guidelines for the life cycle assessment. The computing of the energy requirement and CO_2 emissions is done for a typical cement plant considering ordinary portland cement (OPC) and fly ash based portland pozzolana cement (PPC). The values obtained indicate that the impacts could be much lower than those computed in other countries.

Keywords:
Life cycle assessment; cement; sustainability; energy; carbon dioxide emission

1 INTRODUCTION

With an annual production of about 280 million tonnes and about 200 large cement plants (with more than a million tonne capacity each), India is the second largest cement producer in the world. Assessment of the current scenario leads to the reasonable assumption that over the medium and long term, there will be an increasing trend in both cement and concrete usage. This is also reflected in the report of the Working Group on Cement Industry constituted by the Government of India, which expects cement consumption to increase at the rate of about 10%, and the installed cement production capacity to exceed 1000 million tonnes by 2027 [1]. Such predictions are based on the fact that per capita cement consumption in India is about 180 kg whereas it surpassed 1 tonne/capita in China during the development boom [2]. The major usage of cement in India is in infrastructure projects (about 20%), public buildings (about 18%) and housing (about 42%) [2], the demand for all of which will continue to increase over the next few decades. In addition, the cement usage in road construction, which is currently low, is expected to become significant in the future [2].

Most of the cement production is in integrated plants that produce clinker as well as cement though there are many grinding units that procure clinker to produce cement for supply in bulk or in bags. Due to logistic reasons, clinker production is primarily concentrated in four geographic clusters, where limestone is in abundance. These plants generally operate limestone mines under licence from the government. Some plants are also located near coal belts to reduce fuel transportation costs; 15-20% of the cost of cement production is attributed to coal, electricity and freight [1].

The energy consumption per tonne of cement has decreased over the years, not only due to more efficient and leaner production but mainly due to the increase in fly ash based portland pozzolana cement, which now accounts for about 67% of the total production, and blast furnace slag based portland slag cement, which accounts for about 8% [2].

The present study focuses on process mapping, and the energy and CO_2 emission assessment for cement production in India based on plant data. The peculiarities of the Indian cement sector are highlighted, and the need for assessing different systems are emphasized.

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2 LIFE CYCLE ASSESSMENT (LCA)

2.1 Goal and Scope

The goal of the LCA here is to assess the energy required and CO_2 emissions from production of cement. Based on the limitations of the data available and discussions with industry representatives, 3 sets of system boundaries have been considered: Ground-to-gate, Gate-to-gate and that conforming to the Cement Sustainability Initiative (CSI). An unambiguous explanation of the processes considered for each system is as follows.

(i) Ground-to-Gate (Cradle-to-Gate) System

This system considers all impacts from the mines to the (exit) gate of the cement plant; energy requirements and CO_2 emissions (direct and indirect) from all processes involved in the production of cement are accounted for, including the extraction and transportation of all fuels & raw materials, and the production of electricity. However, energy and emissions from the production of alternative fuel and fly ash consumed are excluded. This system gives a complete (though rather academic) assessment, and is in accordance with most scientific literature. Nevertheless, most assumptions made and conversions are not relevant to Indian conditions and materials, which distort the results considerably.

(ii) Gate-to-Gate System

Only processes attributed directly to the cement plant are considered in this system. All raw material and energy required, and emissions are considered from all processes within the plant, including the extraction and transportation of limestone and the production of electricity. The extraction and transportation of fuel are excluded. This system provides data for reliable comparisons with that compiled by the industry, and avoids assumptions that are not relevant to local conditions.

(iii) CSI System

This system considers only operations that occur within the perimeter of the cement plant. It includes the energy required and CO_2 emissions related to the limestone extraction, and the use of fuels within the cement plant. However, the extraction of raw materials and transportation outside the plant, the electricity production (both on site and purchased) and impacts of alternative (biomass and waste) fuels are excluded. This system facilitates comparison with Indian cement industry data and the CSI database [3]. The values are based on measurable quantities at the plant level, and no assumption is made that is irrelevant to local conditions. This is needed not only to assess the impacts of existing cements but also to compare the impacts and different alternatives proposed [e.g., 4, 5].

In accordance with the above boundary definitions, Table 1 lists the sub-processes accounted for and excluded in each of the systems, where the columns (i), (ii) and (iii) denote the three systems, respectively.

