Health Benefits of Air Pollution Reduction

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Abstract

Air pollution is a grave risk to human health that affects nearly everyone in the world and nearly every organ in the body. Fortunately, it is largely a preventable risk. Reducing pollution at its source can have a rapid and substantial impact on health. Within a few weeks, respiratory and irritation symptoms, such as shortness of breath, cough, phlegm, and sore throat, disappear; school absenteeism, clinic visits, hospitalizations, premature births, cardiovascular illness and death, and all-cause mortality decrease significantly. The interventions are cost-effective. Reducing factors causing air pollution and climate change have strong cobenefits. Although regions with high air pollution have the greatest potential for health benefits, health improvements continue to be associated with pollution decreases even below international standards. The large response to and short time needed for benefits of these interventions emphasize the urgency of improving global air quality and the importance of increasing efforts to reduce pollution at local levels.

Keywords: air pollution; particulate matter; health risks; environmental health

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Air pollution is a grave risk to human health (1). Ambient air pollution is by far the most important environmental risk factor for morbidity and mortality (2), and household air pollution follows closely (3). Air pollution affects nearly every organ in the body, causing or contributing to many illnesses (4, 5).

Poor air quality is a challenge facing all people on the planet, with the greatest risk being for those most heavily exposed. Most air pollution is preventable. This paper looks at the health benefits of pollution reduction at different levels of interventions. Reducing pollution at its source can often be readily accomplished, but how quickly will positive health results occur? What is the magnitude of the response? Do international standards need to be met to obtain health improvement? Is the attainment of national or international air quality standards sufficient to avoid air pollution–related disease? The answers to these basic questions underpin the efforts for and urgency of improving global air quality. This paper seeks to answer these questions by reviewing the literature on the benefits of reducing air pollution.

Benefits of National and Supranational Air Quality Interventions

National policies aimed at lowering pollutant emissions have been enormously successful in reducing air pollution levels and have been shown to improve health outcomes cost-effectively (6). Although published studies have focused primarily on high-income countries, similar policies in low- and middle-income countries may be even more effective, and this can be accomplished without reducing economic growth.

United States

In the United States, concerns about air pollution led to the Clean Air Act of 1970 and its amendments. The Clean Air Act, as it is now called, after further amendments in 1977 and 1990, has been heralded as one of the most effective public health policies of all time in the United States (7). Emissions of the major pollutants (particulate matter [PM], sulfur oxides, nitrogen oxides, carbon monoxide, volatile organic compounds, and lead) were reduced by 73% between 1990 and 2015 while the U.S. gross domestic product grew by more than 250% (8). The U.S. Environmental Protection Agency (EPA) determined that the monetized health benefits of the Clean Air Act exceeded the implementation costs by a factor of 32:1 (6). These benefits, valued at $2.0 trillion in 2020, are primarily attributable to lower mortality—an estimated 230,000 attributable deaths avoided per year—due to lower concentrations of outdoor PM. Other benefits include reductions in premature mortality due to lower ozone concentrations (7,100 deaths avoided per year), reductions in acute myocardial infarction (200,000 fewer cases per year), avoided hospital admissions for respiratory conditions (66,000 fewer admissions per year), and reductions in asthma exacerbations (2.4 million fewer attacks per year) (6).

Ambient concentrations of PM 2.5 μm in aerodynamic diameter or less ($PM_{2.5}$) dropped after enactment of the Clean Air Act; the decline was especially sharp from 1980 to 2000. A study examining pollution exposure and life expectancy in 51 U.S. metropolitan areas over this period determined that a 10-$\mu g/m^3$ improvement in average $PM_{2.5}$ exposure resulted in a mean lengthening of life expectancy of more than 7 months (9), accounting for 15% of the overall increase in life expectancy. These improvements in life expectancy did not differ on the basis of prevalence of smoking, socioeconomic conditions, or the demographic composition of counties, implying that all populations benefit from improved air quality.

