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Impact of current policies on future air quality and health outcomes in Delhi, India

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HIGHLIGHTS

- We model impact of current policies on future air quality for Delhi.
- Comparison with alternate stringent air pollution and climate policy scenarios.
- $PM_{2.5}$ concentrations will not meet national air quality standards by 2030.
- Stringent air pollution and climate policies together needed to achieve NAAQs.

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ABSTRACT

A key policy challenge in Indian megacities is to curb high concentrations of $PM_{2.5}$ and mitigate associated adverse health impacts. Using the Greenhouse Gases and Air Pollution Interactions and Synergies (GAINS) model we carry out an integrated analysis of the air quality regulations across different sectors for the city of Delhi. Our findings show that $PM_{2.5}$ concentrations for Delhi will not reach the recommended national ambient air quality standards (NAAQS) even by 2030 under the current policies scenario. Adopting advanced control technologies reduces $PM_{2.5}$ concentrations by about 60% and all-cause mortality by half in 2030. Climate change mitigation policies significantly reduce greenhouse gases, but have a modest impact on reducing $PM_{2.5}$ concentrations. Stringent policies to control the net flow of air pollution from trans-boundary sources will play a crucial role in reducing pollution levels in Delhi city. Achieving NAAQS requires a stringent policy portfolio that combines advanced control technologies with a switch to cleaner fuels and the control of trans-boundary pollution.

1. Introduction

It is well known that mitigating outdoor air pollution remains a major challenge in most developing countries. Annually, outdoor air pollution contributed to 3.2 million deaths and 76 million life years lost worldwide in 2010, two-thirds of which occurred in Asian countries (Lim et al., 2012). Most Indian cities face an acute problem of outdoor air pollution, with concentration levels often exceeding the recommended guidelines set in the National Ambient Air Quality Standards (NAAQS) (CPCB, 2010). Rapid urbanization, boom in construction activity, increase in number of vehicles, traffic congestion, population growth leave millions of people in urban areas vulnerable to adverse effects of air pollution (Patankar and Trivedi, 2011).

Reducing outdoor air pollution remains a major policy challenge in Indian megacities, like Delhi, despite the implementation of several policies such as shifting of public transport to Compressed Natural Gas (CNG) (Bell et al., 2004) converting coal power plants to natural gas (CPCB, 2010). Policy measures to mitigate air pollution in Delhi are important as it is among the largest megacities of the world with a population of about 16 million people (Census of India, 2011). Whereas this is not the only megacity in India with high amounts of outdoor air pollution, it is representative of larger Indian cities and the insights provided hold for other cities in India (Kandlikar and Ramachandran, 2000).

Previous research in Indian cities has analyzed air quality trends (Kandlikar, 2007), looked at source apportionment (CPCB, 2010; Srivastava and Jain, 2008; Srivastava et al., 2005) and emission

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Abbreviations: GAINS, greenhouse gases and air pollution interactions and synergies; $PM_{2.5}$, particulate matter less than 2.5 microns in size; NAAQ, national ambient air quality standards; TM5, transport model, version 5; CIESIN, Centre for International Earth Science Information Network; PAF, population Attributable Fraction.

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inventories (Guttikunda and Calori, 2013; Guttikunda and Jawahar, 2012; Sahu et al., 2011) to identify areas for policy intervention. Studies linking air quality and health have looked at short term effects of air pollutants on all-cause mortality (Rajarathnam et al., 2011; Cropper et al., 1997), lung function in children and adults (Foster and Kumar, 2011) and estimation of health risks due to multi-pollutant exposure (Pandey et al., 2005). The few studies that have sought to evaluate the impact of policies regulations on air quality in Indian cities (Narain and Krupnick, 2007; Kathuria, 2004; Goyal and Sidhartha, 2003; Bose and Srinivasachary, 1997) have done so for a single policy or a single sector. For instance Narain and Krupnick (2007) found that benefits, on air quality, accrued from switching buses from diesel to compressed natural gas (CNG) were negated by increase in vehicle population over time, ultimately leading to an increase in particulate matter concentrations in Delhi.

However, it remains unclear as to what impact current policies will have on future air quality and health in Delhi. There remain many unsettled questions such as – Are the current policy measures adequate to reduce air pollution to NAAQ standards in the future? What are the future health implications of these policy measures for Indian cities? What impact will alternate development pathways (using advanced control technologies or climate change mitigation strategies) have on city level air pollution in India? The present work addresses the aforementioned questions by building on the analysis of policy actions to curb outdoor air pollution in Delhi. We use an integrated assessment modeling framework, to analyze future air quality related to current policy legislations at the city level and also present health impacts related to the same.

