

Toward cleaner air for a billion Indians

Joshua S. Apte^{a,1} and Pallavi Pant^b

Exposure to fine particulate matter (PM_{2.5}) is a major risk factor for premature death (1). Few regions of the world experience ambient PM_{2.5} concentrations as high as the Indo-Gangetic Plains (IGP), home to more than a billion people in India, Pakistan, Nepal, and Bangladesh. Ground-based monitoring data are incomplete in these countries. However, a robust body of evidence from satellites, urban monitors, and chemical transport models indicates that average population exposures to ambient PM_{2.5} are 75 to 100 $\mu\text{g m}^{-3}$ (Fig. 1), with more than 99% of the population experiencing PM_{2.5} exposures greater than the 10- $\mu\text{g m}^{-3}$ World Health Organization Air Quality Guideline (2, 3). Health consequences of this pollution are severe. In India and other south-Asian countries, ambient PM_{2.5} ranks among the largest risk factors for premature death (1), shortening life expectancy at birth by 1.5 to 1.9 y (3, 4). What types of emissions controls might it take to substantially address this major health challenge? In many settings, air pollution control efforts focus on large, visible sources such as electric power generation, industry, and transportation. In PNAS, Chowdhury et al. (5) reframe this debate for India by showing that mitigating household air pollution sources—especially cooking and heating with wood and other solid fuels—is an essential component of effective air pollution control.

Energy Access and Health

Pollution tends to be symptomatic of other, larger problems. As Chowdhury et al. (5) show, in India's case, one such problem is access to clean energy. Hundreds of millions of Indian households still rely on kerosene for light, and on wood, dung, and other solid fuels for cooking and heating. The consequences of household fuel use for indoor air pollution and its health effects have been appreciated for decades (6, 7). The major impact of inefficient household combustion of low-quality fuels on ambient air pollution across south Asia has also become clear in recent years (e.g., ref. 8). Several careful new chemical transport model

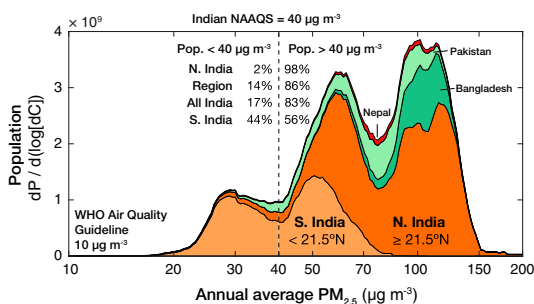


Fig. 1. Distribution of population for south-Asian countries with respect to year-2016 ambient PM_{2.5} concentrations (4). Equal-sized plotted areas reflect equal populations. The 860 million people in the northern portion of India, defined here as the region north of 21.5°N, live predominantly in the heavily polluted Indo-Gangetic Plain. This region extends into Nepal, Pakistan, and Bangladesh, countries which experience PM_{2.5} similar to northern India.

simulation studies suggest that household energy use may be the single-largest emissions sector contributing to ambient PM_{2.5} and mortality in India (9–12). While details vary among these analyses, household sources clearly emerge as having a profound impact on ambient PM_{2.5} in India (Fig. 2). Chowdhury et al. present quantitative evidence of the major air quality and health benefits that could arise from a clean energy transition, creating a compelling argument for the government to enhance and expand clean energy programs in India.

Within the country, PM_{2.5} varies significantly between the northern IGP and southern regions, defined here for simplicity as above or below 21.5°N, the southern boundary of the IGP (Fig. 1). Annual-average PM_{2.5} levels in the northern portion of the country and in neighboring Pakistan, Nepal, and Bangladesh are approximately twice as high as in the southern India region, with population-weighted mean concentrations in excess of 90 to 100 $\mu\text{g m}^{-3}$. Recent analyses have noted that per-capita rates of mortality from air pollution exposure in the IGP are substantially higher

^aDepartment of Civil, Architectural and Environmental Engineering, University of Texas at Austin, Austin, TX 78712; and ^bHealth Effects Institute, Boston, MA 02110

Author contributions: J.S.A. and P.P. analyzed data and wrote the paper.

The authors declare no conflict of interest.

Published under the PNAS license.

See companion article 10.1073/pnas.1900888116.

¹To whom correspondence should be addressed. Email: jsapte@utexas.edu.