A follow-up study examined the effects of the more modest $PM_{2.5}$ improvements in the United States after 2000. Using county-level pollution exposure and mortality data for 545 counties from 2000 to 2007, a 10-$\mu g/m^3$ improvement in $PM_{2.5}$ was associated with an average increase in life expectancy of 4.2 months over the 7-year period, which was more pronounced in urban and densely populated areas (10). A study reviewing air pollution between 2008 and 2017 traced improvements in mortality at county and city levels that largely resulted from decreased $PM_{2.5}$. The smaller effect may have resulted in the lower levels of pollution at the beginning of the comparison period. An overall lack of mortality benefit from better ozone standards was attributed to increases in the size of the exposed population (11).

A follow-up to the original Harvard Six Cities Study examined the relationship between improvements in ambient $PM_{2.5}$ and city-level mortality. In comparison of the 1974–1989 period with a follow-up period, 1990–1998, every 10-$\mu g/m^3$ improvement in city-level average annual $PM_{2.5}$ was associated with a 27% improvement in the relative risk of death (12). In additional follow-up, using data after 2001, the linear association between $PM_{2.5}$ and mortality was present down to an average $PM_{2.5}$ concentration of 8 $\mu g/m^3$, indicating that mortality benefits of reducing $PM_{2.5}$ are likely to continue down to concentrations of average $PM_{2.5}$ exposure below the EPA standards and the World Health Organization (WHO) air quality guideline values (13).

Improved air quality has been linked to improvements in other health measures, including child lung growth and development. In Southern California, air quality control policies have resulted in steady improvements in air quality from the mid-1990s to the 2000s. The Children's Health Study evaluated yearly lung function during these two decades among more than 2,000 Southern California teenagers. The average rate of lung function growth was faster in children with and without asthma who lived in areas with a greater decline in $PM_{2.5}$ and nitrogen dioxide (NO_2) (14). The prevalence of clinically defined low lung function declined from 7.9% in the mid-1990s to 3.6% in 2007–2011 as air quality improved. Reductions in $PM_{2.5}$ and NO_2 between 1993 and 2014 reduced the risk of childhood asthma. A median reduction in NO_2 of 4.3 parts per billion (ppb) reduced the risk of incident asthma by 20% (15). Improved lung growth and development in children also leads to lower risk for chronic lung disease in adulthood (16).

Western Europe

National and European Union air quality regulations have also resulted in dramatic improvements in air quality in Western Europe. In Dublin, for example, black smoke concentrations declined up to 70% after a ban on coal sales in 1990. Subsequently, annual respiratory deaths decreased by 17%, whereas nontrauma death rates and cardiovascular death rates did not decrease compared with control groups (17).

In a Swiss cohort of adults, relationships were examined between the concentrations of PM 10 μm in aerodynamic diameter or less (PM_{10}) and adult respiratory health from 1990 to 2001. A 10-$\mu g/m^3$ decline in PM_{10} over the 11-year period was associated with a 9% decrease in the annual rate of decline in forced expiratory volume in 1 second (FEV_1) (average, 3.1 ml) and a 16% decrease in the annual rate of decline in the forced midexpiratory flow rate (average, 11.3 ml/s) (18). This pattern suggests that the health of adult small airways improved as a result of better air quality. A follow-up study found that the mean decline in PM_{10} from 1991 to 2002 of 6.2 $\mu g/m^3$ was associated with 259 fewer people with regular cough, 179 fewer people with chronic cough or phlegm, and 137 fewer people with wheeze or shortness of breath for every 10,000 persons in the community (19).

