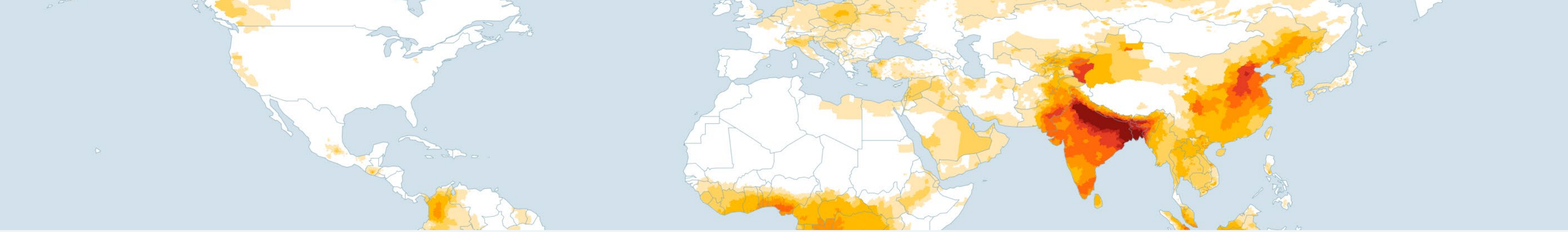
AQLI Air Quality Life Index®

AIR QUALITY LIFE INDEX® | JULY 2020

Annual Update

By Michael Greenstone and Claire Fan



Executive Summary

COVID-19—the disease caused by a novel coronavirus that emerged in late 2019—has had a profound, deadly effect on countries around the world. Its spread and the historic steps taken to prevent it underscore the importance of protecting public health. Yet, as the world awaits a vaccine, there is another, everyday killer: air pollution.

New data from the Air Quality Life Index (AQLI) reveals that air pollution was the greatest risk to human health before COVID-19 and will be after COVID-19 without—its only cure—strong and sustained public policy (See Figure 1). Much of the world, however, has not fully embraced the seriousness of air pollution and billions of people are leading shorter and sicker lives as a consequence.

Working unseen inside the human body, air pollution's deadly effects on the heart, lungs, and other systems have a more devastating impact on life expectancy than communicable diseases like tuberculosis and HIV/AIDS, behavioral killers like cigarette smoking, and even war. Averaged across all women, men, and children globally, the 2018 AQLI data finds that particulate pollution cuts global life expectancy by nearly two years relative to what it would be if air quality met the World Health Organization (WHO) guideline. In fact, that has consistently been the case over the last two decades, with the average loss in life expectancy holding at two years throughout that time period. The reality is, air pollution is a stubborn problem. As some countries improved their air quality, others experienced a decline. This report will unpack some of those trends, as well as point to places where there is a real risk for air pollution worsening.

In South Asia, particulate pollution has been on the rise, and now shortens lives more than anywhere else in the world. Bangladesh, India, Nepal, and Pakistan are consistently among the five most-polluted countries, accounting for 23 percent of the world's population but 60 percent of the life years lost to pollution. The average Indian loses 6.3 years due to particulate pollution. In Southeast Asia, the average life expectancy across 11 countries is 1.4 years lower than it would be if air quality complied with the WHO guideline. Meanwhile, in Central and West African countries, health threats such as HIV/AIDS and malaria there receive a lot of attention, but the effect on life expectancy from particulate pollution is comparable.

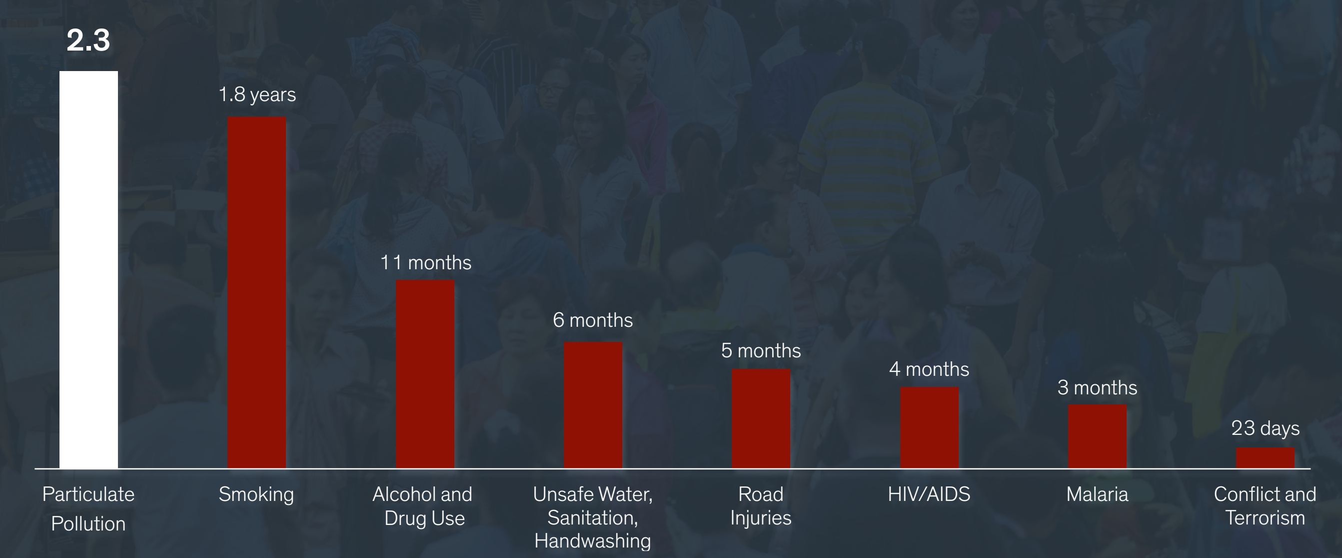
Other parts of the world are important models of how strong air pollution policies can add years onto people's lives. China has recently demonstrated the speed with which strong policies can combat air pollution. From 2013, when it began a vast "war against pollution," to 2018, the most recent year for which data is available, China reduced particulate pollution by nearly 28 percent. If these reductions are sustained, Chinese citizens can expect to live about 1.4 years longer than they would have prior to those reforms. And, China has plans to further reduce air pollution concentrations in the coming years.