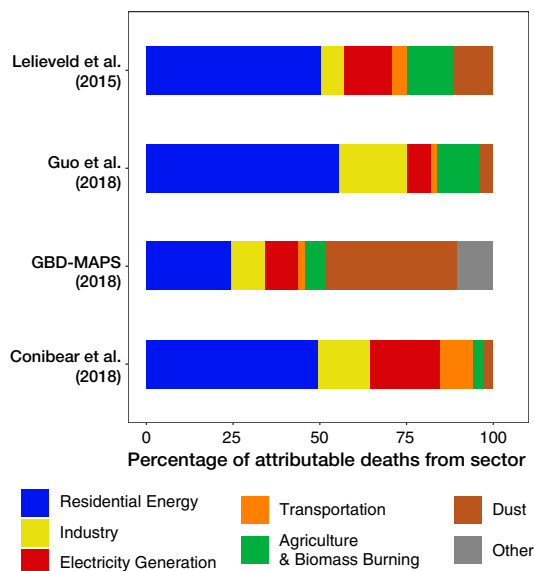


Fig. 2. Source contributions to mortality associated with exposure to ambient PM_{2.5} from 4 recent chemical transport model simulations for India (9–12). The residential energy sector consistently ranks as one of the largest individual sectoral contributors to premature mortality from ambient PM_{2.5} air pollution.

than in southern India (3, 9). In many north-Indian states, more than two-thirds of all households rely on fuels such as wood and dung for cooking (3). Chowdhury et al. (5) illustrate that in a vast swathe of the IGP region in India, from Punjab to West Bengal, well more than a third of all ambient PM_{2.5} comes from household sources (5). A comprehensive solution to India's outdoor air pollution will therefore almost certainly require aggressive mitigation of household air pollution sources.

India is making progress in increasing access to clean energy through fuel delivery programs aimed at households, broader rural electrification, and ongoing investment in renewable energy. The Pradhan Mantri Ujjwala Yojana [rough translation: Prime Minister's Brightness Scheme (for Clean Fuel)] is a national program motivated by social welfare considerations that was launched in 2016 with an aim to provide liquified petroleum gas (LPG) access to 80 million poor households by 2019. Emerging evidence shows dramatic improvements in access to LPG through the Ujjwala program (13); the data are less clear about the sustained uptake of LPG by households (14). In this context, the scenarios used in the analysis by Chowdhury et al. (5) are reasonable, and broadly achievable with effective enforcement. If all household solid fuel use for cooking-, lighting-, and space heating-related activities was converted to clean fuels, the authors estimate that the annual PM_{2.5} standard of 40 μg m⁻³ (Indian National Ambient Air Quality Standard, NAAQS) would be met, on average, nationwide, and this would be accompanied by substantial reductions in associated health impacts (~13% of air pollution-related premature mortality).

The Need for Multisectoral Mitigation

Solutions to PM_{2.5} in India share several conceptual similarities with climate-change mitigation. First, while PM_{2.5} is thought of as a comparatively localized pollutant relative to CO₂, the days-to-weeks atmospheric lifetime of fine particles means that PM_{2.5} is effectively transported not just across building envelopes, but also across villages, cities, states, and countries. This physical reality suggests that coordinated regional action—in addition to

city-level mitigation as envisaged by India's National Clean Air Program—may be required to substantially improve ambient air quality, even in small areas. Second, just like with CO₂ emissions, order-of-magnitude scale emissions reductions will ultimately be required to avert the full risks of PM_{2.5} in south Asia. Third, given that there are multiple major emissions sectors that contribute to PM_{2.5} pollution (Fig. 2), no single sector can provide the silver-bullet controls needed to deliver change at scale. For example, major sources of air pollution include emissions related to household energy, transportation, electricity generation, diesel generator sets, municipal waste burning, agricultural crop residue burning, industrial processes, informal and semiformal industrial activity (e.g., brick kilns, waste recycling), and construction-related emissions, among others (15). Accordingly, a portfolio of solutions will be required. Here, it may be possible to develop pollution control approaches inspired by thinking from climate-change mitigation [e.g., “stabilization wedges” (16)]. Since many of the social and technical drivers of air pollution change on slow timescales (e.g., behavior change, turnover of infrastructure stock), the long-term perspective that the climate field provides may be helpful for considering air pollution. As the experience in many high-income countries shows, improvements in air quality can only come through sustained action on mitigation of major sources of air pollution over decades. Finally, it may be useful to identify technology paths that are incompatible with clean air. Just as long-term global reliance on carbon-intensive electricity would preclude international climate-change mitigation goals, so too would a high magnitude of household emissions close off a pathway to clean air for hundreds of millions of Indians in both rural and urban areas.

Overall, it is critical that air pollution is recognized and treated as a multisectoral problem in India. At the national level, household air pollution is the largest contributor to ambient PM_{2.5} (9–12) (see Fig. 2). However, at the urban or city level, sources such as transportation and waste burning, which are often tied to local land-use and governance decisions, are also significant and need to be addressed (15). Successful air pollution mitigation must consider all sources of air pollution and identify specific interventions and policy programs based on the scale of their impact.

Between 1990 and 2017, India's age-standardized mortality rates attributable to indoor air pollution declined nearly 3-fold from 141 deaths per 10⁵ people to 51 deaths per 10⁵ people (1, 2). During the same time period, mortality rates for ambient PM_{2.5} have increased ~22%, from 58 to 71 deaths per 10⁵ people. These data and the results presented by Chowdhury et al. (5) illustrate the immense potential for health benefits of cleaner energy choices in India, both at the household and the economy-wide scale (1, 2, 5). Drivers of these trends are complex, incorporating shifts in the underlying burden of disease, a reduction in the fraction of households relying on solid fuels (from ~85 to 60% nationwide), and an overall increase in ambient PM_{2.5} concentrations (2, 17). With effective action to reduce household emissions, the share of ambient pollution from household sources might decline in coming years, even as other sources increase in magnitude. To disentangle the effects of these distinct drivers and trends, it may be highly desirable to deploy a suite of complementary monitoring and evaluation techniques. At the household level, systematic surveys and sensor-based monitoring can help document shifts in fuel choices (18). With regard to outdoor air, a robust ambient monitoring network that incorporates both rural and urban areas (19), perhaps complemented by a set of long-term chemical speciation sites for source apportionment (20), will be essential for documenting the changing nature of air pollution emissions and exposures in India.

