Energy Policy 121 (2018) 124–137

Contents lists available at ScienceDirect

Energy Policy

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

How can Indian power plants cost-effectively meet the new sulfur emission standards? Policy evaluation using marginal abatement cost-curves[☆]

Anish Sugathan[a,*], Ritesh Bhangale[b], Vishal Kansal[b], Unmil Hulke[b]

[a] Business Policy Area, Indian Institute of Management Ahmedabad, 380015 Gujarat, India
[b] Indian Institute of Management Ahmedabad, 380015 Gujarat, India

ARTICLE INFO

Keywords:
Power-plant emission standards
SO_2 control technologies
Abatement costs
SO_2 inventory
Indian electric-power sector

ABSTRACT

The first-ever SO_2 emission concentration standards for Indian coal-power plants were notified on December 7, 2015. In light of the new stringent standards, this paper conducts a techno-economic policy evaluation of SO_2 abatement options by building a system-wide marginal abatement cost curve (MACC) for India. An abatement cost model is developed, to estimate retrofit costs for three end-of-process (EOP) SO_2 abatement technologies. A system-wide SO_2 MACC is derived based on cost optimal allocation of EOP abatement technology to each boiler. Compliance with the new stricter emission standards is evaluated at 75% pollution reduction (≈ 4600 kt-SO_2 reductions per year). Compliance with the new standard corresponds to a marginal abatement cost of INR 23,500 per ton of SO2 (≈ USD 368.50 per ton of SO_2) and total system-wide abatement cost of INR 75 billion (≈ USD 1.2 billion) per year. Reduction in pollution is estimated to save 46,000 lives per year at the cost of about INR 1.63 million per life per year. Sensitivity analysis of the MAC curve shows that plant capacity utilization has the most significant impact on total lifetime compliance costs followed by equipment fixed cost, sorbent cost, and water cost in that order.

1. Introduction

The aggregate SO_2 emissions from Indian coal-fired power plants witnessed a 71% increase from 3350 kTons in 2005–5740 kTons in 2012 (Lu et al., 2013). Recent studies show that India is rapidly overtaking China to become the largest emitter of anthropogenic SO_2 (Li et al., 2017). Studies estimate that among the many large point anthropogenic sources of SO_2, coal-fired power plants are responsible for 46–69% of India's total SO_2 emissions (Lu et al., 2013, 2011; Garg et al., 2002, 2001). As a criteria pollutant, there is substantial empirical evidence of the hazardous impacts of SO_2 (EPA, 2016). In particular, SO_2 is a major precursor to fine ambient particulate (PM2.5) concentration and acidic deposition, posing a high risk to human health (EPA, 2016), and agriculture and vegetation (Emberson et al., 2001). In India, pollution from coal power plants is associated with increased incidence of respiratory illness – about 75% of premature cardiopulmonary deaths for persons 30 years and older living in the vicinity of power plants, and about 80,000 to 115,000 premature deaths in total (Gupta and Spears, 2017; Guttikunda and Jawahar, 2014).

This recent spike in power plant building has led to widespread public outcry demanding stringent regulations on hazardous SO_2 emissions from power plants (Gupta and Spears, 2017; Guttikunda and Jawahar, 2014; Ramesh, 2014; GOI, 2013). As a result, the first-ever regulations on Indian coal power plant SO_2 emission concentration were announced on December 7, 2015. Despite the stringent timelines and limits set by the new standards, minimal progress has been reported in the adoption of the sulfur control norms. As per estimates, 90% coal power plants in India continue to violate the emission norms by the first compliance deadline of December 7, 2017 (Patel, 2017). Sethi (2017) argues that it will be easier for the government to enforce the new standards for the newer more efficient supercritical power plants. However, it is likely that Government may invoke the discretionary directive powers vested by the Section-5 of the Environment Protection Act, 1986 to consider the fleet of older power plants on a case by case basis. Consequently, the Central Electricity Authority has extended the deadline for compliance in a phased manner between 2020 and 2024.

A recent survey of plant operators suggests that lack of clarity on the techno-economical viability of SO_2 abatement options suitable for the Indian conditions, and regulatory uncertainty on potential future benefits of investment in abatement — like revenue from emissions trading, etc. — are the most prominent factors responsible for slow adoption (Bhati, 2016). Nonetheless, as per our knowledge techno-economic policy

☆ The corresponding author is thankful to Harvard's Sustainability Science Program for hosting the India Initiative and acknowledges funding support from SAP Labs India, and from Italy's Ministry for Environment, Land and Sea. Rama Mohana R. Turaga, Sarath K. Guttikunda, Amit Garg, and two anonymous reviewers provided invaluable intellectual inputs.
* Corresponding author.
E-mail address: anishs@iima.ac.in (A. Sugathan).

https://doi.org/10.1016/j.enpol.2018.06.008
Received 23 February 2018; Received in revised form 31 May 2018; Accepted 4 June 2018

evaluation of the new SO_2 emission standards for Indian coal-fired power plants using detailed boiler-level data and cost-optimal selection of abatement technologies suitable for India is currently not available.

Our paper aims to fill this gap by evaluating cost-optimal compliance options using comprehensive system-wide SO_2 marginal abatement cost curves (MACC) for Indian coal-fired power plants. Since economic estimation of MACCs based solely on behavioral assumptions without detailed technological considerations often leads to an inaccurate characterization of the abatement costs (Vijay et al., 2010), we estimated abatement costs using an expert based bottom-up approach with detailed boiler level information.

Through the analysis of cost-optimal SO_2 abatement options based on a cost model for India, this paper attempts to contribute to the literature on energy and environmental regulation. By developing analytical tools for mitigation of a significant environmental pollutant, and thereby facilitating sustainable energy infrastructure development for a rapidly growing economy, the techno-economic policy analysis presented in this paper aims to appeal to energy policy scholars, regulators, and utility managers.

