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Limestone calcined clay cement as a low-carbon solution to meet expanding cement demand in emerging economies

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ABSTRACT

This paper aims at assessing the return on investment and carbon mitigation potentials of five investment alternatives for the Cuban cement industry in a long-term horizon appraisal (15 years). Anticipated growing demand for cement, constrained supply and an urgent need for optimisation of limited capital while preserving the environment, are background facts leading to the present study. This research explores the beneficial contribution of a new available technology, LC^3 cement, resulting from the combination of clinker, calcined clay and limestone, with a capacity of replacing up to 50% of clinker in cement. Global Warming Potential (GWP) is calculated with Life Cycle Assessment method and the economic investment's payback is assessed through Return on Capital Employed (ROCE) approach. Main outcomes show that projected demand could be satisfied either by adding new cement plants—at a high environmental impact and unprofitable performance— or by introducing LC^3 strategy. The latter choice allows boosting both the return on investment and the production capacity while reducing greenhouse gas (GHG) emissions up to 20–23% compared to business-as-usual practice. Overall profitability for the industry is estimated to overcome BAU scenario by 8–10% points by 2025, if LC^3 were adopted. Increasing the production of conventional blended cements instead brings only marginal economic benefits without supporting the needed increase in production capacity. The conducted study also shows that, in spite of the extra capital cost required for the calcination of kaolinite clay, LC^3 drops production costs in the range of 15–25% compared to conventional solutions.

1. Introduction

Concrete production has an impact on the climate as it accounts for 5–8% of total anthropogenic CO_2 emissions [1]. 95% of this CO_2 is produced during the fabrication of cement, half of it being released by the decarbonation of the limestone during cement fabrication. Cement is, after power generation, the second largest source of anthropogenic CO_2 emissions [2], and also the second most consumed product, after water. Furthermore, the rapid urban development in emerging countries will push forward the cement demand and recent studies estimate that cement production could represent 10–15% of global CO_2 emissions by 2020 [3].

There is indeed a strong link between economic growth, population and cement demand [3,4]. For low income levels (< US$ 8 000, at 1990 levels), cement demand is proportional to the Gross Domestic Product, GDP. This is consistent with the fact that economic growth begins with a quick build-up of industrial and transport infrastructure, and concrete is by far the most used material for this purpose. In industrialized countries with higher income levels, cement demand and population evolve proportionally. They have developed their infrastructure decades ago, and thus, demand for cement is limited to maintenance and marginal improvement of infrastructure to cope with population growth [3].

Cement production in 2014 was 4.3 billion tonnes. Emerging economies (China, India, CIS, others Asia) account for roughly 3.5 billion tonnes, 81% of the world's production. Industrialized countries (Europe, USA, Japan) produced roughly 0.4 billion tonnes, 9% of the world's cement production [5]. According to the Eleventh Edition of

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the Global Cement Report, global cement consumption was still on the rise in 2015 and further increase for 2016 is expected, notwithstanding that there will be a slower rate than in the past [6].

Most cement consumption takes place in the fastest-growing economies like China, India, Russia, South Africa, Brazil, Mexico and Chile. From an investment perspective, the stock markets of these countries are more volatile than the mature markets of developed countries but offer higher returns. This makes them more attractive as well as riskier. Concerning Cuba, the opening-up process currently undergoing and the untied relationship with US government, will most probably boost the overall investment, thus, fostering the development of new infrastructure [7,8]. The regulatory framework in the country portrays a secure and less risky place where to invest with promising higher profitability and faster payback periods. This also might be the case of many other emerging economy's countries. "Now that Cuba has relations with the United States, the country risk has diminished for foreign investors" [9].

The growth in cement demand in most dynamic economies takes place within short periods. Annual growth rates between 5–15% are common in these scenarios. Coping with a sudden demand could be an issue for the cement industry because installing production capacity is a capital intensive and time consuming process (setting up a new cement plant, 1.0 M tonnes per year would cost more than 250 Million US dollars, and would take around 4–5 years to be operational) [10,11]. Commonly, the period of building up infrastructure in emerging economies ranges between 20 and 30 years. After 20 years, demand enters a stabilization phase that lasts 10–15 years (plateau), and as soon as infrastructure is in place, demand declines. Meeting peak demand prompts for a detailed investment strategy, due to the risk of installed capacity exceeding demand within the payback period.