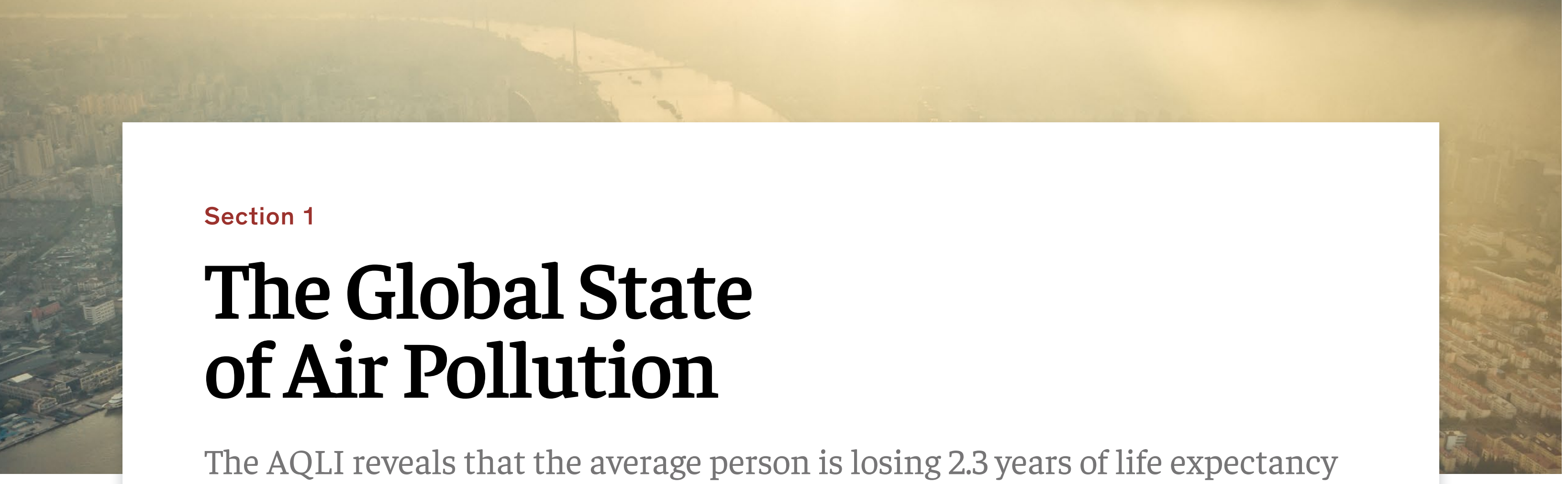
The United States and much of Europe and Japan have likewise experienced a trajectory of high emissions during industrialization and progressively lower emissions as their publics demanded air pollution controls. These countries include 16 percent of the world's population but suffer about 2 percent of the life years lost due to air pollution.

METHODOLOGY

The life expectancy calculations made by the AQLI are based on a pair of peer-reviewed studies, Chen et al. (2013) and Ebenstein et al. (2017), co-authored by Milton Friedman Distinguished Service Professor in Economics Michael Greenstone, that draw on a unique natural experiment in China. By comparing two subgroups of the population that experienced prolonged exposure to different levels of particulate air pollution, the studies are able to plausibly isolate the effect of particulate air pollution from other factors that affect health. The more recent of the two studies found that sustained exposure to an additional 10 µg/m3 of PM_{10} reduces life expectancy by 0.64 years. Calculated in terms of $PM_{2.5}$, that means that additional 10 µg/m3 of $PM_{2.5}$ reduces life expectancy by 0.98 years. The AQLI applies this finding to global, satellite-derived $PM_{2.5}$ measurements to determine the current life expectancy effects of air pollution in countries around the world.

Figure 1 · Average Life Expectancy Lost Per Person





Section 1

The Global State of Air Pollution

The AQLI reveals that the average person is losing 2.3 years of life expectancy due to particulate pollution exceeding the World Health Organization (WHO) guideline—more than devastating communicable diseases like tuberculosis, and HIV/AIDS, behavioral killers like cigarette smoking, and even war.

The average person is exposed to particulate pollution concentrations of 33 µg/m³—over three times the World Health Organization's guideline of 10 µg/m³. If this level of particulate pollution persists, the health consequences of air pollution would shave 2.3 years off global life expectancy compared to a world in which all countries met the WHO guideline. Permanently reducing air pollution to the WHO guideline would therefore increase global average life expectancy from 72 to 74 years; in total, the world's population would gain 17.4 billion years of life.

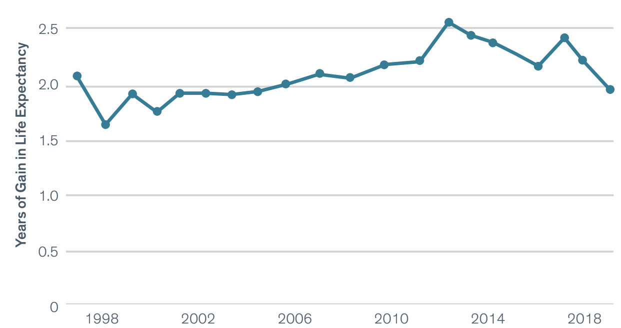
Measured in terms of life expectancy, ambient particulate pollution is consistently the world's greatest risk to human health. Compare it to other major killers. First-hand cigarette smoke, for instance, leads to a reduction in global average life expectancy of about 1.8 years. Alcohol and drug use reduce life expectancy by 11 months. Unsafe water and sanitation take off 7 months. HIV/AIDS cut lives short 4 months, and malaria, 3 months. Conflict and terrorism take off just 18 days.[1] So, the impact of particulate pollution on life expectancy is comparable to that of smoking, twice that of alcohol and drug use, three times that of unsafe water, five times that of HIV/AIDS, and 29 times that of conflict and terrorism.

Air pollution is so deadly because residents of polluted areas can do very little to avoid it. Everyone must breathe air, whereas it is possible to quit smoking and take precautions against diseases. Thus, air pollution affects many more people than any of these other conditions: 6.2 billion people, some 82 percent of the global population, live in areas where $PM_{2.5}$ exceeds the WHO guideline. So, although other risks such as HIV/ AIDS, tuberculosis, or war have a larger impact among the affected, they affect far fewer people. For example, the Global Burden of Disease estimates that those who died from HIV/AIDS in 2017 died prematurely by an average of 52.9 years. However, since the 37 million people affected by the disease is tiny compared to the 6.2 billion people breathing polluted air, the overall impact of air pollution is much greater.

The good news is that strong public policies can make a difference in reducing particulate pollution and improving life expectancies. Since a spike in 2011, particulate air pollution concentrations have generally declined due to policy changes in China and other important countries. If 2011 particulate pollution concentrations had persisted, average global life expectancy would have been 2.6 years lower relative to what it would have been had air quality met WHO standards worldwide. Thanks to an 8 percent drop in pollution since then, average life expectancy will have improved by 4 months if the reduction persists.

