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Modeling energy efficiency to improve air quality and health effects of China's cement industry

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HIGHLIGHTS

- An integrated model was used to model the co-benefits for China's cement industry.
- $PM_{2.5}$ would decrease by 2–4% by 2030 through improved energy efficiency.
- 10,000 premature deaths would be avoided per year relative to the baseline scenario.
- Total benefits are about two times higher than the energy efficiency costs.

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ABSTRACT

Actions to reduce the combustion of fossil fuels often decrease GHG emissions as well as air pollutants and bring multiple benefits for improvement of energy efficiency, climate change, and air quality associated with human health benefits. The China's cement industry is the second largest energy consumer and key emitter of CO_2 and air pollutants, which accounts for 7% of China's total energy consumption, 15% of CO_2, and 14% of $PM_{2.5}$, respectively. In this study, a state-of-the art modeling framework is developed that comprises a number of different methods and tools within the same platform (i.e. provincial energy conservation supply curves, the Greenhouse Gases and Air Pollution Interactions and Synergies, ArcGIS, the global chemistry Transport Model, version 5, and Health Impact Assessment) to assess the potential for energy savings and emission mitigation of CO_2 and $PM_{2.5}$, as well as the health impacts of pollution arising from China's cement industry. The results show significant heterogeneity across provinces in terms of the potential for $PM_{2.5}$ emission reduction and $PM_{2.5}$ concentration, as well as health impacts caused by $PM_{2.5}$. Implementation of selected energy efficiency measures would decrease total $PM_{2.5}$ emissions by 2% (range: 1–4%) in 2020 and 4% (range: 2–8%) by 2030, compared to the baseline scenario. The reduction potential of provincial annual $PM_{2.5}$ concentrations range from 0.03% to 2.21% by 2030 respectively, when compared to the baseline scenario. 10,000 premature deaths are avoided by 2020 and 2030 respectively relative to baseline scenario. The provinces of Henan and Hubei account for 43% of total avoided premature deaths, followed by Chongqing (9%) and Shanxi (10%), respectively. If only considering the energy saving benefits, 37% of energy efficiency measures are not cost effective. However, the co-benefits (including energy saving, CO_2 reduction, and health benefits) are about two times higher than the costs of energy efficiency measures. Hence, this study clearly demonstrates that simultaneous planning of energy and air quality policies creates a possibility of increasing economic efficiency in both policy areas.

1. Introduction

Air pollution due to massive use of fossil fuels has received considerable attention in recent years [1–3]. The World Health Organization (WHO) estimates that about one million premature deaths are caused by outdoor air pollution in the world each year, with

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Nomenclature

WHO	World Health Organization
$PM_{2.5}$	fine particulate matter with a diameter smaller than 2.5 μm
GHGs	greenhouse gases
BC	Black Carbon
OC	Organic Carbon
VOC	volatile organic compounds
CEV	cerebrovascular disease
IHD	ischemic heart disease
MESSAGE	The Model for Energy Supply Strategy Alternatives and their General Environmental Impact
GAINS	The Greenhouse Gases and Air Pollution Interactions and Synergies
UKIAM	the UK integrated assessment model
SIRMOD	Surface Irrigation Model
GIS	geographical information system
LCA	life cycle assessment
SFA	substance flow analysis
ADM	air dispersion modeling
HIA	health impact assessment
MCDA	Multi-Criteria Decision Analysis
CMAQ	Community Multiscale Air Quality
BenMAP	the environmental Benefits Mapping and analysis Program
ECSC	Energy Conservation Supply Curves
IIASA	International Institute for Applied Systems Analysis
USEPA	the United States Environmental Protection Agency
EPPA-HE	emission prediction and policy analysis model with health effects
AirQUIS	the air quality management tool
TM5	the global chemistry Transport Model, version 5
TM	Tracer Model
TM5-FASST	TM5 with fast scenario screening tool
ECMWF	the European Centre for Medium Range Weather Forecast
IPCC	Intergovernmental Panel on Climate Change
AR5	Fifth Assessment Report
HIA	health impact assessments
YOLL	Years Of Life Lost
DALY	Disability Adjusted Life Years
PAF	the population-attributable fraction
C-R	concentration-response
COPD	chronic obstructive pulmonary disease
IHD	ischemic heart disease
VOSL	the value of a statistical life
WTP	willingness to pay
COI	cost of illness
BTA	the benefit transfer approach
WEO	World Energy Outlook
IEA	International Energy Agency
SCC	social cost of carbon
MIIT of China	Ministry of Industry and Information Technology of China
LBNL	Lawrence Berkeley National Laboratory
ERI of China	Energy Research Institute of China
WBCSD	World Business Council for Sustainable Development
MEP of China	Ministry of Environmental Protection of China
CVD	cardiovascular disease
LC	lung cancer disease
RD	disease of the respiratory system
BL	baseline scenario
EEPTP	Energy Efficiency Policy with technical energy saving potential scenario
AEEI	annual autonomous energy efficiency improvement
NSP	new suspension preheater

Symbols

CCE	cost of conserved energy
I	investment
AF	annuity factor
M	annual change in operation and maintenance costs
E	annual energy saving potential
P	energy price
d	discount rate
n	lifetime of the energy efficiency measures
$E_{i,p}$	emissions of pollutant p (for BC, OC, VOC, CO, and dust) in county i
$A_{i,k}$	activity level of type k (e.g., fuel consumption, production of cement/clinker in cement plants) in county i
$ef_{i,k,p}$	emission factors of pollutant p for activity k in county i.
ΔY	the change of mortality/morbidity rate
$\alpha_{2010,>30ages}$	the mortality/morbidity rate of over 30 years of age cohort at the base year (2010)
HR	the Hazard ratio for an increase in $PM_{2.5}$ concentration of 10 μg/m^3
ΔC	the changes of $PM_{2.5}$ concentration under different scenarios
P	the affected population
$VOSL_i$	the VOSL of the year i (2020 and 2030)
$VOSL_{2010}$	the VOSL of the year 2010
I_{2010}	the personal income of the year 2010
I_i	the personal income of the year i
e	the personal income elasticity.

Subscript

i, k, p	county, activity type, pollutant, respectively.

fine particulate matter with a diameter smaller than 2.5 μm ($PM_{2.5}$) as one of the prominent contributors [4,5]. Based on the database of global burden of disease, Lelieveld et al. [6] found that $PM_{2.5}$ related mortality in 2010 was 3.15 million people per year worldwide (1.61–4.81 million death per year at 95% confidence interval), with cerebrovascular disease (CEV) accounting for 42% (1.31 million) of total premature deaths and 34% (1.08 million) due to ischemic heart disease (IHD) [6]. The study also found that the contribution of outdoor air pollution to premature death would double (6.6 million) by 2050 in a business-as-usual scenario [6]. In 2013, an estimated 0.26 million premature deaths in 31 Chinese capital cities could be linked to $PM_{2.5}$ air pollution. The study also found that if the annual $PM_{2.5}$ concentration meets the Air Quality Guidelines set by Chinese government standards, the mortality rate could be decreased by 0.41‰, compared to 2013 [7]. During the period of April 5, 2014 and August 5, 2014, China's population-weighted exposure to $PM_{2.5}$ was 52 μg/m^3, which led to about 1.6 million deaths per year (0.7–2.2 million deaths per year at 95% confidence interval). The diseases of Ischemic heart, lung cancer and strokes accounted for 17% of total number of deaths in China, together [8]. Therefore, the Chinese government released the national action plan on air pollution control. In this strategy, $290 billion (1.75 trillion yuan) has been invested between 2013 and 2017, of which the industry will absorb 36.7%