Asia

Although many parts of Asia have experienced worsening air quality in recent decades, air quality regulations at the national and city levels in some Asian countries have resulted in important public health gains. A 1990 restriction on the sulfur content of fuel oil used for power plants and motor vehicles in Hong Kong led to a 45% drop in ambient sulfur dioxide concentrations. This intervention led to a decline in the annual rates of all-cause mortality (2.1%), respiratory mortality (3.9%), and cardiovascular mortality (2.0%) and improved life expectancy of 20 days for women and 41 days for men (20). The Japanese government passed legislation to limit transportation-related emissions in 2001. By 2009, the average $PM_{2.5}$

concentrations decreased from 38 to 26 μg/m^3, and NO_2 decreased from 30 to 21 ppb. This improvement in air quality was linked to 0.6% and 1.1% lower prevalence of pediatric asthma attributable to $PM_{2.5}$ and NO_2, respectively (21). Recently, China has instituted far-reaching policies to reduce air pollution in its large cities, with great success.

The pollution problems of India are daunting, with urban population growth of 31.8% and overall population growth of 17.6% between 2001 and 2011. Its development boom and 35 cities approaching or exceeding a population of 1 million have intensified the demand for energy. The national government, as well as several cities, have put into place a broad range policies to halt pollution and expand green space (22). Examples of the interventions include developing and monitoring air pollution standards, emissions testing, travel restrictions, increased taxes on and removal of subsidies from polluting sources, increased use of clean energy, and restriction of burning biomass fuels (23, 24). Online media coverage of air pollution has increased awareness and is a basis for ongoing advocacy (23).

Africa

Similar problems of population growth, urbanization, and industrialization make air pollution a major challenge in Africa. A lack of data and information on air quality has prevented the implementation of national policies in many regions (25). However, there is increasing recognition of the need to implement and evaluate the impact of such policies, particularly through partnerships with global agencies, including the United Nations Environment Programme (26). Many national and local programs are in place to reduce indoor air pollution (27).

National Smoking Ban Benefits

Secondhand smoke is a form of air pollution that caused an estimated 1.2 million deaths in 2017 (28). Enactment of legislative bans on smoking in public areas has reduced overall mortality from smoking-related diseases, mainly cardiovascular, cerebrovascular, and respiratory diseases (29). The bans also reduced smoking in the home and smoking behavior in general (30). In Ireland, the national smoking ban in 2004 quickly reduced the incidence of myocardial infarction and pediatric acute asthma (31), with the greatest effect among younger individuals and nonsmokers (32) (Figure 1). Similarly, respiratory symptoms (wheeze, shortness of breath, cough, and sputum), sensory symptoms (irritated eyes, sore throat, nasal itch, and runny nose), and respiratory function (FEV_1) all improved within 1–2 months of the smoking ban in bar workers in Ireland (33). Smoking bans have also been associated with decreased health expenditures (34).

Benefits of Local-Level Interventions

Compelling evidence for the benefits of reducing air pollution may come from situations in which polluting sources abruptly end. Examples of these events are factory closures and the planned reduction of traffic-related pollution during the Olympic Games. Most abatement of indoor pollution is also performed on the local level.

Air Quality Benefits of Factory and Steel Mill Closures

Improved air quality due to factory closures resulted in health benefits to surrounding communities starting almost immediately. A 13-month closure of a large steel mill in the Utah Valley in the United States resulted in a range of cardiopulmonary benefits. When the steel mill was open, winter PM_{10} concentrations were twice as high as when it was closed; hospital admissions for pneumonia, pleurisy, bronchitis, and asthma were greater, especially among children, who had two to three times the admission rates for these respiratory conditions (35). Lower PM_{10} due to steel mill closure also reduced symptoms, school absenteeism (by about 40%) (36), and daily mortality. A PM_{10} concentration decrease of 100 μg/m^3 was associated with a 16% decrease in deaths (37). A follow-up study found that women who were pregnant during the mill closing (especially if in their second trimester) were less likely to have premature births than women who were pregnant before or after the closure (38).

A study examining the effect of a nationwide copper smelter strike from July 1967 to April 1968 in four southwestern U.S. states linked $PM_{2.5}$ concentrations measured by local air monitors to mortality data for cardiorespiratory outcomes during the strike. During the 8.5-month strike period, an approximately 60% decrease in concentrations of suspended sulfate particles was associated with an estimated 2.5% decrease in mortality after controlling for time trends; mortality counts in bordering states; and nationwide mortality counts for influenza, pneumonia, cardiovascular, and other respiratory deaths (39).