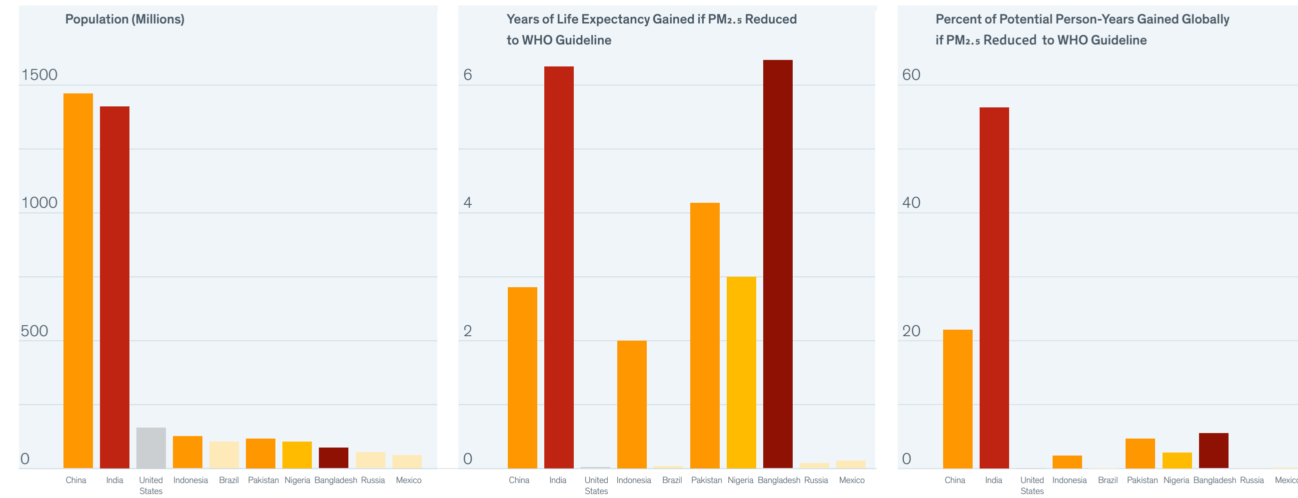
The improvement in air quality in some locations, and the spike in others, points to the fact that air pollution is globally a stubborn problem. While in 2018 particulate pollution cut global life expectancy by two years, the average reduction in life expectancy from pollution over the last two decades remains at two years as well. The rest of this report will further unpack where pollution has increased and where it has decreased over time.

Figure 2 · Global Average Potential Gain in Life Expectancy by Reducing $PM_{2.5}$ to WHO Guideline, 1998-2008



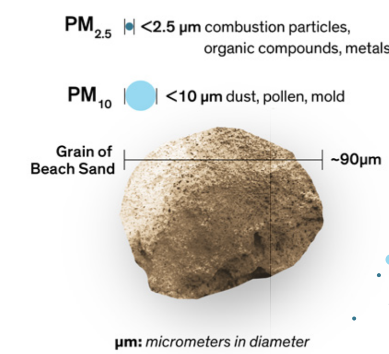
1 The effects on life expectancy from causes and risks of death other than ambient $PM_{2.5}$ air pollution are calculated from mortality rate data from the Global Burden of Disease 2017. For details, see https://aqli.epic.uchicago.edu/about/methodology/

Figure 3 · Potential Gain in Years of Life Expectancy Through Permanently Reducing $PM_{2.5}$ from 2018 Concentrations to the WHO Guideline



What is particulate pollution and where does it come from?

Particulate matter (PM) refers to solid and liquid particles—soot, smoke, dust, and others—that are suspended in the air. Some have their origin in natural sources such as dust, sea salt, and wildfires. But most come from the combustion of fossil fuels—such as from vehicle engines and power plants—and the combustion of biomass—such as through household wood and crop burning. These microscopic particles enter the respiratory system along with the oxygen that the body needs. When PM is breathed into the nose or mouth, each particle's fate depends on its size: the finer the particles, the farther into the body they penetrate. $PM_{2.5}$—or particles with a diameter of less than 2.5 µm, just 3 percent the diameter of a human hair—is the most deadly. They penetrate deep into the lungs, bypassing the body's natural defenses. From there they can enter the bloodstream, causing lung disease, cancer, strokes, and heart attacks. There is also evidence of detrimental effects on cognition. The tiny size of $PM_{2.5}$ particles not only makes them harmful from a physiological perspective, but also allows these particles to stay in the air for weeks and to travel hundreds or thousands of kilometers. This increases the likelihood that the particles will end up inhaled by humans before falling to the ground.



To learn more about particulate pollution, visit: https://aqli.epic.uchicago.edu/pollution-facts/

Section 2

The Burden of Air Pollution is Concentrated in South Asia

People living in the most polluted countries in the world can expect their life expectancy to be cut short by 6 years if current pollution levels persist, with the nearly 400 million residents of northern India seeing their lives shortened by more than 9 years.

Four countries that account for nearly a quarter of the world's population are also among the most polluted: Bangladesh, India, Nepal and Pakistan. These four countries are ranked among the five most polluted countries in the world, accounting for 60 percent of the person-years that would be lost globally if these pollution levels persist. Average life expectancy across these four countries would be 6 years higher if pollution concentrations complied with the WHO guideline.

A quarter of India's population is exposed to pollution levels not seen in any other country, with 400 million residents of northern India—including the megacities of Delhi and Kolkata—on track to lose more than nine years of life expectancy if 2018 concentrations persist (See Figure 5).

In terms of national average, Bangladesh ranks as the most polluted country in the world. Bangladeshis could live 6.7 years longer if pollution levels met the WHO guideline, with the 13 million living in the capital city Dhaka living 7.7 years longer if pollution improved. Across India's total population, life expectancy would increase by 6.3 years. Nepalese could live 5.0 years longer. Pakistanis could live 4.2 years longer—with those living in the second largest city of Lahore, part of the most polluted province of Punjab, living 5.0 years longer.

In each of these countries, the life expectancy impact of air pollution is substantially higher than that of other large health threats. Smoking, for instance, reduced life expectancy in these countries by as much as 1.8 years; unsafe water and sanitation cut lives by as much as 1.2 years; and alcohol and drug use shaved off about a year of life.

The average resident of these four countries is exposed to particulate pollution levels that are 23 percent higher than two decades ago. Had 1998 pollution levels persisted, they would be on track to lose 4.8 years of life expectancy—versus 6 years today. The increase is not surprising. Over the course of the last 20 years, industrialization, economic development, and population growth have led to skyrocketing energy demand in these countries. In India and Pakistan the number of vehicles on the road has increased about four-fold since the early 2000s. In Bangladesh, the number of motor vehicles has roughly tripled just from 2010 to 2020.[2] In Bangladesh, India, Nepal, and Pakistan combined, electricity generation from fossil fuels tripled from 1998 to 2017.[3] Crop burning, brick kilns, and other industrial activity also contributed to rising particulate pollution in the region.

