Impacts Assessment of Local and Industrial LC3 in Cuban Context: Challenges and Opportunities

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Abstract The main goal of the paper is to compare the economic and environmental impacts of local production of low carbon cement based on a new mineral addition of calcined clay and limestone (LC2) versus industrial production of low carbon cement (LC3), considering particularities of Cuban context. First, a technical comparison is carried out comparing also with traditional OPC and PPC and considering standards applied in the island. Secondly, an economic assessment of production and investment costs is carried out using life cycle costing (LCC) technique. Afterwards, to assess environmental impacts a simplified life cycle assessment is performed to compare both cements, OPC and PPC. Cement based on LC2 reports economic advantages in comparison with the other cements: industrial LC3, OPC and PPC. Environmental results show a similar behaviour for local and industrial LC3 but a significant decrease of emissions and energy demand versus OPC and PPC. Technical comparison shows that local LC3 results are variable but complies with the standard for its use in mortars and non-structural applications. Finally, results show that LC3 introduction is a feasible option to reduce impacts of the cement industry in Cuba, and a combination of its local and industrial production is the best alternative to achieve sustainability goals in the short and mid-terms. Main opportunities of local LC3 are the reduction of costs, the easier storage, the use of local materials, amongst other. Main challenge is related to a correct use of the mineral addition in localities.

Keywords Low carbon cement · Mineral addition of calcined clay and limestone · Impacts assessment

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1 Introduction

Research associated with construction materials and its roll in sustainability is highly important in modern times [1, 2]. Production of cement, main component of several construction materials, is considered one of the higher industrial sectors that generates greenhouse gas emissions [3]. At the same time, cement and its derived are products with high cost of elaboration which need to be improved towards less economic and environmental cost [4].

Low carbon cement (LC^3) is a cement with high clinker substitution level with addition of 30% of calcined clay and 15% of limestone [5]. The new product has emerged as result of the innovative work of a multidisciplinary team with specialists from Switzerland, India and Cuba, as part of an international project (LC3). So far, technical, economic and environmental feasibility of industrial LC3 is been proven [6–9], but a new possibility as arisen: to produce LC3 locally. No matter if it is produced locally or industrially, LC3 advantages are strongly related to better use of existing capacities, reduction of energy consumption, capital and productive costs and emissions.

On 2018, an industrial trial was carried out in Siguaney cement factory, located in the centre of the island, to produce LC2. Previous industrial trials have been done to produce low carbon cement (LC3) in the same factory [10] showing satisfactory results that support first laboratory findings of LC3 [11]. The goal of this paper is to compare the economic and environmental impacts of local production of low carbon cement based on a new mineral addition of calcined clay and limestone (LC2) versus industrial production of low carbon cement (LC3), PPC and OPC; considering particularities of Cuban context.

2 Materials and Methodology

2.1 Low Carbon Cement (LC3) and the Mineral Addition LC2

Low carbon cement is a new cement based on a combination of calcine clay and limestone that permit to reduce clinker ratio to 50% (i.e. LC3: 50). Furthermore, a family of low carbon cements can be produced varying the percentage of substitution.

In Cuba, the Centre for Research and Development of Structures and Materials explores the feasibility of produce and use a new mineral addition based on calcined clay and limestone in 2:1 proportion called LC2. This mineral addition could be used to fabricate a large amount of low carbon cement-based products locally. Optimized mix design proposes the addition of 50% of LC2 to be mixed with 50% of OPC. First impact of this addition is the extension of productive capacities that could allow to satisfy a higher percentage of the local demand.

The production of both products is strongly related since LC2 can be considered as an intermediate product in LC3 production. Productive process begins with raw

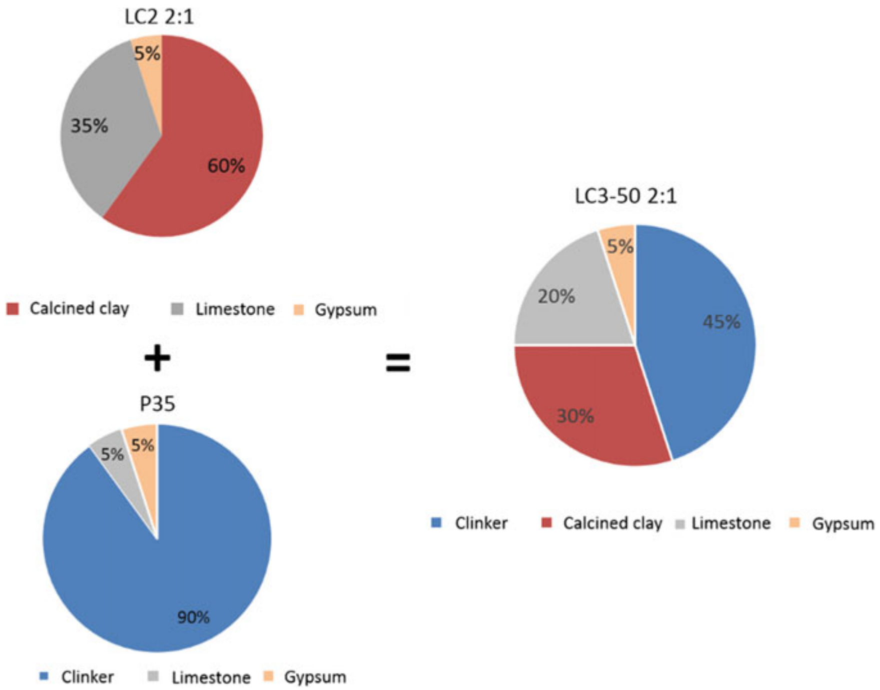

Fig. 1 Chemical composition of LC2 versus LC3: 50. *Source* [12]