Benefits of Pollution Reduction during the Olympic Games

The Olympics Games have led host cities to control congestion to ensure that athletes and spectators can reach events on time. In the summer of 1996, the City of Atlanta implemented a 17-day "alternative transportation strategy" involving 24-hour public transportation, additional bus services, telecommuting options, and closure of downtown Atlanta to private automobile traffic. Peak morning traffic decreased by 23%, and peak daily ozone concentrations decreased by 28%. In the next 4 weeks, there were reductions in children seeking medical care for asthma by 42% based on Medicaid claims and 44% based on health maintenance organization data. There was an 11% decrease in pediatric emergency department visits and a 19% decrease in hospitalizations for asthma (40).

For the 2008 Beijing Olympics, the Chinese government enacted factory emission and travel restrictions from July 1 to September 20 that resulted in pollutant concentrations decreasing by up to 62% (41). The reduction in air pollution in Beijing, including lower concentrations of ultrafine particles (aerodynamic diameter <0.1 μm), was associated with improvement in lung function among healthy adults and adults with asthma (42); 58% fewer asthma-related physician visits (41); less cardiovascular mortality, especially among women and the elderly (43); and lower degrees of systemic inflammation among healthy young adults (44). These results occurred within about 2 months of the pollution reduction.

Benefits of Cleaner Fuel for School Buses

Exposure of children to $PM_{2.5}$, black carbon, particle-bound polycyclic aromatic hydrocarbons, and NO_2 from riding in older diesel-powered school buses can be very high. Although school bus commutes usually make up only a small part of a child's day, they can contribute up to one-third of a child's 24-hour overall black carbon exposure during a school day (45). For many children, especially those in rural areas, a large portion of their day is spent on school