- 1 J. D. Stanaway *et al.*; GBD 2017 Risk Factor Collaborators, Global, regional, and national comparative risk assessment of 84 behavioural, environmental and occupational, and metabolic risks or clusters of risks for 195 countries and territories, 1990-2017: A systematic analysis for the Global Burden of Disease Study 2017. *Lancet* **392**, 1923–1994 (2018).
- 2 Health Effects Institute, State of global air 2019. <http://www.stateofglobalair.org/>. Accessed April 30, 2019.
- 3 K. Balakrishnan *et al.*; India State-Level Disease Burden Initiative Air Pollution Collaborators, The impact of air pollution on deaths, disease burden, and life expectancy across the states of India: The Global Burden of Disease Study 2017. *Lancet Planet. Health* **3**, e26–e39 (2019).
- 4 J. S. Apte, M. Brauer, A. J. Cohen, M. Ezzati, C. A. Pope, Ambient PM_{2.5} reduces global and regional life expectancy. *Environ. Sci. Technol. Lett.* **5**, 546–551 (2018).
- 5 S. Chowdhury *et al.*, Indian annual ambient air quality standard is achievable by completely mitigating emissions from household sources. *Proc. Natl. Acad. Sci. U.S.A.*, 10.1073/pnas.1900888116.
- 6 S. Padmavati, S. N. Pathak, Chronic cor pulmonale in Delhi: A study of 127 cases. *Circulation* **20**, 343–352 (1959).
- 7 K. R. Smith, Fuel combustion, air pollution exposure, and health: The situation in developing countries. *Annu. Rev. Energy Environ.* **18**, 529–566 (1993).
- 8 Z. A. Chafe *et al.*, Household cooking with solid fuels contributes to ambient PM_{2.5} air pollution and the burden of disease. *Environ. Health Perspect.* **122**, 1314–1320 (2014).
- 9 L. Conibear, E. W. Butt, C. Knote, S. R. Arnold, D. V. Spracklen, Residential energy use emissions dominate health impacts from exposure to ambient particulate matter in India. *Nat. Commun.* **9**, 617 (2018).
- 10 H. Guo *et al.*, Source contributions and potential reductions to health effects of particulate matter in India. *Atmos. Chem. Phys.* **18**, 15219–15229 (2018).
- 11 J. Lelieveld, J. S. Evans, M. Fnais, D. Giannadaki, A. Pozzer, The contribution of outdoor air pollution sources to premature mortality on a global scale. *Nature* **525**, 367–371 (2015).
- 12 GBD MAPS Working Group, *Burden of Disease Attributable to Major Air Pollution Sources in India, Special Report 21* (Health Effects Institute, Boston, MA, 2018).
- 13 Ministry of Petroleum and Natural Gas, Government of India, The Ujjwala saga—Unending happiness & health. <http://pure.iiasa.ac.at/id/eprint/15741/1/Ujjwala%20Saga.pdf>. Accessed April 30, 2019.
- 14 A. Pillarisetti *et al.*, Promoting LPG usage during pregnancy: A pilot study in rural Maharashtra, India. *Environ. Int.* **127**, 540–549 (2019).
- 15 S. K. Guttikunda, K. A. Nishadh, P. Jawahar, Air pollution knowledge assessments (APnA) for 20 Indian cities. *Urban Climate* **27**, 124–141 (2019).
- 16 S. Pacala, R. Socolow, Stabilization wedges: Solving the climate problem for the next 50 years with current technologies. *Science* **305**, 968–972 (2004).
- 17 K. R. Smith *et al.*; HAP CRA Risk Expert Group, Millions dead: How do we know and what does it mean? Methods used in the comparative risk assessment of household air pollution. *Annu. Rev. Public Health* **35**, 185–206 (2014).
- 18 I. Ruiz-Mercado, E. Canuz, J. L. Walker, K. R. Smith, Quantitative metrics of stove adoption using stove use monitors (SUMs). *Biomass Bioenergy* **57**, 136–148 (2013).
- 19 P. Pant *et al.*, Monitoring particulate matter in India: Recent trends and future outlook. *Air Qual. Atmos. Health* **12**, 45–58 (2019).
- 20 S. Gani *et al.*, Submicron aerosol composition in the world's most polluted megacity: The Delhi Aerosol Supersite campaign. *Atmos. Chem. Phys.*, 10.5194/acp-2018-1066 (15 November, 2018), in press.