Cuban cement consumption has historically been following the same trend of production output, since demand exceeds the supply by far. There is a large accrued backlog in demand in the country due to some structural and case-specific reasons. Forecasted demand based on the cement group's estimations would be in the order of 18%, 15% and 10% growth rate by the subperiods 2016–2020, 2020–2025, 2026–2030, respectively. The ongoing opening-up process and economic reform in Cuba could possibly foster new joint ventures with a steady potential in the cement industry.

Facing the upward-sloping demand for traditional cement with a very high clinker to cement ratio is no longer bearable for Cuba or for faster-growing economies. Therefore, required cement turnover in cement companies is claimed to be in accordance to global concerns, which means targeting economic goals without impeding the climate change mitigation goals. Bearing this in mind, a shift from conventional to alternative technologies becomes an imperative.

The use of Supplementary Cementitious Materials (SCM) has been well-grounded and well-documented [12–17]. Different clinker substitution levels can be achieved depending on the type of SCM and its particular pozzolanic reactivity. However, limited world wide availability and limits in clinker replacement hinder the ultimate benefits of these substitutions. Other alternatives such as geopolymers have been developed [18,19]. They can have interest in terms of carbon reduction and resource consumption but their use is foreseen in a medium to long term perspective. Among these alternatives, Limestone calcined clay cement, coined as LC^3 has been developed. A deeper undersanding on the technical development of LC^3 can be found in [15,17,20].

This paper focuses on the assessment of the different options in terms of cement technology for the Cuban cement industry, through their economic benefits and carbon mitigation potentials. The financial success was measured using the Return on Capital Employed (ROCE) approach. The environmental impact is considered with Global Warming Potential through CO_2-eq., which enables addressing carbon savings among technological scenarios.

2. Description of alternative technologies for cement production in Cuba

2.1. Cuban cement industry: overview and prospect

Cuba was the pioneer in cement manufacture in Latin America. The first Cuban cement factory was set in production in 1895 with a productive capacity of 6 Ktpy [21]. Nowadays, the Cuban cement industry owns six factories, which all begin operations in the 1980's with a current nominal production capacity of 4.4 Mt per year. Historical cement production capacities increased vertiginously after the Triumph of the Revolution in 1959 as part of the industrialisation process carried out until the 1980's. An economic recession started in the late 1980's followed up by the crisis during the 90's. This was the hardest period for Cuban economy —without supplies or spares, capital for investment or maintenance— and its effect over industry is still visible. All capital investments in cement sector stopped and productive capacities started decreasing.

The cement sector in Cuba has now an installed capacity of 2.8Mt of clinker per year but only 43% of productive capacity can be used. In term of cement type, a variety of types of cement with a large predominance of Ordinary Portland Cement (OPC) and a smaller contribution of Pozzolanic Portland Cement (PPC) made with 20% zeolite addition. In term of clinker technology, 75% of the total clinker production is done with a dry process in two major cement plant (Cienfuegos and Curazao) (Fig. 1).

The best choice to meet demand spikes in the short term is to increase clinker substitution by using Supplementary Cementitious Materials (SCM). This enables the increase of cement production capacity without the need to increase clinker manufacturing capacity [23]. The main sources of SCM are waste from industrial processes, among others, granulated blast furnace slag, pulverized fly ash, natural pozzolans (including agriculture ashes and silica fume), artificial pozzolans and limestone. The use of SCM has proven to impact on the cost of cement, due to the substitution of clinker in cement production [24].

However, the use of SCM has some limitations:

a) Clinker substitution is limited to 35% in most cement international standards, with the exception of slags, where up to 65% of clinker can be substituted. The average clinker substitution worldwide is around 25% [25].
b) The availability of SCM, especially those of industrial origin such as fly ash and slag, is limited to certain regions. The main reserves do not occur in many places where cement demand will grow exponentially in the coming years. Current availability of SCM is approximately 10% of world's cement production [26].

The use of calcined clays has been limited to pure kaolinite clays to

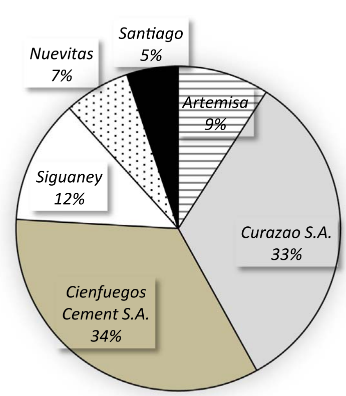

Fig. 1. Market share by factory in 2015. *Data from* [22].