Toward cleaner air for a billion Indians

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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 µg m^{-3} (Fig. 1), with more than 99% of the population experiencing $PM_{2.5}$ exposures greater than the 10-µg 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 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.

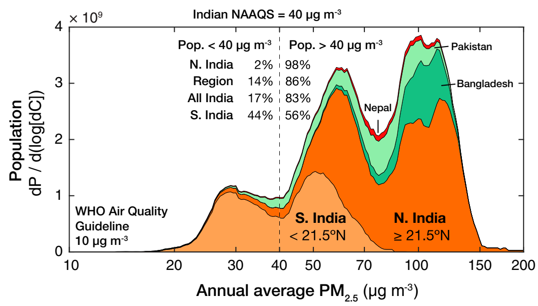

Fig. 1. Distribution of population for south-Asian countries with respect to year-2016 ambient $PM_{2.5}$ concentrations (4). Equal-sized plotted areas reflect equal populations. The 860 million people in the northern portion of India, defined here as the region north of 21.5°N, live predominantly in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

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 µg m^{-3}. Recent analyses have noted that per-capita rates of mortality from air pollution exposure in the IGP are substantially higher

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See companion article on page 10711.

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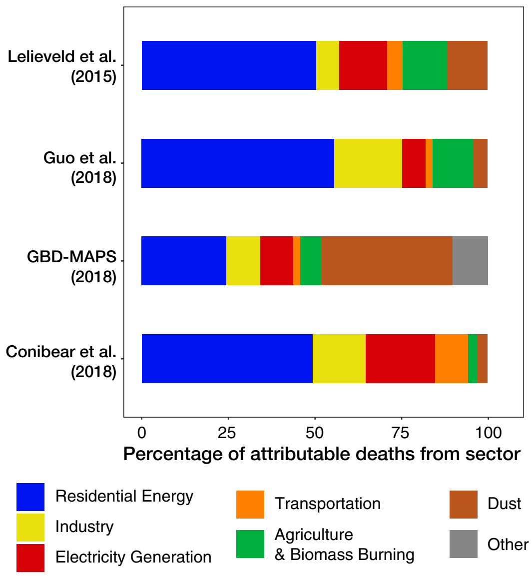

Fig. 2. **Source contributions to mortality associated with exposure to ambient $PM_{2.5}$ from 4 recent chemical transport model simulations for India (9–12). The residential energy sector consistently ranks as one of the largest individual sectoral contributors to premature mortality from ambient $PM_{2.5}$ 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 $\mu g\ m^{-3}$ (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 CO_2, 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 CO_2 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 10^5 people to 51 deaths per 10^5 people (1, 2). During the same time period, mortality rates for ambient $PM_{2.5}$ have increased ~22%, from 58 to 71 deaths per 10^5 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.

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