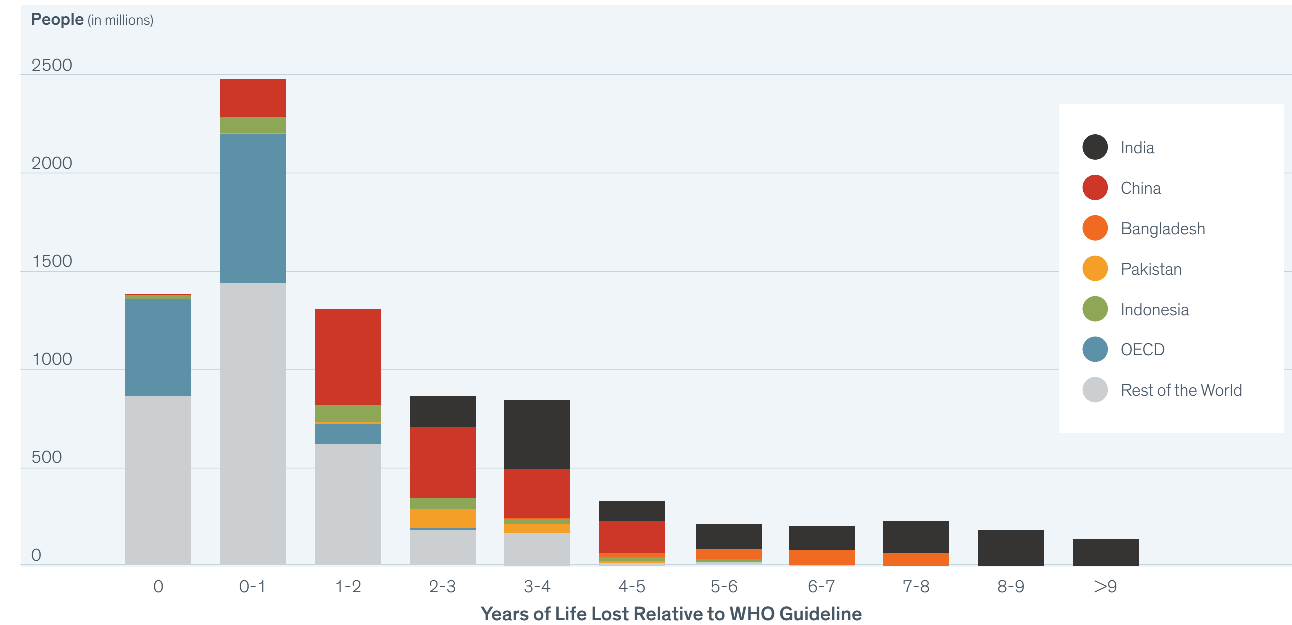
The rise in energy use has driven higher living standards and economic output that have undoubtedly enhanced well-being. The concomitant rise in particulate pollution has, however, had serious consequences, and energy demand in non-OECD regions is projected to continue growing. Without concerted policy action, the threat of air pollution is also likely to continue to grow.

Fortunately, more residents of these countries are recognizing that air pollution is a problem, and governments are beginning to respond. In India, for example, fuel emissions standards on

2 Statistical Year Book of India, 2017, Table 20.4; Pakistan Statistical Pocket Book, 2006, Table 17.5 and Pakistan Today, 2019; Bangladesh Road Transport Authority, 2020.

3 US Energy Information Administration.

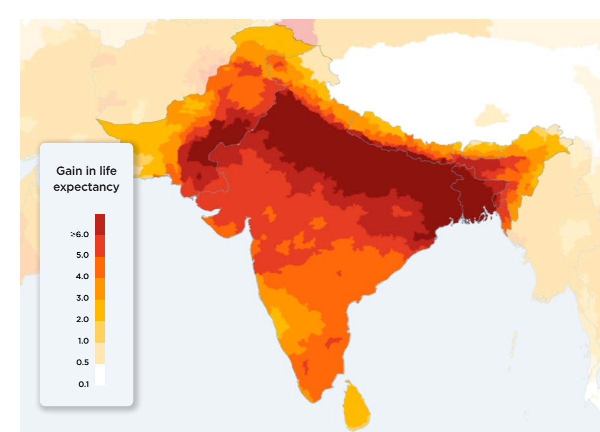
Figure 4 · Distribution of Person-Years Gained if $PM_{2.5}$ is Reduced to WHO Guideline Around the World



Note: India, China, Bangladesh, Indonesia, and Pakistan rank as the top five countries globally in terms of the gain in person-years from reducing PM2.5 concentrations to the WHO guideline.

par with the European Union's have taken effect nationwide as of 2020.This change comes after, the government declared a "war on pollution" in 2019 and announced the National Clean Air Programme (NCAP). The goal of the Programme is to reduce particulate pollution by 20-30 percent relative to 2017 levels by 2024. Though the NCAP's goals are nonbinding, if India does achieve and sustain this reduction nationwide, it would increase India's national life expectancy by as much as 1.7 years, and by as much as 3.1 years for residents of Delhi.

Figure 5 · Change in Potential Gain in Life Expectancy Through Reducing $PM_{2.5}$ to the WHO Guideline in Most Polluted Countries in South Asia, 1998-2018



Other South Asian countries are also beginning to take policy actions. In Pakistan, the government began installing more pollution monitors and shutting down factories in highly polluted districts during the winter months, when energy demand for heating is high. Pakistan and Bangladesh have both pushed brick kiln owners to shift to cleaner technologies. In Bangladesh especially, where brick kilns are responsible for about 60 percent of the particulate pollution in Dhaka, the law governing brick kiln production was amended in 2019 to prohibit the establishment of brick kilns near residential, commercial, agricultural, or environmentally sensitive areas, and the government plans to phase out the use of bricks in favor of concrete blocks by 2025 to lessen the damage to both air quality and topsoil with agricultural potential.

Section 3

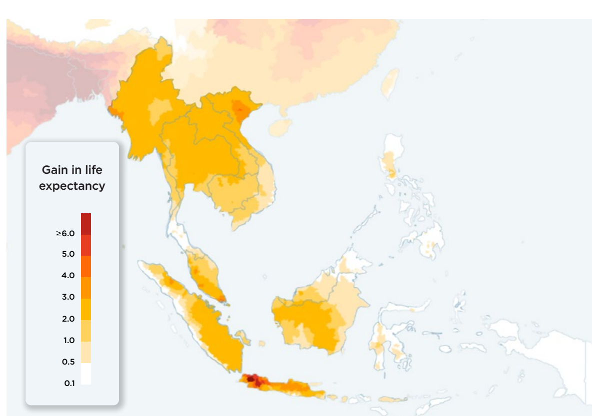
Southeast Asia Shares the Air Pollution Burden

Vehicles, powerplants, and industry subject to lax emissions regulations, along with forest, peat, and cropland fires, contribute to pollution levels in Southeast Asia. In metropolises such as Jakarta, Singapore, and Ho Chi Minh City, growing populations of city-dwellers could gain 1 to 5 years onto their lives if pollution were reined in to meet the WHO guideline.

Ninety-two percent of Southeast Asia's 650 million people live in areas where particulate pollution exceeds the WHO guideline. This pollution cuts short the life expectancy of the average person by 1.4 years, relative to what it would be if the WHO guideline was met. That's a total of 905 million person-years lost to pollution in the 11 countries that make up this region.

In the city-state of Singapore, the AQLI's satellite-derived data indicates that particulate pollution levels are similar to those in Beijing and Mumbai. This makes it the sixth most polluted country in the world. Singapore's 6 million residents would gain 3.0 years in life expectancy if air quality complied with the WHO guideline.

