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Evaluation of energy saving potential in China's cement industry using the Asian-Pacific Integrated Model and the technology promotion policy analysis

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HIGHLIGHTS

- We evaluate the effectiveness of energy savings and emission reductions in China's cement industry via the AIM/end-use model.
- Three scenarios are simulated to project the potential for energy savings and emission reductions over the next decade.
- Structural adjustment and technology promotion are both key approaches for energy conservation.
- Structural adjustment is the most important approach to reduce the CO_2 emissions from the cement industry.

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ABSTRACT

Much of China's cement industry still uses outdated kilns and other inefficient technologies, which are obstacles to improving energy efficiency. Huge improvements in energy consumption intensity can be made by improving this technology. To evaluate the potential for energy-saving and CO_2 emissions reduction in China's cement industry between 2010 and 2020, a model was developed based on the Asian-Pacific Integrated Model (AIM). Three scenarios (S1, S2 and S3) were developed to describe future technology policy measures in relation to the development of the cement industry. Results show that scenario S3 would realize the potential for CO_2 emissions mitigation of 361.0 million tons, accounting for 25.24% of the predicted emissions, with an additional energy saving potential of 39.0 million tons of coal equivalent by 2020. Technology promotion and industrial structure adjustment are the main measures that can lead to energy savings. Structural adjustment is the most important approach to reduce the CO_2 emissions from the cement industry; the resulting potential for CO_2 emissions reduction will be increasingly large, even exceeding 50% after 2016.

1. Introduction

The Intergovernmental Panel on Climate Change Fifth Assessment Report issued in 2013 clearly states that there is an "extremely likely (95–100%)" relation between human activity and warming since the mid-20th century (IPCC, 2013). Rising CO_2 and other greenhouse gas (GHG) emissions largely deriving from energy consumption are contributing to significant global climate change (Zhou et al., 2013). One such challenge is to reduce GHG emissions from industry, which is one of the greatest contributors to anthropogenic GHG concentration (Hashimoto et al., 2010; Wen et al., 2014c). Approximately 5% of global anthropogenic CO_2 can be attributed to cement production. In China, the cement industry is the second most energy intensive industry (after the steel industry) accounting for 5.4% (179 million tce) of the country's total energy use and 15% (1137 million tons CO_2) of the country's total greenhouse gas emissions in 2010 (CCA, 2011).

The cement industry, as a pillar of Chinese economic development, has grown rapidly alongside the national economy. Cement production has increased dramatically from 65.24 million tons in 1978 to 2099 million tons in 2011, with an average annual growth rate of 11.08% (NBSC, 2013). Up to 2011, China has been the largest cement-producer in the world for 26 consecutive years, accounting for about 60% of the world's total cement production. During

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the 12th Five-Year Plan for National Economic and Social Development (12th FYP, 2011–2015), cement production will continue to increase rapidly. Overcapacity has become the biggest obstacle to overcome, and managing this is the key factor for reducing total emissions in the cement industry (CCA, 2011).

In the cement industry, CO_2 emissions come from fossil fuel combustion and the calcination process. In 2010, the CO2 emissions from China's cement industry were 1137 million tons, an increase of 38% from 820 million tons in 2005. According to Wu's calculations (Wu, 2006), every ton of cement production produces 0.815 t CO_2 on average, of which 0.390 t is from fuel combustion and 0.425 t from raw material decomposition in the calcination process.

During China's 11th FYP (2006–2010), the Chinese government aimed to phase out obsolete vertical kilns, and promote dry rotary kilns that have new suspension pre-heaters or pre-calciners (NSP kilns). The specific energy consumption of NSP kilns are 20% lower than that of vertical kilns. Widespread use in China began in 2000 (Xu et al., 2012), and by 2010, the proportion of cement production from NSP kilns had reached 80% (MIIT of PRC, 2011a), which shows a significant shift in the cement industry to promote energy efficiency. From 2005 to 2010, the yearly total energy consumption per unit of cement production decreased from 0.119 tce/t to 0.096 tce/t, a drop of 24%; the total electricity consumption declined from 0.0123 tce/t to 0.0116 tce/t with a drop of 6.4%; and the heat consumption for clinker also went down from 0.146 tce/t to 0.120 tce/t with a decline of 21.7%. However, there are still many outdated kilns (e.g. vertical kilns) used in China's cement industry, which is one of the biggest obstacles to improve the overall energy efficiency of the industry. With the large-scale development of NSP kilns in China's cement industry, the comprehensive energy consumption of domestic advanced kilns has reached the international advanced level. Taking the NSP kilns with large scale production ($>$ 4000 t/day) for example, comprehensive energy consumption of the average domestic kiln and the international level were 0.105 tce/t and 0.096 tce/t respectively. Therefore, overall there is 10% room for improvement in energy efficiency compared with international advanced NSP kilns.