Sub-process	(i)	(ii)	(iii)
Extraction of limestone	✓	✓	✓
Transportation of limestone	✓	✓	×
Extraction of clay and other materials (bauxite, hematite, ferrite, etc.)	✓	×	×
Transportation of clay, gypsum, fly ash and other materials	✓	×	×
Extraction of fuel	✓	×	×
Transportation of fuel	✓	×	×
Production of electricity	✓	✓	×
Limestone crushing	✓	✓	×
Preparation of raw meal	✓	✓	×
Processing of fuel (for coal mill)	✓	✓	×
Preparation of clinker	✓	✓	✓
Grinding of cement	✓	✓	×
Packing of cement	✓	✓	×
Services (lighting of installations and other facilities, living quarters, etc.)	✓	✓	×

Table 1. System boundaries

2.2 Life Cycle Inventory (LCI)

The second step in LCA is the Life Cycle Inventory Analysis (LCI). There are many inventories that exist for cement, such as the popular ecoinvent 3 database [6], accessible through the SimaPro software [7]. However, existing inventories are heavily dependent on local materials and processes, and are not directly applicable to other geographical regions. Further, the use of existing databases for assessing cement production in India is especially unreliable due to the following:

- The raw material input in the clinker is often dominated by limestone, without much input of other materials such as clay, marl, shale, etc., which are common elsewhere.
- Limestone mines are directly managed by the cement companies and the clinkerization units are located near the mines. Therefore, there is little wastage of limestone since the composition of the raw meal is optimized by mixing different qualities of limestone. Further, transportation between the mines and the plant is minimal.

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- Most Indian clinkerization units use the dry process so the process water [8] and overall water consumptions of cement are low.
- Electricity in India is produced mostly (70% or more) by burning coal. Therefore, the use of electricity does not necessarily lead to lower impact unless it is generated by alternative sources in the plant or elsewhere.
- Phosphogypsum, a waste product from the fertilizer industry, is used to a large extent instead of natural gypsum.
- There is substantial use of industrial waste and biomass as alternative fuels for meeting the thermal energy requirement; in some plants, as much as 10%.

Therefore, it is ideal that an inventory be compiled for typical plants in India so that conclusions regarding the industry can be made more reliably. The process of compiling a thorough inventory is tedious and the data gaps [e.g., 8] may require assumptions to be made that limit the reliability of the database. However, this is not easy or even feasible most of the time. In the present study, the following hierarchy of data sources is proposed to compile the inventory (with reliability or priority reducing in the descending order):

Data sources for energy requirements

- Experimental data – Bomb calorimetry of fuels; Thermogravimetric analysis and differential scanning calorimetry of the raw materials
- Reports of the cement plant, say those made for the CSI assessment [9]
- Environmental Protection Agency (EPA) emission factors for greenhouse gas inventories [10]
- Intergovernmental Panel on Climate Change (IPCC) 2006 guidelines for National Greenhouse Gas Inventories [11]
- The ecoinvent 3 database [6]

Data sources for CO_2 Emissions

- Experimental data – CHNS elemental analysis of the fuel or other chemical analysis to provide carbonate and organic carbon content, and to assess the composition of the organic matter
- EPA Emission factors for greenhouse gas inventories [10]
- The CSI Protocol [9]
- IPCC 2006 Guidelines for National Greenhouse Gas Inventories [11]
- The ecoinvent 3 database [6]

2.3 Life Cycle Impact Assessment (LCIA):

The LCI results are used for the Life Cycle Impact Assessment (LCIA), in the third step in LCA. As mentioned earlier, the energy consumption and global warming are considered as the critical impact categories in this work. The impacts are quantified in terms of the energy consumption (MJ/Tonne of cement) and CO_2 emissions (kg/Tonne of cement), respectively. Here, the impacts of ordinary portland cement (OPC) and fly ash blended portland pozzolana cement (PPC) have been evaluated and compared.

3 CASE STUDY

The region of Ariyalur, Tamil Nadu, India, which has rich limestone deposits, was chosen for a case study. The integrated plant assessed has a leased limestone quarry for its use. Since the limestone is soft in this region, it is extracted by excavation without blasting, and has an average composition with about 44% CaO, 12.5% SiO_2, 10% moisture and 35.5% loss on ignition. For the PPC, it is considered that Class F Fly ash is transported from the Mettur Power Plant (over 200 km), with a composition of 61% SiO_2, 27% Al_2O_3 and 4% Fe_2O_3, and incorporated at 28% by weight of PPC. Phosphogypsum, transported from Tutticorin (385 km), is used in the cement.