materials extraction in the quarry. Afterwards these materials are transported to the factory to be calcined resulting in thermally activated clay and clinker (when producing LC3 industrially). The process ends with a grinding and mixing step followed by delivery in bags or in bulk. Figure 1 shows LC2 and LC3: 50 composition showing their technical relationship.

2.2 Impacts Assessment, Goal and Scope

The impacts assessment is performed through a life cycle assessment completed in harmony with ISO 14044:2006 [13]. This study focusses on the production and transport of the cement components. The analysis ends at an intermediate stage (cradle to gate) as shown in Fig. 2. Transport of final product to site has been excluded in the analysis since there are a vast variety of options for its destination. The functional unit used in the study is 1 ton of cement.

Life cycle inventory for productive process of the cements OPC, PPC and LC3_industrial is taken from [14]. Production of LC3_local combines data form OPC and LC2 production which is carried out in Siguaney cement factory following the next phases:

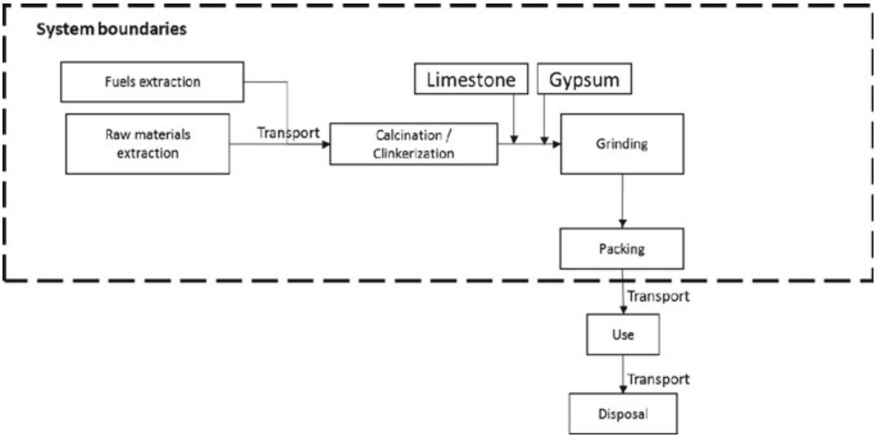

Fig. 2 System boundaries of impacts assessment performed

Extraction of clay. Previous analysis made to the quarry certifies that the kaolinite clay present has the needed quality to be reactive after calcination. Also a measurement of the reserves concluded there are enough resources to guarantee more than 35 years of production.

Transport to factory and homogenization. The quarry is located 60 km from the factory. Transport process was done with trucks of the cement factory. Due to the existence of different technological types of clay, a homogenization process was required before calcination. This process was performed in the factory using a frontal charger in the clay storage place of the factory.

Calcination of clay. This process was carried out in a wet process rotary clinker kiln. Thus, the material was first converted into paste and then calcined. Estimated consumption of energy reports a reduction of 40% respect to clinkerization process.

Grinding and blending with gypsum and limestone. During grinding process limestone and gypsum are incorporated to the mix. A closed circuit mill with high efficiency was used. Estimated energy consumption is around 45 Kwh per ton of LC2. It is assumed that 100% of the material is delivered in bulk.

Calculations are performed using the software Simapro vs- 8.0.3.14 and the Windows tool Microsoft Excel 2013. The environmental indicator category considered was global warming potential over 100 years (GWP100) [15]. This category measures emissions over a 100-year time period of any greenhouse gas, using CO^2 as an equivalence measure. For economic impact assessment, a life cycle costing technique is employed. Finally, a combined analysis is made through an eco-efficiency dispersion chart that allows to compare both dimensions.

3 Results and Discussion

Breakdown of life cycle costs from cradle to gate shows that low carbon cement, local and industrial, presents lower impact over economy and environment if they are compared with OPC and PPC. Figure 3 details costs composition of calcined clay. Main impacts are related to energy consumption for calcination, amortization and raw materials extraction and transport. High amortization costs are related to factory conditions where decapitalization process is high. LC2 cost reports a reduction of 50% when compared with OPC, product that could be substituted by this mineral addition.

Global warming potential results show higher impact related to OPC and PPC, as shown in Fig. 4. The higher the clinker ratio, the higher the costs and emissions. Comparison between local and industrial LC3 shows similar results with small reduction when industrial production is performed. This could be related with scale economies resulting from industrial production and extra transport involved to obtain LC3 locally. When LC3 is industrial, usually all raw materials are close to factory but LC3 local has transport costs for OPC and LC2 and all their constituents. This issue should be further studied.