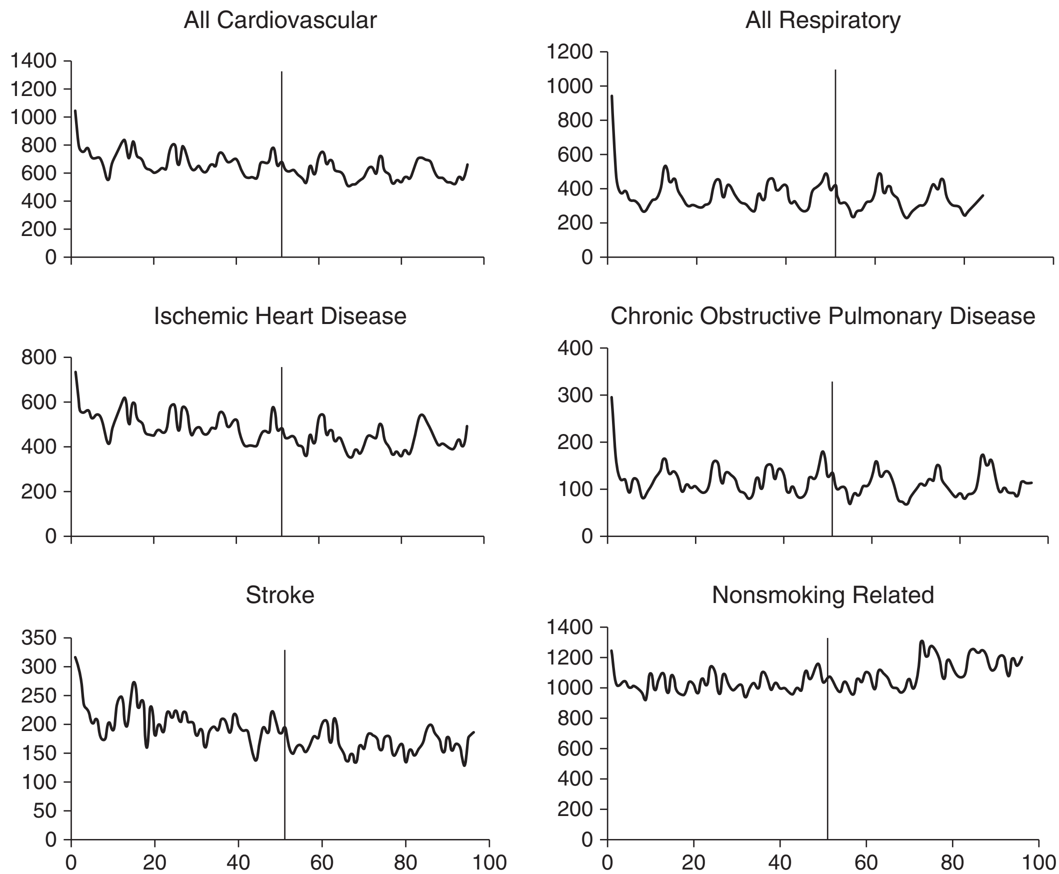

Figure 1. Smoking ban–associated mortality. The smoking ban in Ireland reduced indoor air pollution greatly, with improved health not only for hospitality workers but also for the general population. Monthly mortality in Ireland from 2000 to 2007 is on the ordinate. The sequence of months during this time is on the abscissa. The vertical line indicates the month that the smoking ban was implemented. There was an overall decrease in smoking-related deaths after the smoking ban, with the most marked decrease starting immediately. Mortality reduction was 13% overall, 26% for ischemic heart disease, 32% for stroke, and 38% for chronic obstructive pulmonary disease. Although there was a 15% decrease at first in nonsmoking-related deaths, there was a 5% increase each year after the ban. Reprinted by permission from Reference 29.

buses (46). Installation of a high-efficiency cabin air filtration system on school buses has decreased in-cabin ultrafine particle and black carbon concentrations by over 80% (47). Anti-idling campaigns for school buses have reduced the average concentrations of $PM_{2.5}$ and black carbon near schools (48).

The health benefits of changing fuel used for public buses of all types from diesel to cleaner compressed natural gas has great potential to reduce premature respiratory and cardiovascular morbidity and mortality (49). Moving to electric buses would provide even cleaner public transportation and presumably greater health benefits.

Benefits of Reducing Household Air Pollution

Household interventional studies in low- and middle-income countries have involved "clean" cookstoves with improved combustion efficiency or ventilation, such as the Patsari (50) and Plancha (51) stoves in Mexico and Guatemala, respectively; the replacement of wood or kerosene by less-polluting fuels, such as ethanol or liquefied petroleum gas; and the use of household air filters. Studies in high-income countries similarly involve fuel switching, stove technology upgrades, and use of household air filters.

Essentially all studies have shown that "clean" stoves improve respiratory and nonrespiratory symptoms, such as eye discomfort and headache (52). The Patsari replacement stove intervention lowered the rate of lung function decline over 1 year (50). Compared with traditional open fires, there were fewer upper and lower respiratory tract infections in Mexican children, with an exposure–response relationship (53). Compared with children who had a Plancha stove installed in their home at birth, children whose homes did not have a stove installed until 18 months of age had lower peak expiratory flow growth at ages 5–8 years (54), highlighting the importance of early childhood exposure to pollution to lung growth and development (55).