Based on detailed site visits and discussions with plant personnel, process maps were developed and relevant available data was collected.

Process maps

The manufacturing of cement can be sub-divided broadly into four major phases, namely the preparation of raw meal (i.e., input for clinkerization), preparation of clinker, production of cement, and packing of cement. Figure 1 shows the process map from extraction of limestone up to the stocking of the raw meal silo. Figure 2 covers the process up to clinker production. Figure 3 gives the process of transforming the clinker to OPC. In the case of PPC, the fly ash is fed into the horizontal ball mill for blending/grinding. Figure 4 shows the process until dispatch (i.e., exit gate of the plant) of the cement in bulk and bags.

Energy and CO_2 emissions

Following the principles outlined in the previous section, the inventories were compiled, and the energy and CO_2 emissions were computed for OPC and PPC fabricated in the same plant. Results for the gate-to-gate and CSI systems are given, respectively, in Tables 2 and 3. The gate-to-gate values indicate that the OPC in this plant requires significantly less energy than those of typical plants elsewhere, for example, the value of 4220 MJ/tonne reported for the US [8]. Similarly, the CO_2 emissions are also lower; 852 kg/tonne has been reported for the US [8]. The CSI compatible data in Table 3 show that the energy and CO_2 values obtained are lower than the gate-to-gate values since some impacts, such as that of energy production with alternative fuels, are excluded. In all cases, PPC gives lower impacts, as expected, since fly ash is not

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attributed with any impact during its production. Note that average values for India, as reported by CSI, in 2012 are 2400 MJ and 580 kg of energy and CO_2 emissions per tonne of cement, corresponding to a clinker factor of 70.5%, which again indicate that the plant considered is relatively more efficient.

Impact/tonne of cement	OPC	PPC
Energy consumed or Embodied energy (MJ)	3760	2940
Emission of CO_2 (kg)	790	600

Table 2: Gate-to-Gate System Output.

Impact/tonne of cement	OPC	PPC
Energy consumed or Embodied energy (MJ)	2585	1935
Emission of CO_2 (kg)	695	520

Table 3: CSI Compatible System Output.

4 CONCLUSIONS

An attempt has been made to perform an appropriate life cycle assessment on cement production in India, in accordance with the guidelines of the ISO 14040 standard. A typical integrated cement plant that produces both OPC and PPC has been assessed as a case study. Generic process maps of cement production have been drafted, and the energy consumption and CO_2 emission have been calculated following a proposed framework. The energy and emission values seem to be comparatively lower than the values reported in the literature for other locations.

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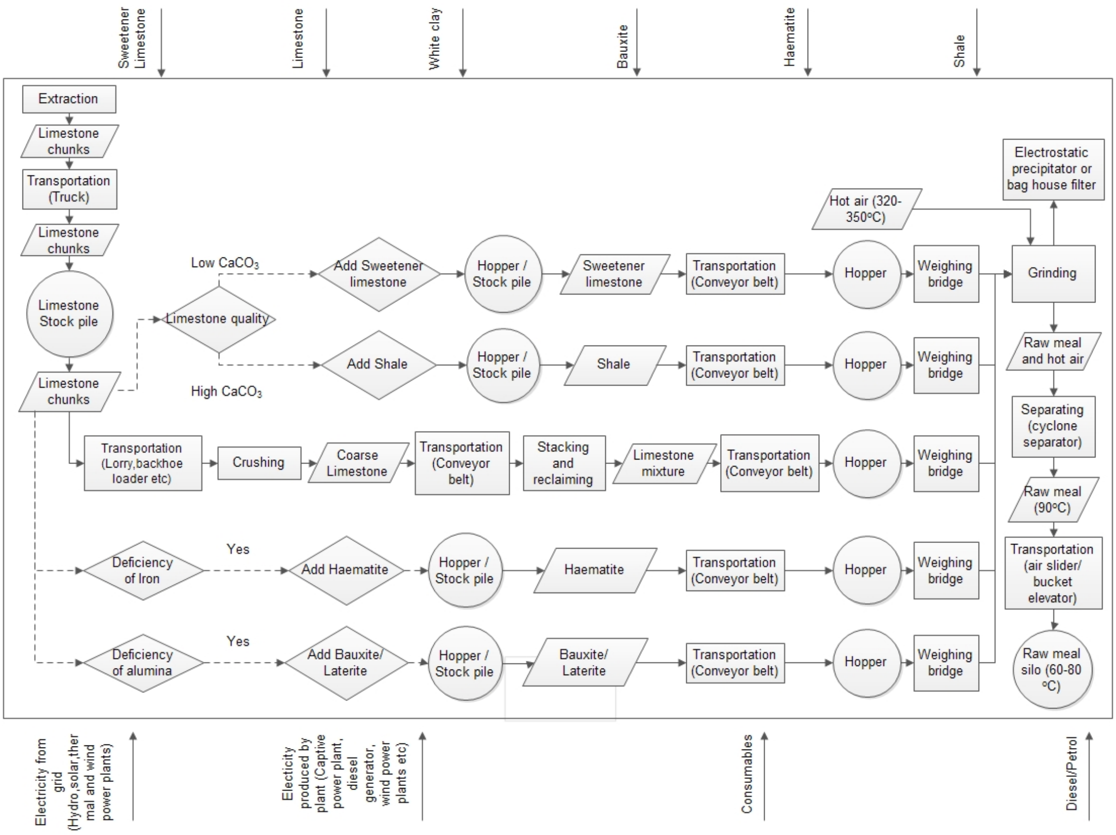