2. Materials and methods

2.1. Modeling paradigm

Emissions and future concentrations of fine particulate matter ($PM_{2.5}$) were estimated using the Greenhouse gases and Air pollution Interactions and Synergies (GAINS) model developed at the International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria (Amann et al., 2011). The GAINS model is currently implemented globally on regional, national or provincial levels for 45 countries in Europe (Amann et al., 2011), for the Annex-I countries of the Kyoto Protocol (Wagner et al., 2012), for fast growing economies of China (Amann et al., 2008) and India (Purohit et al., 2010), as well as for remaining countries in East and South Asia, Africa, Middle East and South America. It covers the time horizon up to 2050 in 5-years steps. IIASA along with The Energy and Resources Institute (TERI, India) adapted the GAINS modeling framework for India (Wagner et al., 2008). The GAINS model allows for comprehensive analysis of air pollution and greenhouse gas mitigation strategies in an integrated assessment framework as well as identification of emission control technologies, estimation of impacts and mitigation costs under different policy scenarios (Wagner et al., 2008). The detailed workings of the model have been published elsewhere (Amann et al., 2011).

Like all models, GAINS attempts to develop a holistic understanding of a complex reality through a variety of reductionist steps. This simplification process is burdened with many uncertainties related to methodological issues, lack of understanding and insufficient data. Thus, there exist considerable uncertainties in almost all parts of the GAINS model, e.g., in the emission inventories, the estimates of emission control potentials, the atmospheric dispersion calculations and the impact assessment (Amann et al., 2011). In addition, uncertainties are pertinent in all other components of the integrated assessment framework that feed information into GAINS (e.g., models of energy and agricultural activities, atmospheric dispersion and environmental impacts).

A full quantitative assessment of the role of individual model and data uncertainties in an integrated assessment model framework such as GAINS is a complex task. A methodology has been developed by Schoepp et al. (2005) to quantify how statistical errors (i.e., quantified uncertainties) in input parameters propagate through the GAINS model calculations to policy-relevant output, e.g., from projections of economic activity to the protection of ecosystems. In practice, however, it was found difficult to reliably quantify the input uncertainties on a solid basis, so that a robust quantification of the uncertainties themselves was considered the most uncertain element in the analysis. Furthermore, a solid quantification of correlations between input parameters (or, in several cases, even their signs) turned out to be an almost impossible task, although they could have overwhelming influence on the conclusions of an uncertainty assessment (Amann et al., 2011).

For Europe, Schoepp et al. (2005) found a typical range of uncertainties for modeled national emissions of sulfur dioxide, nitrogen oxides and ammonia was between 10% and 30%, which is consistent with the Streets et al. (2003) for developed countries. For India, Streets et al. (2003) estimated uncertainties for modeled national emissions of sulfur dioxide, nitrogen oxides and ammonia at 26%, 48% and 101%, respectively. Neither study analyzed uncertainties related to $PM_{2.5}$ which is likely to be much higher given perturbation effects, distributional impacts and the contribution of dust.

The GAINS-Asia module has India as a region, which is further subdivided into 23 regions corresponding to the major Indian states (Purohit et al., 2010). Delhi is a separate region in the GAINS. Air quality, for all Indian regions, is estimated in 1° by 1° spatial resolution (Dentener, 2008) based on source-receptor relationships derived from Transport Model, Version 5 (TM5) atmospheric chemistry and transport model (Krol et al., 2005). In addition the model adjusts for an “urban increment” for major urban agglomerations by using detailed population data from the Centre for International Earth Science Information Network (CIESIN) $2'5 \times 2'5$ population database (Purohit et al., 2010). Furthermore, for health-impact assessment a routine has been developed to capture variations in emissions at the sub-grid level as a function of local emission densities and spatial extensions of urban areas within a grid cell (Amann et al., 2011).

We use the grid cell 29° North and 77° East in the model for analysis of Delhi city and its surrounding regions of Uttar Pradesh and Haryana and assume that sector specific emissions are distributed over this resolution. While the spatial resolution is sufficient to allow us to look into our primary objective of analyzing future air quality and health impacts for the region as a whole, we do not take into account sub-grid differences related to industrial and traffic hotspots.

Validation checks by comparing GAINS estimates with full model estimates for an emission scenario other than that used in deriving transfer coefficients as well as comparison with measurements have been carried out for Delhi and overall agreement levels are reasonable (Amann et al., 2011).

We adopted the reference energy scenario developed by the International Energy Agency (IEA) for the World Energy Outlook (WEO) 2011 as the base case. IEA/WEO (2011) estimates that real GDP growth rate for India will be 6.4% between the years 2008 and 2035. While economic growth in the Delhi region is likely to be higher, we do not correct for this. Economic development in conjunction with population growth (from 1.1 billion in 2005 to 1.5 billion in 2030) will enhance the demand for energy supply. The total primary energy demand is expected to increase by a factor of 2.75, from 2005 to 2035 (Purohit et al., 2010), indicating decoupling between energy consumption and economic growth brought about by technological improvements and structural transformations of the Indian economy (Shukla, 2006).

In this scenario coal remains the key source of primary energy in India, constituting about 50% of the energy mix in 2030 (IEA, 2011;