Figure 6 · Potential Gain in Years of Life Expectancy Through Permanently Reducing $PM_{2.5}$ from 2018 Concentrations to the WHO Guideline

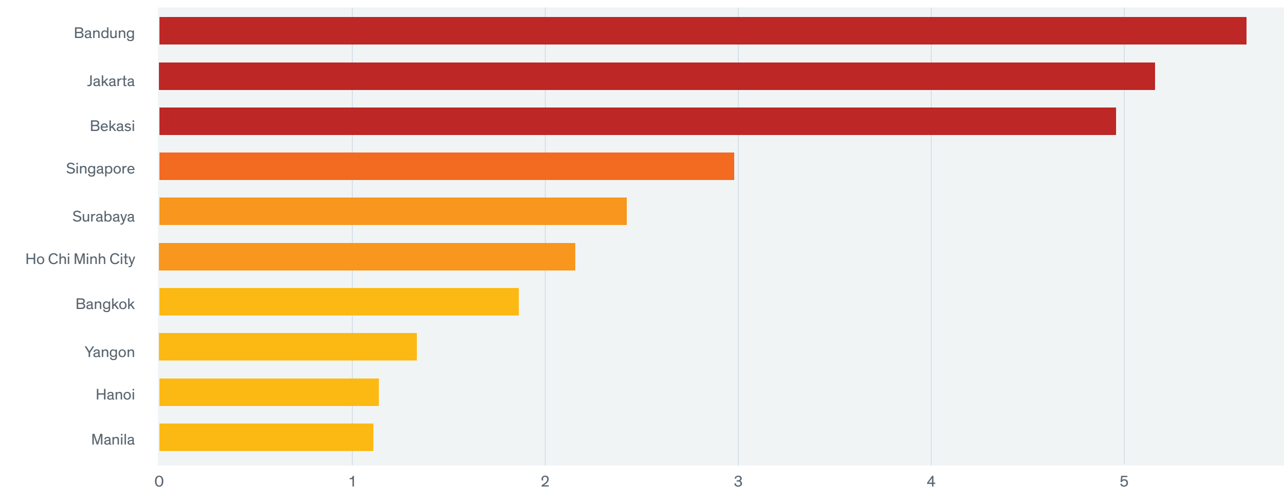


Densely populated and industrialized regions in other Southeast Asian countries also see the highest health burdens of air pollution. On Indonesia's island of Java, the country's population and industrial center, the 11 million residents of Jakarta would gain an average of 5.2 years in life expectancy if particulate pollution met the WHO guideline. In the cities of Bogor, South Tangerang, Bandung, and Bekasi, residents would similarly gain about 5 years. On mainland Southeast Asia, Vietnam has the highest levels of particulate pollution. In Vietnam's capital Hanoi, a city of 8 million, life expectancy would rise by 1.2 years if air quality were improved to comply with the WHO guideline. The average resident of Vietnam would gain 1.3 years in life expectancy. Similarly, in Thailand's capital Bangkok, residents would gain 1.7 years if pollution levels met the WHO guideline. The average for the country is 1.2 years.

Though the current health toll of particulate pollution is not as severe in Myanmar and Cambodia, pollution there is on the rise. From 1998 to 2018, pollution in Myanmar and Cambodia increased by 22 percent and 19 percent, respectively, cutting short life expectancy by 0.4 and 0.3 years relative to 1998 levels.

Whereas China and India have implemented fuel emissions standards at least as stringent as the Euro-6 standards in place in the European Union, Indonesia, Vietnam and Thailand currently require that fuel meets Euro-4 standards. Euro-4 standards allow for up to three times as much diesel NOx

Figure 7 · Potential Gain in Years of Life Expectancy Through Permanently Reducing $PM_{2.5}$ from 2018 Concentrations to the WHO Guideline, in 10 Largest Cities in Southeast Asia



emissions and five times as high fuel sulfur content as Euro-6. Meanwhile, Indonesia's coal-fired power plants – of which there are around 10 within a 100km radius of Jakarta[4] – are allowed to emit 3 to 7.5 times higher concentrations of particulate matter, NOx and SO2 than China's coal plants and 2 to 4 times higher concentrations than India's plants installed between 2003 and 2016[5]. NOx and SO2, once emitted into the atmosphere, can form particulate matter.

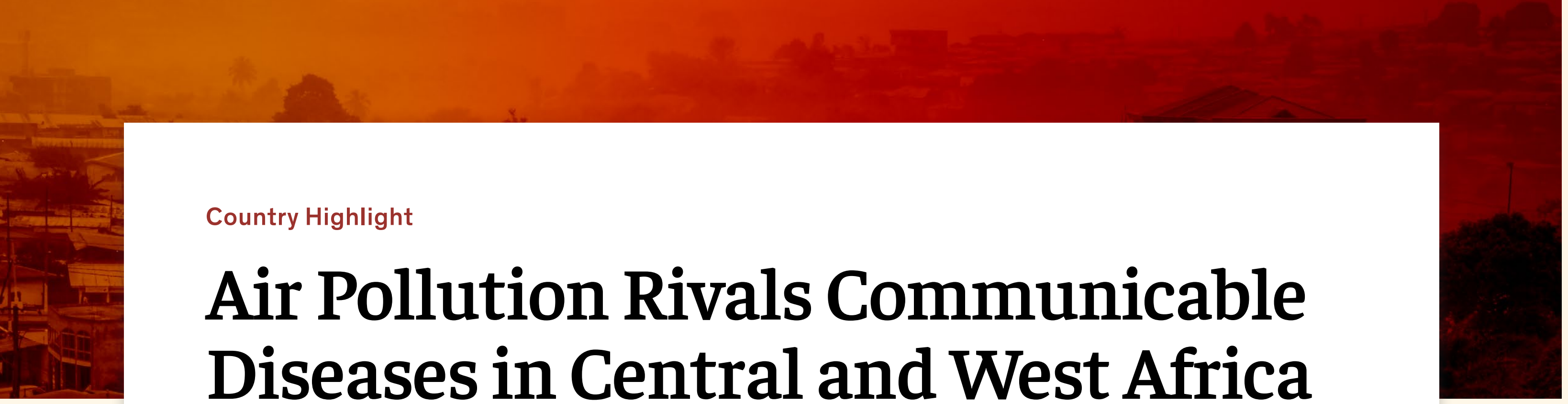
Aside from vehicles, coal, and industrial plants, biomass burning is a source of intense seasonal air pollution for much of the region. On the Indonesian islands of Sumatra and Kalimantan, forest and peatland fires, often set illegally to clear land for agricultural plantations, create annual haze events. Though fire intensity and hotspots vary across time, the recurrence of fires in these areas each year means that residents are exposed to a high long-term average pollution concentration. In the cities of Palangka Raya in Central Kalimantan and Palembang in South Sumatra, and their surrounding areas, the 10-year average particulate concentration is about three times the WHO guideline. Life expectancy for the residents of these cities is two years lower than what it would be if the long-term average particulate matter exposure were instead at the WHO guideline. Moreover, the fires create transboundary pollution with especially significant repercussions in Indonesia's neighboring downwind countries. In 2006 and 2015, years with particularly severe fires exacerbated by El Niño, average particulate pollution spiked visibly in Malaysia and Singapore. Amidst the 2015 Southeast Asian Haze event, Malaysia closed 7,000 schools as well as businesses and government offices.[6] Particulate pollution in Malaysia was about 39 and 43 percent higher in 2006 than in 2005 or 2007; in 2015, it was 12 and 35 percent higher than in 2014 and 2016, respectively.[7]

4 Taylor, 2019

5 Zhang, 2016

6 Straits Times, 2015

7 In addition to local and transboundary air pollution, the burning of forests and carbon-rich peatlands in Indonesia are a significant contributor to climate change. For example, the 2015 fires are calculated to have emitted more CO2 per day than the European Union (Huijnen et al., 2016).



