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Evaluating co-benefits of energy efficiency and air pollution abatement in China's cement industry

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HIGHLIGHTS

- Implementation rates of 37 EEMs are quantified for China's cement industry.
- Energy Supply Cost Curves were implemented in the GAINS model.
- The economic energy saving potential is 3.0 EJ and costs is $4.1 billion in 2030.
- Energy efficiency would lead to large reductions in air pollution.
- The co-benefits decrease average marginal costs of EEMs by 20%.

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ABSTRACT

China's cement industry is the world's largest and is one of the largest energy consuming, and GHG and air pollutant emitting industries. Actions to improve energy efficiency by best available technology can often bring co-benefits for climate change and air quality through reducing emissions of GHGs and air pollutants emission. In this study, the energy conservation supply curves (ECSC) combined with the GAINS (Greenhouse Gas and Air Pollution Interactions and Synergies) was used to estimate the co-benefits of energy savings on CO_2 and air pollutants emission for implementing co-control options of energy efficiency measures and end-of-pipe options in the China's cement industry for the period 2011–2030. Results show that there are large co-benefits of improving energy efficiency and reducing emissions of CO_2 and air pollutants for the China's cement industry during the study period. The cost-effective energy saving potential (EEP1 scenario) and its costs is estimated to be 3.0 EJ and 4.1 billion $ in 2030. The technical energy savings potential (EEP2 scenario) and its costs amount to 4.2 EJ and 8.4 billion $ at the same time. Compared to the baseline scenario, energy efficiency measures can help decrease 5% of CO_2, 3% of PM, 15% of SO_2, and 12% of NOx emissions by 2030 in EEP1 scenario. If we do not consider costs (EEP2 scenario), energy efficiency measures can further reduce 3% of CO_2, 2% of PM, 10% of SO_2, and 8% of NOx by 2030. Overall, the average marginal costs of energy efficiency measures will decrease by 20%, from 1.48 $/GJ to 1.19 $/GJ, when taking into account avoided investments in air pollution control measures. Therefore, implementation of energy efficiency measures is more cost-effective than a solely end-of-pipe based policy. The plant managers and end users can consider using energy efficiency measures to reach new air pollutants emission standards in China's cement industry.

1. Introduction

The cement industry consumes around 2% of global primary energy use and produces 5–7% of anthropogenic CO_2 emissions worldwide, together with very high air pollutant emissions, including sulfur dioxide (SO_2), nitrogen oxides (NOx) and particulate matter (PM) [1–4]. Past studies estimate that the global potential of improved energy efficiency and reduced greenhouse gas emissions in the cement industry could save up to 50% of fuel use, and mitigate 18% of direct CO_2 emissions and almost 20% of process CO_2 emissions from current level by 2050, through adopting best available technology, shifting process from wet to dry, replacing fossil fuels with alternative fuels, and decreasing clinker to cement ratio [1,5,6].

China's cement industry has attracted attention worldwide. Despite several efforts, such as increasing the new dry process

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Nomenclature

Abbreviations

ECSC	energy conservation supply curves
MACC	marginal abatement cost curves
GAINS	Greenhouse Gas and Air Pollution Interactions and Synergies
BL scenario	baseline scenario
EEP1	energy efficiency policy scenario 1
EEP2	energy efficiency policy scenario 2
BLAP	baseline scenario with air pollutants policy scenario
EEPAP1	energy efficiency policy with air pollutants policy scenario 1
EEPAP2	energy efficiency policy with air pollutants policy scenario 2
GHGs	greenhouse gases
SO_2	sulfur dioxide
NOx	nitrogen oxides
PM	particulate matter
Mt	million tons
NSP kilns	new suspension preheater/precalciner kilns
WHR	waste heat recovery
SEC	specific energy consumption
ESP	electrostatic precipitator
SNCR	Selective Non-Catalytic Reduction
AEEI	annual autonomous energy efficiency improvement
EEI	energy efficiency investment
OECD	The Organisation for Economic Co-operation and Development
WEO	World Energy Outlook
IEA	International Energy Agency
IIASA	International Institute for Applied System Analysis
LBNL	Lawrence Berkeley National Laboratory
ERI	Energy Research Institute of China
MIIT	Ministry of Industry and Information Technology of China
NCSC	National center for Climate Change Strategy and International Cooperation of China
ITIBMI	IT Institute of Building Materials Industry
CSIBM	China Development Strategy Institute for Building Materials Industry
CAS	The Chinese Academy of Sciences
EMEP/EEA	European Monitoring and Evaluation Programme/European Environment Agency
CSI	Cement Sustainability Initiative
IPCC	Intergovernmental Panel on Climate Change