Fig. 1: Preparation of Raw Meal.

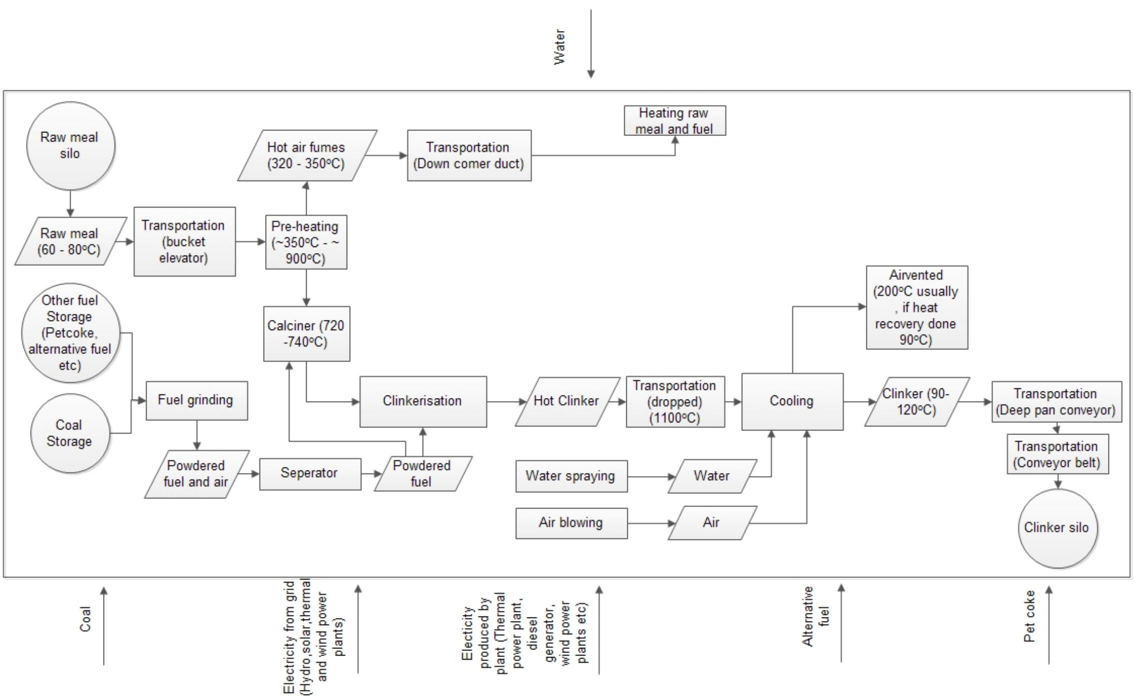

Fig. 2: Production of Clinker.