Country Highlight

Air Pollution Rivals Communicable Diseases in Central and West Africa

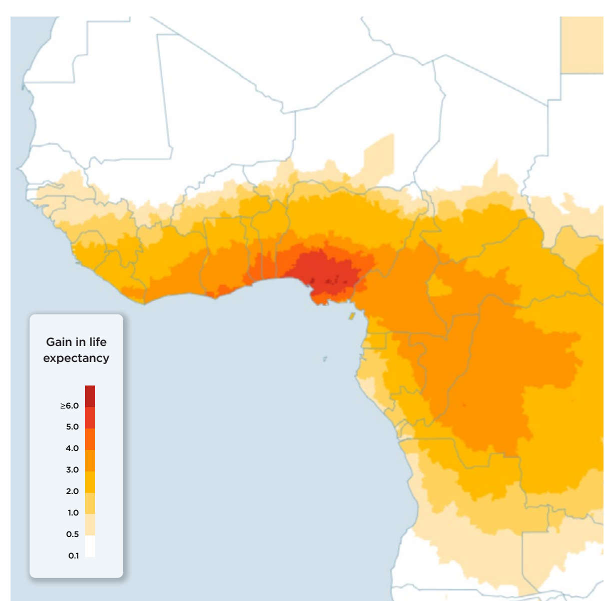
While challenges like HIV/AIDS and malaria grab headlines in Central and West Africa, particulate pollution poses just as serious a health threat. Many in these areas are seeing their life expectancy cut by 3 to 5 years relative to the WHO guideline.

The health discourse in Sub-Saharan Africa has centered on infectious diseases such as HIV/AIDS and malaria. However, particulate pollution's impact on life expectancy is no less serious. In Central and West Africa,[8], regions together comprised of 27 countries and 577 million people, the average person is exposed to particulate pollution levels that are triple the WHO guideline. If these particulate pollution levels persist, average life expectancy in the regions would be 1.9 years lower, and a total of 1 billion person-years would be lost, relative to if air quality met the WHO standard. While Asian countries rightly receive the most attention for air pollution, African countries also rank among the most polluted countries in the world: during the last decade, Benin, the Democratic Republic of the Congo, the Republic of Congo, Ghana, Nigeria and Togo have all been among the top ten most polluted countries in one or more years.

Nigeria is one of the region's pollution hotspots. In Lagos, home to 20 million people, permanently reducing particulate pollution to meet the WHO guideline would increase life expectancy by 4.2 years. In the Niger Delta, where oil refineries—many illegal—are linked to the grim daily reality of air pollution, life expectancy is 3 years lower than what it would be under the WHO guideline. Old vehicles running on high sulfur content fuel, open waste burning, and diesel electricity generation in the absence of a reliable grid are also sources of air pollution in cities throughout the country.

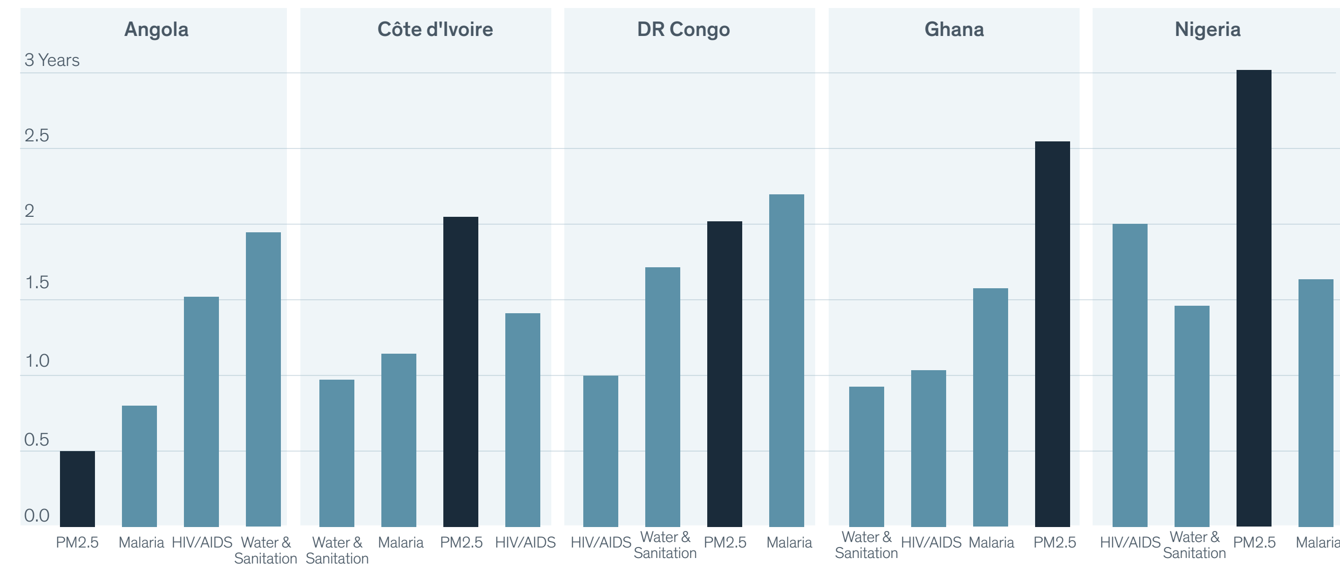
In Anambra, the most polluted city in Nigeria, residents are losing 5 years of life relative to expectations under the WHO guideline. Swaths of other African countries also see large impacts on life expectancy from particulate pollution. In Lomé, Togo, residents are losing 3.7 years. In Kinshasa, capital of the Democratic Republic of the Congo and home to more than 10 million people, life expectancy is lowered by 2.6 years. In Abidjan, Côte d'Ivoire, a city of 5 million, life expectancy is lowered by 2.9 years.

Figure 8 · Potential Gain in Years of Life Expectancy Through Permanently Reducing $PM_{2.5}$ from 2018 Concentrations to the WHO Guideline



8 Central Africa is here defined as the 11 countries in the Economic Community of Central African States. West Africa is defined following the United Nations' definition, which includes 16 countries.

Figure 9 · Life Expectancy Impacts of Particulate Pollution and Other Health Threats in the Five Most Populous Countries in Central and West Africa



Note: "DR Congo" refers to the Democratic Republic of the Congo.