The Cooking and Pneumonia Study of a cookstove intervention incorporated a fan to improve combustion efficiency, but it did not find a reduced risk of pneumonia in children under 5 years of age in rural Malawi (56). The negative results could be attributed to addressing only a single source exposure in communities that largely cook outdoors and have not achieved clean air because of rubbish burning and use of older, polluting vehicles (52). A retrospective Chinese

Pollution Reduction

Time	Events
Starting at week 1	Irish indoor smoking ban (population): 13% all-cause mortality: 26% reduction in ischemic heart disease, 32% reduction in stroke, 38% in COPD (29)
17 days	Olympic games: decreased clinic, emergency department visits and hospitalizations for childhood asthma (40)
Weeks	Steel mill closure: decreased respiratory symptoms (35), school absenteeism (36), daily mortality (37), premature births (38)
4 weeks	Home heater change: asthmatic symptoms improved (64)
1 month	Irish smoking ban (workers): decreased wheeze, dyspnea, cough, phlegm, irritated eyes, painful throat, nasal itch, runny nose and sneeze (33)
2 months	Olympics: Improved lung function (healthy and asthmatic adults), fewer asthma-related physician visits (41); less cardiovascular mortality (43)
8.5 months	Smelters strike: decrease in mortality by 2.5% (39)
Pregnancy term	Clean cook stoves: higher birthweights, gestational age at delivery, less perinatal mortality (60)
6 years	Swiss air pollution decrease: Respiratory deaths decrease by 15.5%; cardiac deaths by 10% (18)
7 years	USA pollution tracking: life expectancy increase 0.35 years for each 10 μg/m reduction of $PM_{2.5}$ (10)
10 years	Accounting for fine particle change: life expectancy gain 7 months (9)
15 years	Harvard 6 cities study: decrease in fine particles reduced the risk of death by 27% (13).
25 years	US EPA estimates: Health benefits exceed cost by 32:1 (6)

Figure 2. Timeline of benefits of pollution reduction. The times at which the beneficial events were recorded were compiled from many studies. *Not all studies have the same time effect. In many papers, the end of the study is the time, and the effect could have occurred much before then. COPD = chronic obstructive pulmonary disease; EPA = Environmental Protection Agency; $PM_{2.5}$ = particulate matter less than or equal to 2.5 μm in aerodynamic diameter.

study showed that installation of chimneys in households using coal stoves reduced the incidence of chronic obstructive pulmonary disease (57). Similar results were noted in a 9-year prospective Chinese cohort study involving interventions to improve kitchen ventilation and promote the use of clean fuels (58). This study also demonstrated a slower decline in FEV_1 over time, by 16 ml/yr, than among those who took up neither intervention (58).

Improved cookstoves with chimneys were associated with a pronounced improvement in respiratory quality of life among rural Bolivian women (59). In a small trial in Nigeria, cooking with an ethanol stove was associated with greater infant birth weight, greater gestational age at delivery, and lower perinatal mortality, after adjustment for covariates, as compared with continued cooking with a kerosene or firewood stove (60).

Several trials have also demonstrated a long-term reduction in blood pressure values after cookstove interventions (61, 62). These studies found a greater reduction in diastolic blood pressure than in systolic blood pressure.

Benefits of interventions to reduce household air pollution have shown similar results in high-income countries (52). Installing less-polluting heating (e.g., heat pump, wood pellet burner, and flued gas) in the homes of children with asthma in New Zealand reduced symptoms of asthma, days off school, healthcare use, and visits to a pharmacist (63). Eighteen Australian schools using unflued gas heating in winter were randomly allocated either to retain their heaters or to have replacement flued gas or electric heaters installed (64). Difficulty breathing during the day and night, chest tightness during the day, and daytime asthma attacks were significantly reduced in the intervention group. A randomized wood stove change-out study in the rural United States found an increase in peak expiratory flow and a reduction in the respiratory symptoms and activity limitation part of the questionnaire, but no overall improvement in the quality of life score, in children with asthma relative to the placebo condition (65).

Personal-Level Interventions

Household Air Filters or Purifiers

Most studies have focused on the use of plug-in high-efficiency particulate air (HEPA) purifiers to decrease exposure to indoor allergens; they also reduce PM in homes (66). These filtration systems do not remove gaseous pollutants, such as ozone and nitrogen oxides, unless a carbon filter is included, and they may have decreased acceptability because of noise, air movement, and cost. Specific devices with electrostatic filters may produce ozone (67).

