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Striking a balance between profit and carbon dioxide emissions in the Saudi cement industry

Walid Matar [a,*], Amro M. Elshurafa [b]

[a] King Abdullah Petroleum Studies and Research Center (KAPSARC), P.O. Box 88550, Riyadh 11672, Saudi Arabia
[b] King Abdullah Petroleum Studies and Research Center (KAPSARC), Saudi Arabia

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ABSTRACT

Cement manufacturing is a major industry in Saudi Arabia. As a highly polluting sector, it may be part of CO_2 abatement policy for the country. This paper presents a multi-criteria analysis to examine how two competing objectives affect the performance of the cement industry in Saudi Arabia. Namely, these criteria are profit and CO_2 emissions. We examine the joint effects of economic costs and biases of the industry's senior management on decisions. Relevant decisions include fuel use, and investment in carbon capture and storage and more energy efficient kilns.

The analysis adopts an operational model that we have developed for the industry, where 2015–2020 is the period of interest. It allows us to account for events that are not anticipated by the industry, such as the rise in energy prices that took place in 2016. Allowing imports and deeming the reduction of CO_2 emissions as highly important, the industry would choose to import clinker and bypass the pyroprocessing stage in manufacturing; however, the country has broader local content and economic diversification requirements that make this infeasible. By not permitting imports to observe the actual operation of the industry at all levels, we find:

- In environmental regulations and depending on the CO_2 price, behavioral considerations have a major impact on the decision-making process of cement manufacturers.
- For a low carbon price of up to 1 $/ton, the industry would have to care for emissions considerably in order to mitigate it. At 45 $/ton or above, behavioral considerations have a limited impact in the wake of profits.
- An example of a policy that could induce a reaction is one that consists of a carbon price of 27 $/ton. At that price, the industry's decision-makers do not have to weigh pollutants highly relative to the industry's profits. The policy would garner $4.9 billion in government revenue and reduce emissions by 181 million tons in the six-year period. The deal would generate $1.3 billion in profit in 2020, compared to $2.5 billion without government intervention.

1. Introduction

According to British Petroleum (2016), Saudi Arabia is the ninth largest CO_2 emitter globally. In addition to power generation and petrochemicals, cement manufacturing constitutes a major polluting industry in the Saudi economy. The country has produced over 61 million tons of cement in 2015 (AlJazirah Capital, 2016). To put that in perspective, the United States produced around 80 million tons of cement in 2015 (United States Geological Survey, 2016); the US has over 10 times the population and 27 times the economic output compared to Saudi Arabia. Cement manufacturing has become a major industry in Saudi Arabia due to the rapid construction being witnessed throughout the country. These projects are fueled by economic performance in much of the last decade and a young population.

Cement manufacturing is additionally one of the most energy- and carbon-intensive domestic sectors. The fuels allocated by Saudi Aramco (2009) to this sector in 2013 amounted to 5.5 percent of the country's total final energy consumption that year, according to total energy use data by the International Energy Agency (2016); this figure excludes the electricity consumed by the industry. Based on standard coefficients of CO_2 emissions per unit of fuel during stationary combustion from the United States' Environmental Protection Agency (EPA) (2014), about 21 million metric tons of CO_2 would have been emitted just from fuel use. Hence, devising an

* Corresponding author.
E-mail addresses: walid.matar@kapsarc.org (W. Matar), amro.elshurafa@kapsarc.org (A.M. Elshurafa).

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environmental policy may take this sector into account. Not only does it produce CO_2 as a result of fuel combustion in kilns, CO_2 is also formed during the calcination process and electricity generation. Improving energy efficiency and utilizing carbon capture and storage (CCS) by the sector could help mitigate the country's emissions.

The objectives of this paper are twofold. One, we put forth an analysis of CO_2 emissions for the Saudi cement industry. To our knowledge, there is no paper discussing this topic for Saudi Arabia. The second is to explore the idea of behavioral considerations of firms. The people making decisions for companies have behavioral inputs, or biases, to their decision-making process (e.g., Economic & Social Research Council (ESRC), 2013). The behavioral driver may stem from corporate social responsibility considerations as sustainability concerns have become increasingly important across countries and industries (Jenkins and Yakovleva, 2006; Carroll and Shabana, 2010). Furthermore, a situation may be political, as with emission regulations, and the use of a multi-criteria decision analysis can increase the probability that implementation is successful (Luoma, 2016).

The topic of investment in energy efficiency in the cement industry to improve air quality is not new. Previously, Worrell et al. (2008) reviewed the technologies that can be adopted for this purpose in cement manufacturing. More recently, Wang et al. (2014) applied an integrated assessment model to study the potential of CO_2 mitigation technologies in China's cement industry. For the same region, Zhang et al. (2015) studied how energy efficiency can improve air pollution in the process of cement-making. They found the cost-effective energy-saving measures given the present fuel prices, investment costs and other costs to the cement industry. Xu et al. (2016) later applied a cost-minimization approach to this problem, which included the CO_2 costs explicitly in the objective function. They had several kiln technologies and CCS as part of their model. Later, Huang et al. (2016) used a simulation-based bottom-up model to assess the prospects of higher energy efficiency in the Taiwanese cement sector.