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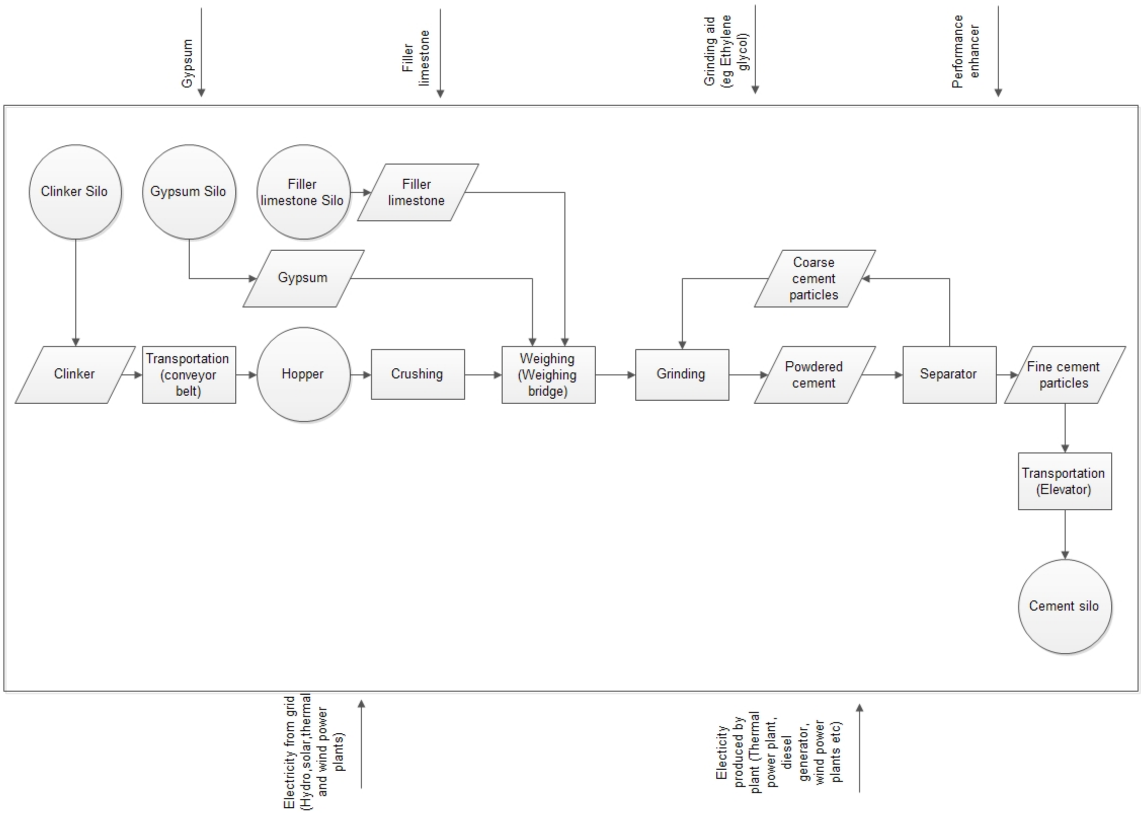

Fig. 3: Production of Ordinary Portland Cement.

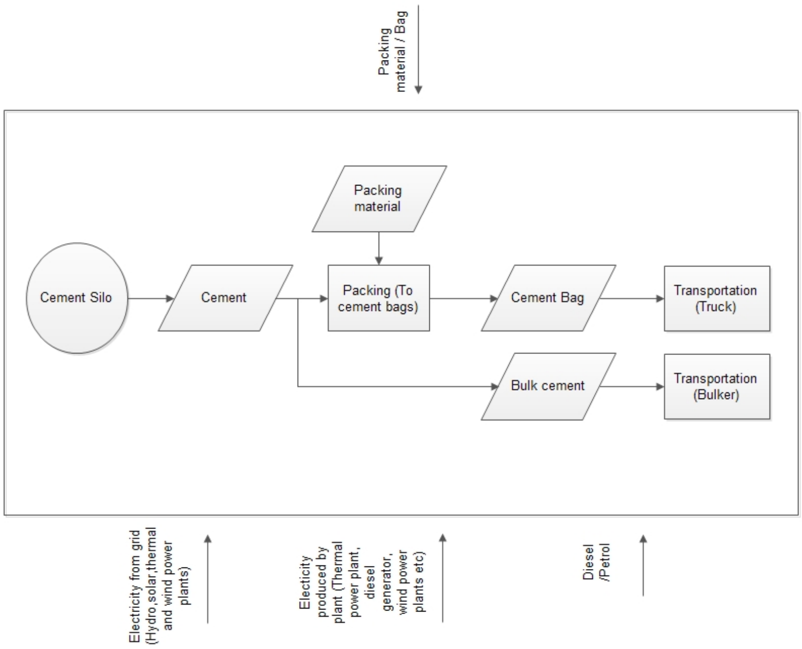

Fig. 4: Packaging of Cement.

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