In a comparison with other environmental health risks and prominent communicable diseases, in Nigeria, air pollution is second only to HIV/AIDS in terms of its impact on life expectancy—shaving off more years than malaria and water and sanitation concerns (see Figure 9). In the Democratic Republic of Congo, it is second only to malaria. In Ghana, it ranks as the deadliest of these threat, while in Cote d'Ivoire it shortens life by about the same amount as those communicable diseases.[9] Yet, while about 10 percent of health expenditures in sub-Saharan Africa go towards combatting HIV/AIDS or malaria, the problem of air pollution is rarely acknowledged in the region.[10] For example, when the Niger Delta city of Port Harcourt was covered in soot beginning in November 2016, it took four months and public outcry before a state of emergency was declared---this in a country where the government's response to the Ebola crisis has been praised for its promptness and effectiveness.

Of all 27 Central and West African countries, only one– Cameroon –has set a national standard for particulate pollution. Further, only three real-time air quality monitoring stations exist throughout the entire region to provide transparent pollution data to the public.[11] As a point of comparison, about 200 of these monitors exist in India, a land mass smaller than Central and West Africa.

Going forward, the populations and economies of African countries are projected to grow. In Africa as a whole, energy consumption is expected to see more rapid growth than before: the projected increase in coal consumption from 2017-2040 is more than three times the increase observed from 1995-2017,[12] a period of about the same length, and natural gas consumption is projected to increase by more than twice that observed from 1995-2017. Unless action is taken to address the emissions generated by economic and household activities, one would expect particulate pollution to rise along with the emissions.

9 Life expectancy impacts of causes and risks of death besides ambient $PM_{2.5}$ air pollution are calculated from mortality rate data from the Global Burden of Disease 2017. For details, see https://aqli.epic.uchicago.edu/about/methodology/

10 $18 billion of combined domestic and foreign aid money was spent to combat HIV/AIDS in 2015, and $2.7 billion to combat malaria in 2016. Total health spenootding for sub-Saharan Africa was $194 billion. (Dieleman et al., 2018; Haakenstad et al., 2019).

11 UNICEF, 2019

12 BP Energy Outlook 2019

Section 4

China is Winning its "War Against Pollution"

China was able to reduce its particulate pollution by 28 percent between 2013 and 2018—dropping the country from its top five ranking in recent years. If the reductions are sustained, China's people can expect to live 1.4 years longer.

In China, public concern about worsening air pollution began rising in the late 1990s. Beginning in 2008, the U.S. embassy in Beijing began publicly posting readings from its own air quality monitor on Twitter and the State Department website, and residents quickly pointed out discrepancies with the local government's air quality reports. In 2013, China experienced some of its highest pollution levels to that point, and public criticism reached new heights. At the same time, Chen et al. (2013) published their Huai River study, which found that high air pollution had cut the lifespans of people in northern China by about five years compared to those living in the south. The severity of the problem was clear.

The very next year, Premier Li Keqiang declared a "war against pollution." The National Air Quality Action Plan set aside $270 billion and the Beijing city government set aside an additional $120 billion, to reduce ambient air pollution. Across all urban areas, the Plan aimed to reduce particulate matter (PM_{10}) by 10 percent in 2017 relative to 2012 levels. The most heavily polluted areas in the country, including Beijing-Tianjin-Hebei, the Pearl River Delta, and the Yangtze River Delta, were given specific targets.

The government's strategies for achieving these goals included building pollution reduction into local officials' incentives so promotions depended on both environmental audits and economic performance; prohibiting new coal-fired plants in some regions and requiring existing coal plants to reduce emissions or be replaced with natural gas; increasing renewable energy generation; reducing iron and steel making capacity in industry; restricting the number of cars on the road in large cities; and increasing transparency and better enforcing emissions standards. In 2013-2014, the government rolled out a nationwide network of air quality monitors that report pollution readings automatically. Statistical analysis shows that this network has alleviated the problem of underreporting of pollution concentrations by government officials, hence making accurate real-time air pollution information available to the public so they can take appropriate defensive measures.[13]

Due to these actions, all of the targets set by the National Air Quality Action Plan, which expired in 2017, were met. As a result, between 2013 and 2018, particulate pollution exposure declined by an average of 28 percent across the Chinese population.[14] If that reduction is sustained, it would equate to a gain in life expectancy of 1.4 years (Figure 9, Table 1).China was among the five most polluted countries in the world each year from 1998 to 2016, but fell out of the top five in 2017 and 2018. The Beijing-Tianjin-Hebei area, one of China's most polluted areas in 2013, saw a 33 percent reduction in particulate pollution, translating to a gain of 2.6 years of life expectancy for its about 109 million residents, if sustained.

To put the scale and speed of China's progress into context, it's useful to compare it to the United States and Europe after their periods of industrialization. In the United States, following the passage of the Clean Air Act, it took almost three decades and five recessions to achieve about the same percent decline. In Europe, after their environment agency was created, it took about two decades and two recessions to achieve approximately China's percent reduction. While China reduced its pollution by 28 percent, real per capita gross domestic product grew by 36 percent.

13 Greenstone et al., 2020

14 This statistic, calculated using the AQLI's satellite-derived $PM_{2.5}$ data, is very similar to the statistic of 41 percent nationwide decrease from 2013-2018 observed by the improved ground-level air quality monitoring network.

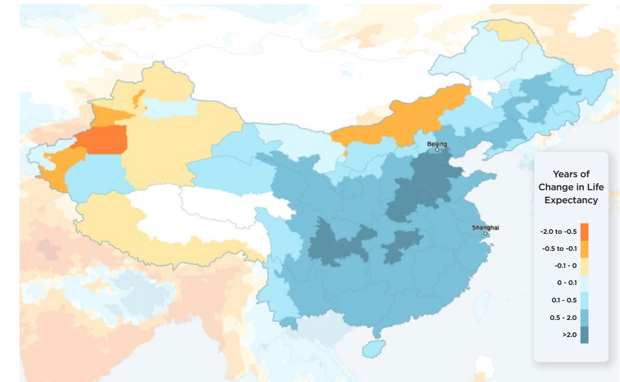


Figure 10 · Years of Change in Life Expectancy Relative to the WHO Guideline Due to Change in Particulate Matter Concentrations, 2013-2018

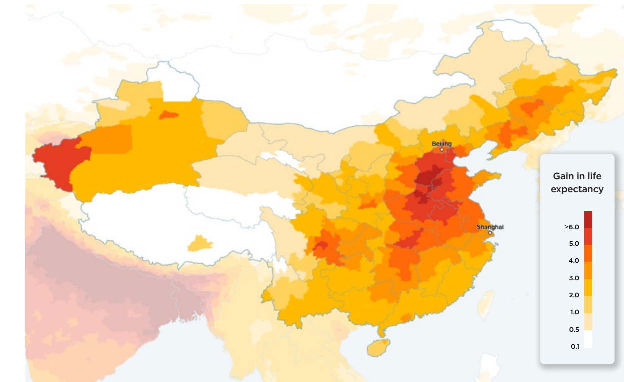


Figure 11 · Potential Gain in Years of Life Expectancy Through Permanently Reducing $PM_{2.5}$ from 2018 Concentrations to the WHO Guideline.