The Saudi cement industry has predominantly relied on simple long-dry kilns. These companies have not minded the kilns' fuel inefficiency because energy costs have been low. Using 2015–2020 as the time period of interest, our methodology allows to account for changes in energy prices that are not anticipated by the industry. Allowing for imports and weighing importance for CO_2 emissions highly, the industry would choose to import clinker and bypass the pyroprocessing stage in manufacturing. We have thus not permitted imports in the analysis to observe the actual operation of the industry at all levels; if the sector only imports, there would not be an industry. Ideal CO_2 abatement policies can be reached between policymakers and the cement industry.

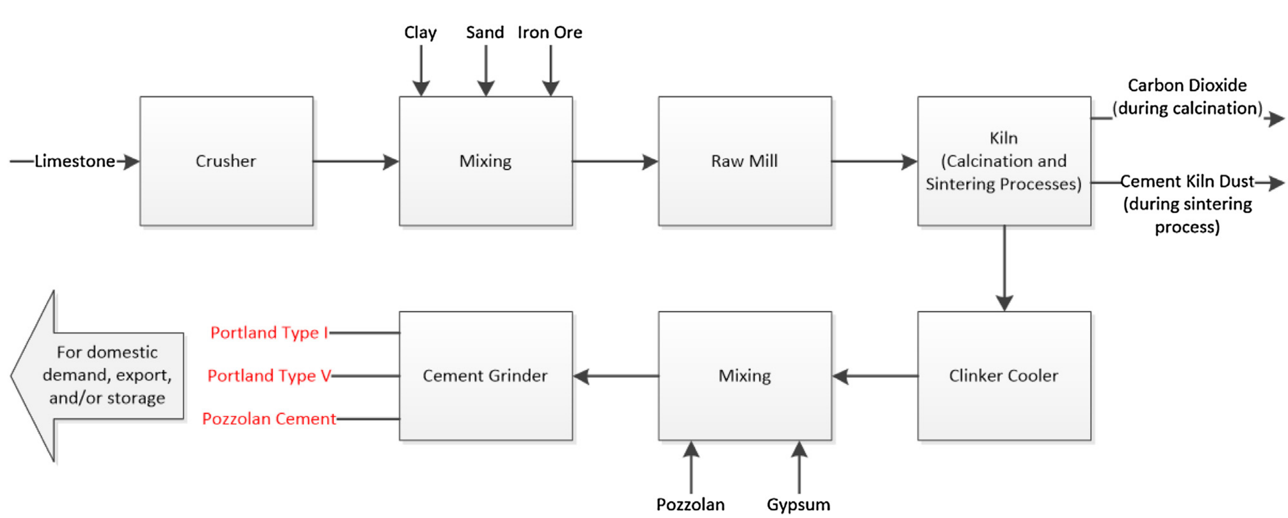
The rest of the paper is organized as follows: the next two sections provide an overview of the cement-making processes and the industry in Saudi Arabia. The subsequent section discusses the carbon emissions policies used in practice. After that, we describe how the analysis was approached, and the paper is concluded with model-based results.

2. An overview of cement production: an energy- and carbon-intensive process

Cement production follows a linear path, as stylized in Fig. 1. A processed mixture of crushed limestone, clay, sand, and iron is first formed then enters the pyroprocessing phase. Pyroprocessing entails the kiln, which includes the calcination and sintering processes, and the heat-induced chemical process produces cement clinker. CO_2 and dust are formed as part of the process at this point, in addition to the emission of CO_2 as a fuel combustion product; CCS could be installed at this stage. Once the clinker is cooled, it is mixed with Pozzolan ash and gypsum, depending on the type of cement the consumers demand, and ground to end up with finished cement. In Saudi Arabia, the cement demand almost exclusively consists of Portland types I and V, and Pozzolan cement. The finished product may either be sold to the market or stored for future sale.

All the units require electricity and/or fuel to operate. The pyroprocessing step requires the greatest amount of energy and emits a large quantity of pollutants. According to Princiotta (2011), a kiln without preheating or precalcination uses around five GJ of energy per ton of clinker produced. Whereas a kiln with both features takes down that value to 3.3 GJ per ton of clinker. Moreover, we estimate from the work of Alsop et al. (2001) that over 5.61 kWh of electricity are used for every ton of clinker in this process. We therefore focus on the energy efficiency of the kilns to tackle the issue of energy consumption and pollutant emissions.

Ultimately, three options have the biggest impact on emissions. One is fuel selection, where choosing to burn less polluting fuels, even if more expensive, is one path to take. The second is by investing in more energy efficient equipment or CCS used in the pyroprocessing phase. The last option is to buy all electricity from the grid rather than generate it on-site; of course, this option is not



(Source: KAPSARC, 2016)

Fig. 1. Cement production path.