Symbols

CCE	cost of conserved energy for an energy efficiency measures
I	investment
AF	annuity factor
$O\ \&\ M^{Fix}$	annual change in operation and maintenance fixed cost
$O\ \&\ M^{Var}$	annual change in operation and maintenance variable cost
ESP	annual energy saving potential
PE	future energy price ($/GJ)
d	discount rate
n	lifetime of the energy efficiency measures
E_p	emissions of pollutant p (for e.g. SO_2, $PM_{2.5}$, CO_2, PM_{10}, PM_{TSP}, etc.)
cn	unit cost of end-of-pipe measures
A_k	energy consumption of each fuel (e.g., coal consumption) in iron and steel industry
$ef_{k,m,p}$	emission factor of pollutant p for activity k after application of control measure m
$x_{k,m,p}$	share of total activity of type k to which a control measure m for pollutant p is applied
A	activity
ef	uncontrolled emission factor
ef_m	controlled emission factor under end-of-pipe measures

Subscript

k, m, p	activity type, abatement measure, pollutant, respectively

application, closing obsolete plants, and using various best practice technologies, that have been made by Chinese government in the past two decades, recent studies indicate that there is still large opportunity to improve energy efficiency, reduce emissions of GHGs and air pollutants [7–10]. Comparing the disparity between the current energy efficiency level in China and best practice, indicates a cumulative energy savings potential of 5.0–37.5 EJ in the period 2011–2030, under different scenarios [8,10]. Likewise, if all Chinese cement plants adopted energy efficiency improvement measures, alternative fuels, and clinker substitution (to reduce the clinker–cement ratio), 2.5–4.7 Gt or 53% CO_2 would be saved up to 2050 [7,11]. Lei evaluated local air pollutants, such as PM, SO_2, and NOx in China's cement industry using the proportion of different types of kilns to produce cement and air pollutant emission standards for the Chinese cement industry, and they found that PM and SO_2 emissions would decrease, by shifting from wet to dry process. NOx emissions would decrease because of the increase of precalciner kilns [12]. Furthermore, many studies have shown that the co-benefits (including direct co-benefits and indirect co-benefits) of health effects of energy efficiency improvement and CO_2 mitigation can be substantial [3,13,14]. For instance, Xi [15] estimated the interaction between carbon mitigation and air pollutant control measures in China's cement industry during the 12th Five Year Plan period, and found significant co-benefits of 18 energy saving technologies. However, most of these studies usually do not monetize the co-benefits when assessing the best available technologies and end-of-pipe options. Therefore, synergies between policies to address energy efficiency and air pollutant emissions mitigation have been neglected by policy makers [15]. The aim of this paper is to address this gap by assessing the co-benefits of energy efficient technologies and air pollutant control in the China's cement industry and quantify how co-benefits would affect the cost effectiveness of energy efficiency technologies.

The structure of this paper is as follows, Section 2 gives an overview of China's cement industry. The methodology, data collection, and scenarios construction is given in Section 3. The results of energy saving potential and emission mitigations of GHGs and air pollutions and associated costs for different scenarios are discussed in Section 4. Section 5 provides a discussion of sensitivities and comparison with other studies. Finally, the conclusion is given in Section 6.

2. Overview of China's cement industry: production, energy consumption and emissions

In this section, we first give an analysis of historical production of clinker and cement and associated fixed investment in China. The Historical energy use, emissions of GHGs and air pollutants and intensity are presented in Sections 2.2 and 2.3, respectively.