Journal of Cleaner Production 31 (2012) 126–136

Contents lists available at SciVerse ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Evaluation of the environmental performance of lime production in Cuba

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ARTICLE INFO

Article history:
Received 9 November 2011
Received in revised form
28 February 2012
Accepted 28 February 2012
Available online 7 March 2012

Keywords:
Life Cycle Assessment
Impact assessment
Lime
Quicklime

ABSTRACT

Lime production is characterized by large emissions of CO_2 and by other environmental impacts. In Cuba this industry operates with outdated technology, resulting in low energy and material efficiency and in high environmental impacts. In order to improve the environmental performance of the lime industry in Cuba it is necessary to have an overview of the environmental impacts associated with the production process. This paper quantifies the environmental impacts of lime production in Cuba by means of LCA methodology in a cradle-to-gate evaluation. It also aims at establishing a benchmark for improvement by comparing the environmental impact of this industry in Cuba with a plant in an industrialized country. For the inventory evaluation the process of lime production was divided in five production stages. When necessary, the data was completed with literature sources. For the impact assessment the impacts in the following categories were considered: energy consumption, global warming, human toxicity, photo-oxidant formation and acidification. Results show that the calcination stage and the consumption of fuel, electricity and limestone are the main contributors to environmental impact of the production process. The economic assessment shows possibilities to improve the environmental performance while achieving cost reductions in the production process. The larger improvements in the environmental performance and cost saving can be achieved by improving the energy efficiency of the calcination stage. This can partially be accomplished with moderate investments.

1. Introduction

Calcium oxide (CaO), known as lime or quicklime, is an energy intensive product, yet one of the most widely used and cheapest alkali products employed in industry. The process of lime production involves the emission of large quantities of CO_2, main actor of climate change. In fact, the production of 1 t of lime entails the emission of around 1.2 t of CO_2 (Ochoa et al., 2010; European Commission, 2001), making lime one of the produced materials with the highest associated specific emission of CO_2 (Hoening and Schneider, 2002; Wolter and Fuchs, 2007).

The environmental impact of lime production can be local, regional or global in scale. Local effects include dust emissions and changes in landscape because of the mining of limestone. Emitted sulfur dioxide and nitrogen oxides contribute to acid rain on regional scale, whereas CO_2 emission contributes to global climate change.

Lime industry is widespread both in developing and industrialized countries. In Cuba, lime industry consists of seven small commercial plants distributed over the country (see Fig. 1). In 2004, the Cuban lime industry produced 53,600 t of lime (Bermúdez-Lugo, 2008), emitting about 75,000 t of CO_2, 0.31% of the Cuban emission of 24 Mt of CO_2 − equivalent (Cuba, 2010).

Lime industry in Cuba falls in the category of small and medium-sized enterprises (SMEs). Ciliberti et al. (Ciliberti et al., 2008) analyzed corporate social responsibility in SMEs in developing countries pointing out that "*SMEs that operate in developing countries face several specific challenges, e.g., lack of mentorship and skills transfer, communication gaps, lack of awareness on development opportunities and support networks, infrastructure scarcity, low saving rates and difficulties in accessing financial services*". In agreement with this analysis, the lime plants exploited in Cuba operate with outdated technology and with very low to non-existing automation of the production process. Moreover, these plants are usually exploited by personnel lacking the necessary qualifications, leading to pour operation standards. These characteristics contribute to the low energy and material efficiency of this industry in Cuba. This situation causes a poor environmental performance, with specific CO_2 emissions reaching values over 1.4 t per t of lime (Ochoa et al., 2010; Sagastume and Vandecasteele, 2011). Emissions of CO_2, causing climate change, are one of the most serious environmental threads of our time (Benhelal et al.,

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doi:10.1016/j.jclepro.2012.02.035

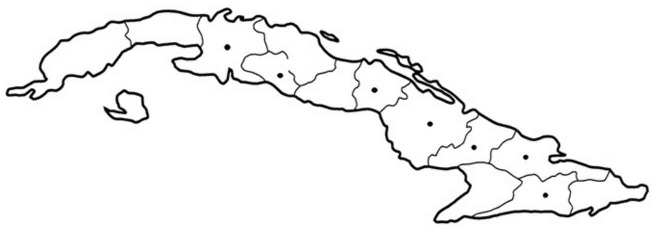

Fig. 1. Location of lime plants in Cuba.

2012). A better utilization of resources improves competitiveness and profits, which also improve the environmental performance of a company (Strazza et al., 2011). Therefore, understanding and quantifying the environmental implications associated with lime industry in Cuba will help the country on its way toward sustainability.