In recent years, China's cement industry has taken several measures to reduce its energy consumption and CO_2 emissions, primarily through: increasing production efficiency; regulating the industry; and promoting advanced energy-saving and CO_2 emissions-reduction technologies (Chen et al., 2012). During the 11th FYP, total CO_2 emissions per ton of cement production decreased to 0.605 t in 2010 from 0.770 t in 2005. And there was a total CO_2 emissions reduction of 309 million tons in 2010 compared with the CO_2 emission level in 2005. A total reduction of 28.88 million tons of CO_2 emissions was achieved by eliminating outdated cement clinker capacity; the use of low-temperature cogeneration technologies reduced emissions by 14.45 million tons; and mixing materials with waste residues reduced emissions by 139.70 million tons. The rest of emissions reductions were induced by other energy saving and emission reduction technologies such as combined grinding technology, motor frequency conversion transformation and so on (Tsinghua University and ITIBMIC, 2012). Overall this led to a significant effect on energy savings and the reduction of CO_2 emissions. Related effects in China's cement sector have been discussed at depth in academic literature. For example, Jiang (2007) estimated the effects on energy-savings and CO_2 reduction from the increased production efficiency. Other studies (Wang et al., 2010; Xiong et al., 2004) focused on the potential for energy-savings and CO_2 emissions reduction from changes in industrial structure, while some (Zeng, 2006) measured the benefits of the promotion of energy saving technologies. However, the literature mentioned above only focuses on one aspect of energy saving and emission reduction measures, such as production efficiency, industrial structure, promotion of a few technologies and others. Further, many of the existing studies lack quantitative evaluations on the influence of technology promotion (Gäbel et al., 2004; Worrell et al., 2000), while the potential for energy saving and emissions reduction by technology promotion is also rarely mentioned. Those disadvantages make it difficult for government managers to fully understand the potential for energy saving and emission reduction and formulate proper policies.

Several energy modeling approaches based on the system integration method have been used to forecast future trends in energy demand and CO_2 emissions, and to assess strategies for energy-saving and emissions reduction; these can be categorized into "top-down" and "bottom-up" models (Matsuoka et al., 1995; Turton, 2008). Top-down models start with an economic mechanism using prices and elasticity as economic indices and present relationships between energy consumption, production and economic indices in an in-depth manner (Kainuma et al., 2000; Liang et al., 2013), of which the CGE (Computational General Equilibrium) model is the most common (Farmer and Steinberger, 1999; Naqvi and Peter, 1996; Wang et al., 2005). Bottom-up models simulate energy systems based on technologies for energy consumption and production (Bohringer and Rutherford, 2009). Of these, the LEAP (Long-range Energy Alternatives Planning System) and AIM (Asian-Pacific Integrated Model) are the most common (SEI, 2006; UNFCCC, 2008; Wen et al., 2014b). The AIM/end-use model can simulate industry production processes and the effectiveness of energy-saving and CO_2 emissions-reduction approaches with an independent technical optimal selection module (Mikiko et al., 2000; Xu and Masui, 2009; Wen et al., 2014a; Chunark et al., 2013, 2014; Selvakkumaran et al., 2014a, 2014b), which is unique amongst the analysis of energy-saving and CO_2 emissions-reduction approaches. Other bottom-up models include the Model for Analysis of Energy Demand (MAED) model, developed by the International Atomic Energy Agency (IAEA) (Hainoun et al., 2006; Yuksek et al., 2006), the MESSAGE model and the Market Allocation (MARKAL) model etc. (Berger et al., 1987; Fishborne and Abilock, 1981). Moreover, the Industrial Water Conservation Potential Analysis Model (IWCPA) has been developed for research on the potential for water saving in the electricity, iron and steel, petrochemical, and textile industries (Du et al., 2007). The Conservation Supply Curve (CSC) model has been applied to the analysis of the energy efficiency and CO_2 emissions of the steel and cement industries in India (Morrow et al., 2014).

In this paper, we analyze different technology policies and approaches for energy-saving and CO_2 emissions reduction in China's cement industry using the AIM/end-use model. This paper has been divided into five sections: Section 2 describes the methodology used for this study on the cement industry and gives a sketch of three scenarios developed to describe future technology policies in relation to the development of the cement industry; Section 3 presents analyses of the results and key findings; discussion is presented in Section 4; and the final section provides conclusion and policy implications.

2. Methods

2.1. AIM/end-use model

Developed by Japan's National Institute for Environmental Studies (NIES), the AIM/end-use model is based on a cost minimization linear programming approach. It simulates the flows of energy and materials in an economy, from the source and supply of primary materials and energy, through the conversion into secondary energy and materials, and finally to the delivery of end-use products or services. It is commonly used to estimate future