Journal of Cleaner Production xxx (2015) 1–15

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Goal and technology path of CO_2 mitigation in China's cement industry: from the perspective of co-benefit

Qilu Tan [a], Zongguo Wen [a, b, *], Jining Chen [a]

[a] State Key Joint Laboratory of Environment Simulation and Pollution Control (SKLESPC), School of Environment, Tsinghua University, Beijing 100084, China
[b] Joint Center for Global Change Studies (JCGCS), Beijing 100875, China

ARTICLE INFO

Article history:
Received 6 August 2014
Received in revised form
19 June 2015
Accepted 24 June 2015
Available online xxx

Keywords:
CO_2 mitigation
Local air pollution (LAP)
Co-benefit
Cost-effectiveness
Bottom-up model

ABSTRACT

The concept of co-benefit, a negotiation topic in CO_2 mitigation attracts worldwide attention including China in coping with climate change. Energy saving technologies as common measures for CO_2 abatement, generally lead to co-benefits of local air pollution (LAP) because most LAP emissions are generated from combustion of carbonic fuels along with CO_2. However, in the technological dimension, there are technologies that induce opposite effects on the co-benefit of CO_2 and LAP in specific industry sectors. Precalcinating line and shaft kiln, two types of technologies adopted in clinker calcinating procedure in cement industry are examples: the former consume less energy but emit more dust and NO_x than the later. As a result, the overall co-benefits of LAP reductions for cement industry are uncertain. This study consequently aims at assessing the overall co-benefit (although it may be a negative co-benefit) of CO_2 mitigation policy on dust, NO_x, SO_2 emissions in China's cement industry aggregately by establishing bottom-up optimization model on the basis of all types of technologies which are called technology system in cement production. CO_2 mitigation goal, as represented by reduction rate is regarded as constraint input into the model. In order to investigate the evolution of co-benefits and technology paths with the change of CO_2 mitigation goal, hundreds of reduction rates are selected randomly between the range 0.5–10.5%. The lower bound 0.5% reveals CO_2 emission reduction that can be reached for cement industry under existing political constraints and without any extra CO_2 mitigation goal. The upper bound 10.5% is the greatest reduction rate under which the model could derive feasible solution. According to changes of technology penetration rates as CO_2 goal tightens, we could evaluate the more cost-effective technologies from the perspective of co-benefit. They are vertical milling, precalcinating line with the scale of 7000–10,000 ton/day, roll-squeezer belonging to Main Production Technology (MPT), utilization of cement grinding aids, multi-channel coal burner belonging to Affiliated Energy-saving technology (AES), combination of bag-filter and electrostatic precipitator and ultra-low NO_x burning technology belonging to Pollution Control Technology (PCT). With respect to the evolution of co-benefits on air pollutions, when the CO_2 reduction rate is below 2.3%, co-benefit of dust and SO_2 reduction exist while that of NO_x does not; and when the rate is above 2.3%, co-benefits of all the three pollutants exist. A practically referable goal of CO_2 mitigation rate of short/mid-term is approximately 5.5% in view of the following three considerations: a) co-benefits augment as CO_2 reduction rate increases; b) total cost increases as the CO_2 abatement goal becomes stricter; and c) the majority of emerging technologies normally cannot penetrate to 100% in cement production within a relatively short time.

1. Introduction

In 2007, United Nations Framework Convention on Climate Change (UNFCCC) in its report of the Conference of the Parties on the thirteenth Session (also called the Bali Action Plan) identifies the sectoral approaches as a critical method in dealing with the effects of climate change (UNFCCC, 2008). Since then, such strategy has attracted extensive attention from both academics and politicians in addressing climate change issues.[1] For China, cement industry is one of the sectors that need to be focused on the most in

* Corresponding author. State Key Joint Laboratory of Environment Simulation and Pollution Control (SKLESPC), School of Environment, Tsinghua University, Beijing 100084, China. Tel./fax: +86 10 62792921.
E-mail address: wenzg@tsinghua.edu.cn (Z. Wen).

[1] See for example, Cai, et al., 2009; Kannan and Strachan, 2009; Majumdar and Galghate, 2011; Gross, 2012; Oxley et al., 2012; Xu et al., 2014.

http://dx.doi.org/10.1016/j.jclepro.2015.06.148
0959-6526/

GHGs mitigation. China, producing 2.21 billion tons of cement in 2012 and accounting for more than 60% of the world's total production, has become the largest cement producer in the world (China Cement Almanac, 2013). Cement industry contributes considerably to the whole country's CO_2 emission with the proportion of about 13–15% (Building Material Industry and Technology Information Institute (BMITII), 2012). It suggests that as rigid demand continuously increases and the alternatives of cement accounts for little proportion, cement production and its CO_2 emission will continue to grow rapidly in at least five years. Cement industry is worth taking seriously not only because of its huge amount of CO_2 emission but also for its significant local air pollution (LAP) emissions. Emissions of industrial dust, NO_x (oxides of nitrogen), soot and SO_2 (sulfur dioxide) account approximately 50%, 16%, 15% and 9% for the whole country industrial emissions respectively (the proportions are calculated from emission amounts of these air pollutants and national total air pollutions in the China Statistical Year Book on Environment, 2013). Dust and NO_x, the former produced from production procedure and the latter emitted due to coal burning, are two primary air pollutants in China cement industry.