Life Cycle Assessment (LCA) is an important method in modern environmental management (Löfgren et al., 2011) and is a useful tool to estimate the environmental impact of lime production. Application of LCA will allow the optimization of the production process by identifying its most significant impacts. Although LCA is a widespread tool, there is only limited information on LCA of lime production, the only LCA study of lime production found by the authors being the ecoinvent report No.7 (Kellenberger et al., 2007), which gives the life cycle inventory of the lime production in KalkFabric Nestal (KFN), the only plant producing hydrated lime in Switzerland. More examples of LCA were found in the cement industry, which is closely related to lime production. Applications of LCA to products and processes can be found in literature. Huntzinger et al. (Huntzinger and Eatmon, 2009) compared the environmental impacts of traditional Portland cement production with three alternative technologies applying a cradle-to-gate approach. The study identifies different possibilities to reduce the environmental impact of cement production. Valderrema et al. (Valderrama et al., 2012) also implement LCA with a cradle-to-gate approach to establish environmental improvements associated with the upgrade of a cement plant. The study shows important reductions of the environmental impacts of the production process because of the technological upgrade. González-García et al. (González-García et al., 2010) described the environmental impact of a non-wood based pulp production process using an LCA cradle-to-gate approach. In the study the authors collect the inventory data through on-site measurement and when necessary the data were completed with data from literature. The study identifies the hot spots of the production process showing the benefits of using renewable fuels rather than fossil fuels. Valente et al. (Valente et al., 2011) performed an extended LCA for evaluating the impacts of a woody biomass supply chain for heating plants in the alpine region assessing three main aspects of sustainability: greenhouse gas emissions, costs and direct employment potential. The study demonstrates that mountain forests are a viable source of wood fuel, which can be exploited without generating excessive impacts.

CO_2 emissions during limestone calcination in a Cuban plant are discussed by Ochoa et al. (Ochoa et al., 2010). The authors introduce a method to evaluate, optimize and control the thermal efficiency of lime kilns and discuss the reductions in CO_2 emissions as a result of the improvement of thermal efficiency, but no further environmental implications are discussed.

An important characteristic of the lime and other industries in Cuba, and probably in other developing countries, is the lack of equipment to measure all relevant emissions. Consequently, it is not possible to inventory all the significant information necessary for the LCA. However, some emissions can be calculated from the mass and the energy balances of the process and the rest can be estimated with reasonable assumptions. This situation may affect the accuracy of the impact assessment. Moreover, De Benedetto and Klemes (De Benedetto and Klemes, 2009) indicate that in most LCA studies assumptions are made. Nevertheless, considering the current situation of the lime industry in Cuba, it seems reasonable to describe its environmental impact, even if a number of emissions have to be estimated, rather than to wait for the possibility to measure all the emissions. The outcome of the LCA is important to achieve a more environmentally friendly production of lime in Cuba.

The objective of this work is to describe, with the aid of LCA, the environmental impacts, particularly global warming, of the lime production in Cuba. Comparing the environmental indicators between different companies allows to evaluate the potential savings within a company environmental program (Jasch, 2000). Benchmarking is a proven tool to improve both the economic and the environmental performance of companies (Altham, 2007). Moreover, in order to establish a benchmark for improvement, a plant operating with high material and energy efficiency in an industrialized country is also evaluated.

2. Lime production

The flow diagram of lime production can be different from plant to plant, and generally depends on the technological characteristics of the production process in place. Nevertheless, the process includes five basic steps:

1. Quarrying of limestone
2. Limestone crushing and screening
3. Calcination of limestone
4. Hydration of quicklime and classification of hydrated lime
5. Packaging

For the sake of simplicity these steps are used to generalize the flow diagram of the production process in the plants under scope.

Fig. 2 shows the general flow diagram of lime production considering the associated inputs and emissions relevant for the environmental impact assessment. In the first stage, limestone is quarried and transferred to the crushing and screening unit to size the stones for the calcination stage. The stones with the correct size are fed to the kiln, where, with the proper supply of heat, $CaCO_3$ dissociates into CaO and CO_2. Quicklime is then milled and hydrated by supplying water. The obtained product goes through a classification process to increase the quality of the product. Finally, the product is packed and stored.

In general, the amount and characteristics of the process emissions depend on the plant technology, the operation standards, the raw material consumed and the fuel type. The major emissions of lime production are the gaseous emissions. The most impacting pollutants to be expected in this case are CO_2, CO, SO_2 and NO_x. The emissions of CO_2 are from the dissociation of $CaCO_3$ and from fuel combustion. The plant technology and operation standards strongly influence the thermal efficiency that defines the amount of CO_2 emissions. The rest of the gaseous emissions are mainly influenced by the technological and operational standards of the plant rather than by the type of fuel. CO emissions are directly dependent of the burner technology and the air excess of the combustion. According to Kocabiyik (Kocabiyik, 2007), fuels with high sulfur content do not cause SO_2 pollution in lime kilns. Finally, in limekilns temperatures usually reach values above 1300 °C; under these conditions the principal mechanism of NO_x formation is thermal-NO_x (Werther and Ogada, 1999). Consequently, the change of fuel type will mainly influence CO_2 emissions, the rest of