A randomized controlled trial using multiple individualized, home-based environmental interventions, including HEPA purifiers, found a decreased exposure to indoor allergens in inner-city U.S. homes and a reduction in asthma-associated morbidity (68). Air filters increased symptom-free days in inner-city children with asthma residing with a smoker (69). In a pilot randomized controlled trial of 25 elementary school children with asthma in the Boston area, a HEPA filter intervention improved peak expiratory flow without affecting asthma symptoms or FEV_1 (70). Air filters may have beneficial effects outside the lung and have been shown to improve nasal symptoms in children with allergic rhinitis (71) and to decrease blood pressure values (66). Furthermore, air filtration systems have undergone several technological advances to improve the healthfulness of building ventilation in the time since some of these studies were performed (72).

In China, air filtration systems installed in both homes and workplaces reduced $PM_{2.5}$ exposure by 26–79% (73). This was comparable to other large-scale mitigation programs to reduce air pollution that included closure of polluting factories and the use of cleaner fuels.

Intermittent air filtration can abate PM exposure during environmental disasters. Home air filtration after a Southern California wildfire prevented 11–63% of the hospital admissions and 7–39% of the deaths attributable to wildfire particles (74). Modeling methods showed that particle-related premature mortality can be significantly decreased in such instances with improvements in filtration systems in homes and commercial buildings, with a predicted reduction in mortality ranging from 0.25 to 2.4 per 10,000 persons. The economic benefits exceeded the costs, with benefit-to-cost ratios ranging from 3.9 to 133 (75). Although tightly sealed indoor environments exclude outside pollutants, there is potential for increases in carbon dioxide concentrations and mold.

Personal Respirators

The use of filtering facepiece respirators (personal respirators or face masks) as protection against air pollution is becoming more common around the world. Their health effects are difficult to evaluate because of the many different respirators, styles, times of use, fitting of the mask, breathing characteristics, pollutants, ambient conditions, and technical difficulties in assessing the actual reduction of inhaled air pollutants. When tested as filters, most respirators that meet international occupational standards efficiently capture particles in the range of 4–20 μm (76); N95 or N95-equivalent devices are much more effective than surgical or flat fold masks (77). When examined under environmental conditions, however, the efficiency of even approved respirators varies greatly. One study found a median reduction in $PM_{2.5}$ of 48% but reductions of only 19% for "particle numbers" and 19% for black carbon. In that study, finer particles were less effectively filtered (78). Another study had persons with heart disease walk a specified route for 2 hours in Beijing with and without efficient respirators. It found that the respirators abrogated the adverse effects of air pollution on blood pressure and heart rate variability (79).

Benefits of Climate Change Abatement Strategies for Air Quality

Many studies have shown that the changes occurring in the Earth's climate contribute to poor air quality (80, 81). Concentrations of ozone and PM, air pollutants that especially impact human health (28), will be affected by warmer temperatures (82), including more extremely warm days (83); changing weather patterns, including increased stagnation (84), altered frequency of weather fronts (85), and more frequent heavy rain events (86); and changing emissions from vegetation and human sources (87). Projected climate change will increase ozone concentrations because of a direct heat effect and increased emissions of precursors and PM concentrations due to increased emissions from combustion of fossil fuels for power generation to adapt to hotter temperatures.

The energy and transportation sectors account for 84% of the U.S. emissions of the radiatively important gases (those that absorb infrared radiation from the Earth), such as carbon dioxide, methane, and other gases, driving climate change. These sectors also account for 80% of the emissions of nitrogen oxides that lead to ozone production and 96% of sulfur dioxide, the major precursor of sulfate aerosol and an important component of PM (82, 88, 89). With current energy use worldwide still heavily dependent on fossil fuels, similar percentages are found in many other countries. Mitigation policies to reduce the degrees of future climate change would also greatly lower emissions of PM, ozone and PM precursors, and other pollutants.

