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Eco-efficiency of the world cement industry: A data envelopment analysis

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ABSTRACT

Chemical reactions and the combustion of dirty fuels, such as coal and petroleum coke (petcoke), that are used in cement production processes generate a significant amount of CO_2 emissions. In this paper, we provide an eco-efficiency measure for 21 prototypes of cement industries operating in many countries by applying both a data envelopment analysis (DEA) and a directional distance function approach, which are particularly suitable for models where several production inputs and desirable and undesirable outputs are taken into account. To understand whether this eco-efficiency is due to a rational utilization of inputs or to a real carbon dioxide reduction as a consequence of environmental regulation, we analyze the cases where CO_2 emissions can either be considered as an input or as an undesirable output. Empirical results show that countries where cement industries invest in technologically advanced kilns and adopt alternative fuels and raw materials in their production processes are eco-efficient. This gives a comparative advantage to emerging countries, such as India and China, which are incentivized to modernize their production processes.

1. Introduction

Cement is essential for the economic development of a country, but its production is highly energetic and emission intensive. Among the non-metallic mineral production processes, cement manufacturing is the most expensive in terms of energy consumption. According to the European Cement Association (Cembureau), "each ton of cement produced requires 60 to 130 kg of fuel oil or its equivalent, depending on the cement variety and the process used, and approximately 105 KWh of electricity".[1] On average, energy costs, in the form of fuel and electricity, represent 40% of the total production costs for one ton of cement (see European Commission, 2009). In addition, the cement industry is responsible for approximately 5% of the current worldwide CO_2 emissions (see IEA, 2009). These data are worrisome because the worldwide production of cement has more than quadrupled over the last 25 years, reaching 3 million tons in 2009 (see Cembureau, 2009). Production is expected to further increase because of the exponential growth rates in developing countries, such as China and India, which are the major cement producers in the world. Clinker production is primarily responsible for CO_2 emissions. Clinker is a cement sub-product that is produced by burning a mixture of limestone, silicon oxides, aluminum oxides and iron oxides in kilns and differs according to the process adopted[2] at an average temperature of approximately 1450 °C. This high temperature, which is usually reached by burning highly emitting fuels, such as coal and petcoke, leads to chemical reactions that transform raw materials into clinker and also generate CO_2 and other greenhouse gas emissions as undesirable outputs.

CO_2 emissions become a problem for industries that operate in countries where environmental regulations apply. This is the situation that European cement industries have faced since 2005, when the European Emission Trading Scheme (EU-ETS) was developed. Introduced by Directive 2003/87/EC, the EU-ETS is the widest cap-and-trade system applied in the world and regulates CO_2 emissions generated from specific installations.[3] The cap-and-trade system implies the imposition of a CO_2 emission ceiling for all covered installations in the different countries, the National Allocation Plans (NAPs[4]), and the creation of an emission permit market where players can buy or sell CO_2 allowances at a certain price defined by the market. The EU-ETS

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[1] See http://www.cembureau.be/about-cement/cement-industry-main-characteristics.

[2] Cement can be produced with four different processes: dry, wet, semi-dry and semi-wet. Dry and semi-dry processes are generally more productive and require a lower amount of energy than the other two. Cement production is subdivided into two main steps: first, clinker is produced from raw materials in kilns, whose efficiency varies according to the process adopted, and then cement results from the mixture of clinker with other additives.

[3] The sectors currently involved are: energy, refining, cement, iron, steel and pulp and paper.

[4] See http://ec.europa.eu/clima/policies/ets/allocation_2005_en.htm for the National Allocation Plans of the two phases.

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was originally organized in two phases: the first has already concluded and was conducted from 2005 to 2007, and the second covers the period 2008–2012.[5] A third phase has been announced for the period 2013–2020. This will be regulated by the new Directive 2009/29/EC, which enlarges the number of sectors and greenhouse gases subject to regulation. The European energy intensive industries (and also cement producers) complain about EU-ETS because it imposes additional costs from emissions abatement and the purchase of allowances, which put their European plants at a competitive disadvantage with respect to those operating in countries where emissions constraints are more lenient or even absent (see Business Europe, 2010; Cefic, 2007). In fact, in many countries, emission trading schemes are not mandatory but are organized on a voluntary basis. This is the case in Switzerland, Japan, Canada and the USA (see Appendix A for more details). In Australia, the announced ETS program has not been approved by the government, and its application will be postponed (see Appendix A).

However, one can notice a growing awareness of greenhouse gas emissions and of the environment in general in developing countries. China is the world's largest CO_2 emitter but has shown a determination to curb its greenhouse gas emissions. The application of China's National Climate Change Program has been the first step in a modernization process whereby China intends "to address climate change and promote sustainable development" through "policies and measures, such as economic restructuring, energy efficiency improvement, development and utilization of hydropower and other renewable energy".[6] This means that China will not impose a cap on CO_2 emissions but will reduce emissions by setting binding energy intensive reduction targets, stringent fuel efficiency standards and investments in more efficient technologies. Several key sectors are involved in this program, and cement is one of them. Note that the effectiveness of the targets imposed by the Chinese climate program on the cement sector[7] is confirmed by a study conducted by the International Energy Agency, which suggested that cement industries dispose of four tools suitable for reducing their CO_2 emissions, namely, thermal and electric efficiency, the utilization of alternative fuels, clinker substitution and the adoption of a carbon capture and storage process that captures CO_2 before being released into the atmosphere (see IEA, 2009).