LC2 is also presented in Fig. 4 showing an opposite location in comparison with OPC. OPC is located in the less eco-efficient quadrant of the figure and LC2 in the most sustainable one.

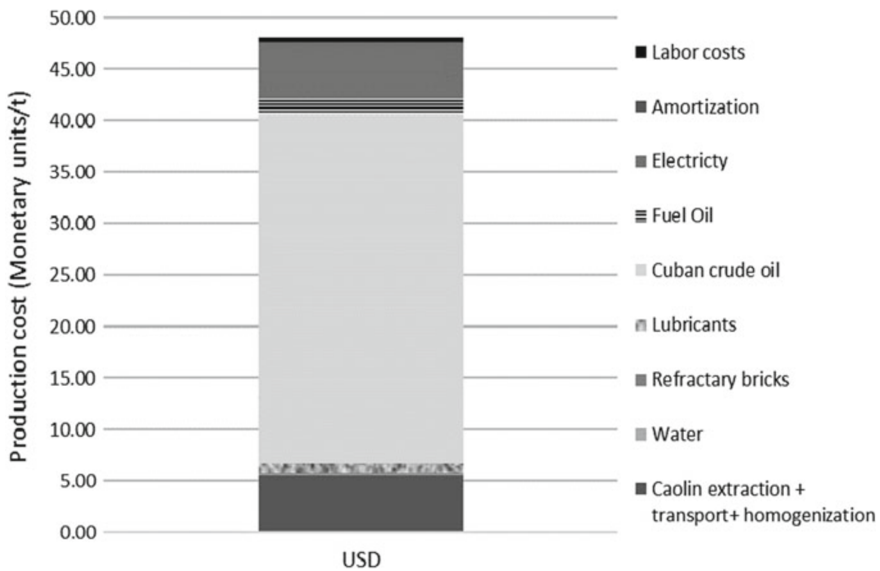

Fig. 3 Life cycle costing of calcined clay in Siguaney. Costs in USD

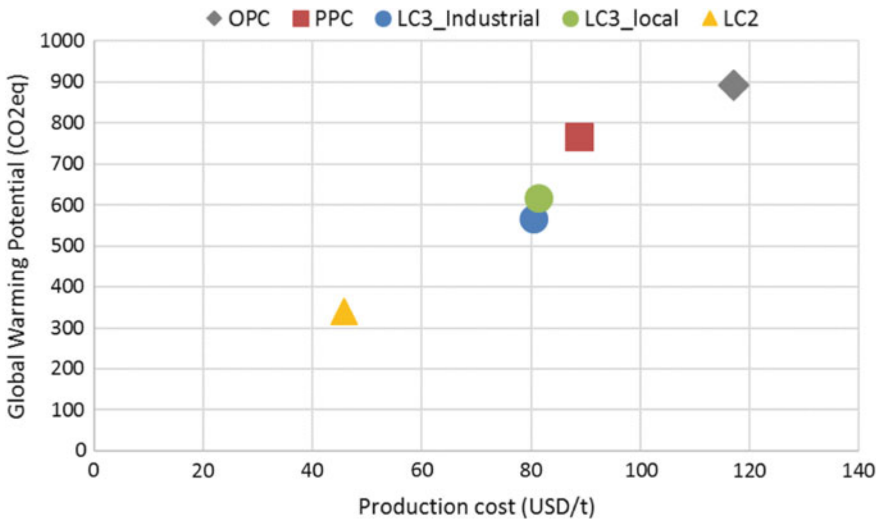

Fig. 4 Environmental versus economic impact. OPC, PPC, LC3 industrial and local

Despite of the minor differences in results between local and industrial LC3, it has been proven the feasibility of this type of cement in comparison with other traditional cements produced in Cuba.

Local production of LC3, through LC2, will allow to extend the use of available OPC, to adapt to construction needs and change mix-design accordingly reaching different clinker ratios depending on destination (e.g. mortars, concrete, blocks). No investment is needed in short term, but an investment should be considered to import an industrial rotary clay calciner in order to increase efficiency.

Another advantage is that LC2 can be stored for long periods and can survive to wet conditions with a drying process to revert humidity. As a strategy, this product could be produced in campaigns and stored. Its possible distribution and use need to be established.

However, a proper communication strategy should be designed once this product is approved to clarify its properties and ways of use. One big threat is the uncertainty on the correct mix-design; everywhere this product could be applied despite the fact of correct instructions available.

4 Conclusions

The assessment of environmental and economic impacts of LC3 production both locally and industrially shows that this cement reduces the production cost and carbon emissions in comparison with traditional OPC and PPC made in Cuba. Industrial manufacture of LC3 increases efficiency in a small amount with respect to local production.

Local production is more viable in Cuban present conditions to introduce low carbon cement but the process has to be organized and well controlled. Industrial production could be considered in a mid-term period.

Existing technology accomplishes the needs to produce calcined clay but some efficiency reserves exists. To improve, efficiency investment is needed.

Results could be used to support communication strategies on this new product oriented to different stakeholders.

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