China has made great efforts in controlling emissions of CO_2 and LAP in cement industry, majority of which are based on improvement of energy efficiency of technologies. Examples can be found in the document of Cement Industry Access Regulation promulgated by Ministry of Industry and Information Technology (MIIT) in 2009. It lays down the lowest acceptable energy efficiencies of clinker calcination technologies which means if the energy efficiency is smaller than provisions, such calcinations lines should not be put into operation (for new lines) or should be eliminated (for built lines). National Development and Reform Commission (NDRC) has issued a series of energy conservation technology directory since 2008, emphasizing the technologies in cement industry whose applications need to be promoted and the possible penetrations of such technologies in at least five years. In practice, such political measures pose great benefit on improvement of energy efficiency: China cement industry ranks the third and the fourth lowest in energy consumption per ton clinker and per ton cement respectively all over the world (BMITII, 2012). However, CO_2 emission intensity and energy consumption per GDP are still high in comparison with other countries in the world-the former cannot even reach the world's average level. Obviously further efforts are in great necessity on efficiency improvement for energy-saving technologies and their popularization.

In China, judgment of whether certain energy saving technology is suitable for applying and promoting usually depends on experts' judgments or narrow-sense cost-benefit analysis based on a single project. Both methods are insufficient of depicting real-world's situation: expert judgments almost thoroughly rely on experts' experiences and ignore the importance of impersonality of quantitative analysis whilst narrow-sense cost-benefit analysis is incapable of considering cost/benefit aspects other than monetary terms. For an instance, pollution reduction derived from implementation of energy-saving technology should also be regarded as benefits. Understanding the comprehensive cost/benefit of technology promotion policy could increase the accuracy and effectiveness of decision-making. Therefore, quantitative method, including systematic view on assessing cost-effectiveness of energy conservation technologies, is required. Bottom-up model where technology system is constructed on the basis of industrial production procedures could be an alternative in supporting system-view. Several studies have already been engaged in employing bottom-up model to conduct technological cost-benefit analysis of cement industry (Cai et al., 2009; Chen et al., 2012). This paper also establish a bottom-up model based on cement production process, of which the major difference comparing to other similar studies is that it takes both monetary costs and mitigation abilities of CO_2 and LAP into consideration when assessing technological cost-effectiveness. More advantages of the model in this study will be elaborated in Section 3.1.

Considerable measurements as aforesaid are adopted in China to mitigate CO_2 and LAP emissions, usually separately. However in reality certain measurements have impact both on CO_2 and LAP, which means co-effects exist. A typical measurement is energy conservation technology, commonly used to mitigate CO_2. Energy conservation technologies aiming at saving carbonic fuels can reduce CO_2, as well as SO_2, dust and other LAP that are generated by combustion of coal-the primary fuel in cement industry. In this case, applications of such technologies have co-benefit on LAP reductions, but the situation is possibly inverse when regarding pollution control technologies because their employment could consume energy and hence offset CO_2 mitigation in a way. Regarding two types of technologies above, we can find that uncertainty exists in the outcomes of co-benefits when technology system contains both CO_2 abatement and air pollution reduction technologies. Obviously, it is worth addressing whether co-benefit exists when aggregating all technologies in cement industry, which is another target of the study.

This paper is structured as follows. Section 2 gives an overview of studies relevant to carbon-air mitigation co-benefit, illustrates several crucial literature similar to our study and emphasizes the progress we made. Section 3 details the technology-based bottom-up model of cement industry on the aspects of algorithms, parameters, data and scenario analysis. Results of technology cost-effectiveness and co-benefits of LAP are interpreted in Section 4, and Section 5 concludes the article.

2. CO_2 mitigation policy from the perspective of co-benefit

Intergovernmental Panel on Climate Change (IPCC) (2001, 2007) defines co-benefits as “the benefits of policies that are implemented for various reasons at the same time — including climate change mitigation” — acknowledging that most policies addressing greenhouse gas mitigation have other equally important rationales. IPCC provides no more supporting document on typology and analytical framework of co-benefit except for this conceptual definition, therefore studies of co-benefit consequently vary on type, method and tool. Table 1 summarizes types of co-benefit in related research, especially in those that investigates co-benefits induced by climate policies. Among these co-benefits resulted from implementation of climate policies, air pollution reduction is the most common and fundamental one. Except recognizing the absolute values of LAP reduction as a type of co-benefit, majority of related research conduct “air-health pathway” to evaluate improvement of human health, either in physical item (Rydal et al., 2007) or monetary item (Cifuentes et al., 1999; Dessus and O'connor, 2003; Aunan et al., 2004). Additionally, cost saving relevant to air pollution control is another type of co-benefits induced by air pollution reductions which attracts attention mainly from studies in Europe (Alcamo et al., 2002; van Vuuren et al., 2006; Rive, 2010).

China has encountered severe challenges in responding to local environmental pollution due to its rapid growth of urban population and economic development recently. Meanwhile China, reported as the world's largest contributor of GHGs emission, also has mounting pressure on CO_2 mitigation. Although China has taken

Please cite this article in press as: Tan, Q., et al., Goal and technology path of CO_2 mitigation in China's cement industry: from the perspective of co-benefit, Journal of Cleaner Production (2015), http://dx.doi.org/10.1016/j.jclepro.2015.06.148