The magnitude of air quality cobenefits from climate mitigation depends on a number of factors. Countries with higher levels of air pollution have more potential for air quality cobenefits than areas where emission controls have been enacted and air pollution levels have been reduced. However, even in countries with relatively low average air pollution concentrations, populations in hot spots, such as highly urbanized areas with a high traffic load, can benefit profoundly from carbon-neutral mobility through its cobenefits of reducing air pollutants. Different approaches to climate mitigation also yield different reductions. For example, diesel vehicles emit less of radiatively important gases than gasoline-powered vehicles, but without correctly operating pollution control devices, diesel vehicles emit more particles and ozone precursors and thus contribute more to air pollution–related human health risks (82).

Reducing projected changes in climate will also reduce poor air quality episodes due to wildfires and dust storms. More frequent and longer droughts will increase PM by lengthening the wildfire season and lead to more catastrophic wildfires with large smoke emissions. Climate change, with longer summer dry seasons and drier soil and vegetation, has increased the likelihood of wildfires and dust storms (82) and the associated generation of atmospheric particles.

Challenges for Policy Makers

National and international agencies (e.g., the EPA in the United States, Central Pollution Control Board in India, Air Pollution Prevention and Control Action Plan in China, European Environmental Agency for the European Union, and the WHO) have been monitoring the health impacts of air quality for many decades. The United States, Europe, China, and India use the same metric of mean diurnal average 8-hour concentration to define their ozone standards. The values used are different, with India having the most conservative standard of 100 $\mu g/m^3$ (about 50 ppb) but with inadequate enforcement. Europe has a standard of 110 $\mu g/m^3$; the United States, 140 $\mu g/m^3$ (about 70 ppb); and China, 160 $\mu g/m^3$ (about 80 ppb). The WHO's guideline for ozone is that 8-hour concentrations should not exceed 100 $\mu g/m^3$. Even so, research suggests that ozone exposure greater than 33–42 ppb is harmful to human health (90, 91). Similar standards exist for particles.

Policymakers are often torn between further tightening the controls on emissions to enhance health and welfare and succumbing to economic and other societal pressures not to reduce emissions. This tension is particularly acute in developing countries where economic development is seen as positively impacting health by reducing poverty, but often at the expense of air quality because of increased power and transportation requirements (92). Climate change will further stress these conflicting challenges. As the world population shifts toward urban centers, cities will increasingly concentrate more-exposed populations. Recent studies found that local air pollution policies not only benefit air quality in cities but also are important for mitigating and adapting to global climate change (93). Such studies show the need for more in-depth, cross-city studies to highlight best practices both locally and globally. They call for the inclusion of a more human rights–based approach as a means of guaranteeing clean air for all and reducing climate change. The economic costs of adopting regulatory policies that achieve cobenefits in improved air quality and greenhouse gas emission reduction can be outweighed by the savings in health-related costs (94). Subnational jurisdictions, such as California, are adopting such policies (95).

Conclusions and Call to Action

Air pollution is largely an avoidable health risk that affects everyone, although the most vulnerable—the ill, the elderly, children, and the poor—face disproportionate risks. Urban growth, expanding industrialization, global warming, and new knowledge of the harm of air pollution are among the factors that raise the degree of urgency for pollution control and stress the consequences of inaction. Fortunately, reducing air pollution can result in prompt and substantial health gains. Sweeping policies affecting a whole country, such as banning secondhand smoke from the workplace in Ireland, reduced all-cause mortality within weeks. Local programs, such as reducing traffic and tempering an industrial polluter, have also promptly improved many health measures. Figure 2 shows the time line of benefits after stopping the pollution source.

The benefits of protection at a personal level and against short-term hazards are more difficult to evaluate but may be immediate. An important aspect of air pollution control is education of decision makers, the medical community, and the general populace. The studies presented in this article are examples of actions taken that produced favorable results and can be applied in other settings. For the health of their citizens and the world, nations should adopt and enforce WHO guidelines for air pollution. ■

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