Similar policies are also in force in India, where an Energy Conservation Act[8] was introduced in 2001, and in Brazil, where the National Climate Change Plan has been effective since 2008.[9] Also, in Turkey, there are some signals for policies in this direction. Turkey's candidacy to become a European Member State induced the Turkish government to ratify the Kyoto Protocol in May 2009[10] and to introduce eco-innovation policies to reduce their emissions (see OECD, 2008).

Considering this framework, the aim of this paper is to study the eco-efficiency level of cement industries operating in different countries. There are several environmental performance indicators to choose from (see Tyteca, 1996 for a complete review). We have chosen to apply a data envelopment analysis (DEA) approach. DEA evaluates the efficiency of chosen decision making units (DMUs), such as plants, firms or even entire sectors that produce a homogeneous good. This approach has the advantage of simultaneously considering multiple inputs (with their respective measures) and both the desirable (produced good) and undesirable (waste and pollutants) outputs that characterize a certain production process. This allows DMUs to have immediate information on their global efficiency (or inefficiency) status and, depending on the DEA approach adopted, on which input or output should be examined to improve their production.

This study is different from other studies on the cement sector already existing in the literature (Bandyopadhyay, 2009; Mandal and Madheswaran, 2010; Sadjadi and Atefeh, 2010) where the analysis is conducted at the interstate level. In our study, the DMUs are prototypes of cement plants located in 21 countries. We measured their eco-efficiency by including CO_2 emissions as an undesirable production factor. According to the DEA literature, undesirable factors can be modeled either as an input or as an undesirable output. We apply both of these existing approaches in addition to a directional distance function model. With these models, the eco-efficiency of cement DMUs can be measured either as a contraction of CO_2 emissions or as an increased utilization of alternative fuels and raw materials. Our analysis shows that the units' efficiency levels are affected by the tendency of different DMUs to invest in technologically advanced kilns and adopt alternative fuels and raw materials in their cement production processes. Surprisingly, emerging countries, such as India and China, which are the largest cement producers in the world, appear efficient. As we will explain in Section 4, their recent economic booms and the energy efficiency targets imposed by their authorities have forced their cement companies to invest in the most advanced technologies.

The remainder of the paper is organized as follows. Section 2 presents the model used in our analysis, while Sections 3 and 4 illustrate the dataset used in our simulations and the obtained results, respectively. Final remarks are reported in Section 5.

2. Modeling eco-efficiency

The notion of eco-efficiency comes with different meanings and definitions. We define *eco-efficiency*, in an operational way, as the ability to produce goods or services by saving energy and resources and/or by reducing waste and emissions. Different instruments for measuring eco-efficiency are introduced in the literature (see Tyteca, 1996), but most of them are simple indicators[11] that approach eco-efficiency from a very limited perspective because they only consider a few factors in the production process. One should aggregate all these indicators to synthesize information on the overall impact of certain production processes on the environment. Moreover, measuring eco-efficiency at a worldwide scale, as we do in this paper, creates a

[5] European Commissions list the countries involved in the EU-ETS and provides information about the two phases at http://ec.europa.eu/clima/policies/ets/index_en.htm. A special case is represented by Norway. This EU country started a domestic emission trading scheme in 2005. The organization of the original Norwegian ETS was similar to that of the EU-ETS. Thanks to an agreement between the EU and the members of the European Economic Association (Iceland, Liechtenstein and Norway) signed in October 2007, Norway officially entered into the EU-ETS in 2008 (see Reinaud and Cédric, 2007). The same happened to the United Kingdom, which, after some problems in determining its NAP, was included in the EU-ETS in 2008.

[6] Directly taken from http://www.ccchina.gov.cn/WebSite/CCChina/UpFile/File188.pdf.

[7] At point (4) of China's National Climate Change Program, one can read that "new dry process kiln with precalcinator technology should be developed; promote energy efficient grinding equipment and power generating technology by using waste heat recovered from cement kiln; improve the performance of existing large-and medium-size rotary kiln, mills and drying machines for the purpose of energy conservation; gradually phase out mechanized vertical kiln, wet process kiln and long dry process kiln and other backward cement production technologies". Taken directly from http://www.ccchina.gov.cn/WebSite/CCChina/UpFile/File188.pdf.

[8] See http://www.powermin.nic.in/acts_notification/pdf/ecact2001.pdf.

[9] See http://www.eoearth.org/article/Greenhouse_Gas_Control_Policies_in_Brazil.

[10] See http://en.wikipedia.org/wiki/List_of_Kyoto_Protocol_signatories#cite_note-13.

[11] For instance, economic output per unit of waste ratios.