In particular, the paper makes five notable contributions to the literature. *First*, a comprehensive and updated dataset of coal-fired power plants operational in India in 2016–17 is prepared for MACC estimation. The emission factor per unit of coal-based power generation is computed for India using a spatially disaggregated SO_2 emissions inventory from coal power-plants. *Second*, three end-of-line SO_2 abatement technology options most suitable for Indian coal power plants were identified in consultations with major power plant operators and technology vendors in India. *Third*, a model of boiler level SO_2 abatement cost is developed using an algorithm that selects for each boiler the retrofit end-of-line SO_2 abatement technology optimizing over both capital investment costs and operating costs discounted over the equipment lifetime. This engineering cost model takes into account detailed information on generation technology, boiler vintage, plant operating efficiency, coal and water usage, and geographic location. *Fourth*, a system-wide SO_2 MACC is estimated consisting of all Indian coal power plants. *Fifth*, technology adoption choices and cost implications are evaluated for compliance with the new Indian emissions standards which will come into force from the year 2020. The MACC is benchmarked against comparable cost curves in other countries, and a cost sensitivity analysis is also performed.

The rest of the paper is organized as follows. A background on coal power-plant building, the resulting increase in SO_2 emissions, and the utility of SO_2 MACCs for techno-economical evaluation of abatement options in India are outlined in Section 2. The methodology used for system-wide computation of MACCs is described in Section 3. Data used for the emission inventory and MACC estimate is described in Section 4. In the results Section 5, the estimated plant-level/system-wide MACC and total-cost curves are described (Section 5.1), distribution of optimal abatement technology adoption is described (Section 5.2), benchmarked with recent estimates of other large SO_2 emitting countries (Section 5.3), and sensitivity analysis is performed for the MACC with varying plant load factor, equipment capital costs, water and reagent costs (Section 5.4). Finally, salient findings and policy relevance of the study are discussed in Section 6.

2. SO_2 marginal abatement cost curves for Indian coal power plants

India is the world's third-largest producer of electricity with a total installed generation capacity of 329.23 GW as of August 2017, of which coal-fired thermal plants (GOI, 2017) generate about 60% (193.47 GW). In the last two decades as the Indian power sector opened up for private investments in generation, coal-based power plant building had picked up a rapid pace. Although Indian coal has low sulfur concentration (~ 0.4–0.6% by weight), aggressive plant building led to about 105% increase in SO_2 emissions from power plants between 1996 and 2010 in India (Lu et al., 2013).

Table 1
Emissions standards in India, China and USA.
Sources: Bhati and Ramanathan (2016).

Country	PM (mg/Nm^3)	SO_2 (mg/Nm^3)	NO_x (mg/Nm^3)
India			
Old standards	150–350	None	None
New standards			
Units installed before 2004			
<500 *MW*	100	600	600
> = 500 MW	100	200	600
Units installed between 2004 and 16			
<500 MW	50	600	300
> = 500 MW	50	200	300
Units installed after Dec 2016	30	100	100
China	30	100	100
USA	14.5	100	100

Studies show that stringent regulatory norms have led to a significant reduction in SO_2 emissions in China (Li et al., 2017). However, due to delayed standard setting and negligible abatement efforts by Indian thermal power plants, Indian sulfur emissions continue to increase, and India is likely to overtake China to become the largest SO_2 emitter in the world (Li et al., 2017). Historically regulatory limits were not imposed on SO_2 emission concentration from coal power plants in India. First-ever regulations on coal power plant SO_2 emission concentration were announced on December 7, 2015. These stringent regulations limit the SO_2 emissions to 200 mg/Nm^3 for power plant boiler units greater than 500 MW, and 600 mg/Nm^3 for boiler units smaller than 500 MW (MoEFCC, 2015). Table 1, exhibits the new Indian standards benchmarked against equivalent regulations in China and USA.

For the existing units, the new norms will come into effect from the year 2020, which would require power plants — with nearly 90% of installed coal-power capacity constituting about 60% of the total generation capacity in India — to invest in SO_2 control technology (Bhati and Ramanathan, 2016). Additionally, for plants commissioned after January 1, 2017, the emissions limit has been set to a stricter 100 mg/Nm^3. Fig. 1 shows the growing trend of coal-fired power plant installations, total SO_2 emissions growth estimated in this paper, and the change in the ambient atmospheric concentration of SO_2 observed over India.

In this context, a detailed techno-economic evaluation of SO_2 abatement options for Indian coal-fired power plants will facilitate technology adoption decisions by the electric utilities and simultaneously assist policymakers in designing an enabling regulatory framework. Specifically, a system-wide marginal abatement cost curve (MACC) — unit abatement costs as a function of emission levels — is a vital tool for techno-economic evaluation, environmental policy analysis, and energy system modeling of SO_2 abatement options.

A point on MACC provides the cost of reducing an additional unit of a pollutant at an existing abatement level in the industry. The MACC yields the costs associated with different abatement options and simultaneously informs about the level of emissions that can be potentially reduced. Given the finite set of options available for reducing pollution, MACCs have become popular policy instruments to evaluate net benefits of alternative pollution abatement options i.e. the area under the MACC gives the level of abatement that optimally balances the expected social benefits of the abatement (such as reduction in human deaths, morbidity, damage to environment, etc.) with the total cost[1] of achieving those target levels of pollution reduction.

Estimation of emission abatement costs, or conversely valuation of undesirable outputs of production, is challenging since market prices

[1] Total cost of abatement under the MACC corresponding to the desired level of overall abatement.