China's government, however, remained acutely aware that the country's air pollution was still a serious problem—the average particulate pollution concentration in 2018 was still more than three times the WHO guideline.

Reducing pollution to meet that guideline would mean an additional increase in life expectancy for the Chinese people of 2.3 years (See Figure 11). In Hebei and Henan provinces, home to much of the country's coal and steel industries, residents could see their life expectancies rise by up to an additional 5 years if pollution declined to the WHO guideline.

To achieve further improvements, the Chinese government announced in July 2018 a new plan for 2018-2020.[15] Regions that did not meet the national air quality standard of 35 μg/m³ would need to reduce particulate pollution by 18 percent relative to 2015 levels. Though the national targets are less ambitious than those set for 2013-2017, some prefectures set more stringent targets for themselves in their local five-year plans. For example, Beijing committed itself to a 30 percent reduction from 2015 levels by 2020.

15 China Ministry of Ecology and Environment, 2018

Table 1 · 10 Most Populous Prefectures

		2013-2018		2018	
Prefecture	Population (Millions)	Percent Decrease in $PM_{2.5}$	Years of Life Expectancy Gained Due to $PM_{2.5}$ Reduction	$PM_{2.5}$ (μg/m)	Years of Life Expectancy Gain if $PM_{2.5}$ is Further Reduced to WHO Guideline
Chongqing	30	38%	2.1	36	2.5
Shanghai	24.1	25%	1.1	34	2.3
Beijing	20.5	30%	2	48	3.8
Chengdu, Sichuan	13.9	39%	3.1	50	3.9
Tianjin	13.6	34%	2.8	55	4.4
Guangzhou, Guangdong	13.2	27%	1	29	1.9
Baoding, Hebei	11.6	29%	2.4	60	4.9
Harbin, Heilongjiang	11.1	19%	0.9	37	2.7
Suzhou, Jiangsu	10.8	27%	1.4	40	2.9
Shenzhen, Guangdong	10.8	27%	0.9	24	1.4

Section 5

Decades of Reducing Pollution in Industrialized Countries Deliver Benefits

After sustained enforcement of strong air pollution policies, the United States, Europe and Japan have seen significant reductions in particulate pollution, and their citizens live longer because of it. Their experience provides case studies of success.

Europe, Japan and the United States, which make up 16 percent of the world's population, account for about 2 percent of the health burden from particulate pollution. However, it was not always this way. Places like London—once known as "the big smoke"—Los Angeles—dubbed the "smog capital of the world"—and Osaka—once the "big smoke"—used to be as polluted as the most polluted countries today.

Since that time, the offshoring of polluting industries and, crucially, well-implemented air pollution policies have played large roles in attaining cleaner air. For example, in the United States, the Clean Air Act was enacted in 1970. The Act established the National Ambient Air Quality Standards (NAAQS), setting maximum allowable concentrations of particulate matter, among other pollutants. It also created emissions standards for pollution sources, leading industrial facilities to install pollution control technologies and automakers to produce cleaner, more fuel-efficient vehicles. Further, it required each state government to devise its own plan for achieving and sustaining compliance with the standards.

The Act rapidly improved the air Americans breathed.[16] By 1980,

16 Several factors that could have affected air pollution have been at play simultaneously since 1970, but research supports an outsize role of the Clean Air Act. For example, Shapiro and Walker (2018) decompose the decline in emissions from manufacturing plants from 1990-2008 into the portions caused by (1) the use of pollution abatement technologies as required by CAA environmental regulations, (2) changes in what Americans produce (i.e. offshoring of pollution-intensive industries), and (3) increases in production efficiency. They find that the total pollution emissions decline is primarily driven by (1).

Figure 12 · Gain in Life Expectancy Due to Change in $PM_{2.5}$ in United States, 1970-2018

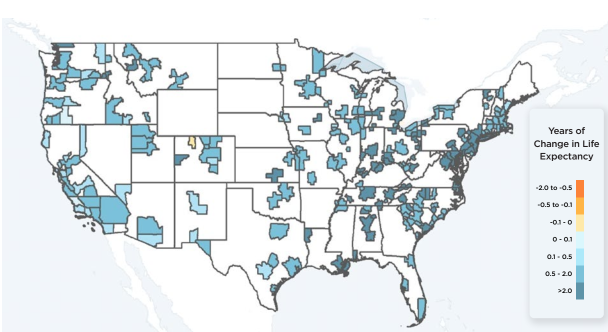


Figure 13 · Gain in Life Expectancy Due to Change in $PM_{2.5}$ in Europe, 1998-2018

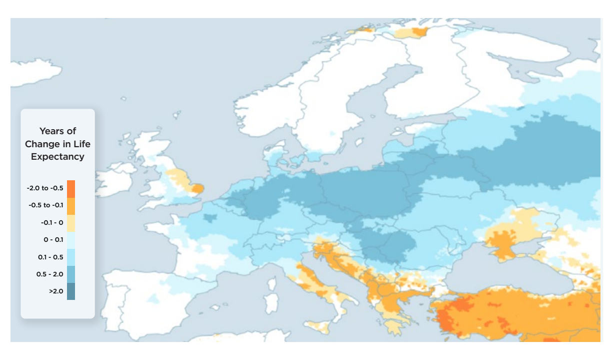


Figure 14 · Gain in Life Expectancy Due to Change in $PM_{2.5}$ in Japan, 1998-2018

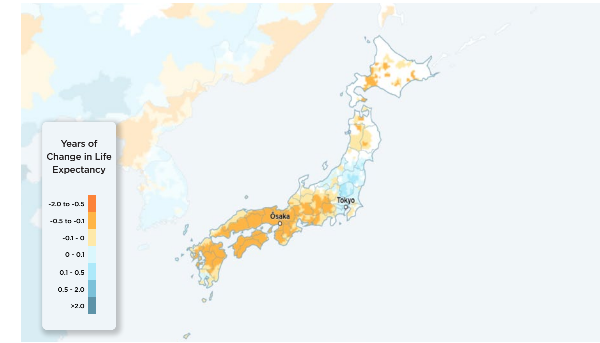
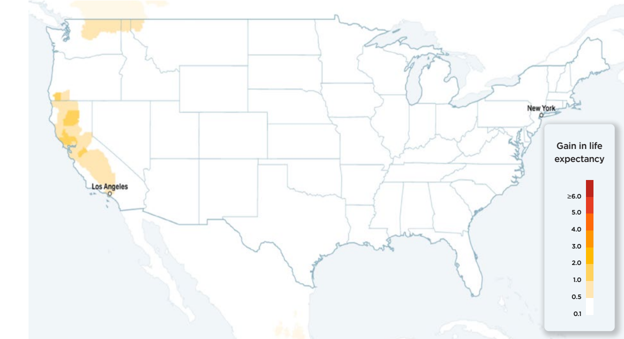


Figure 15 · Potential Gain in Years of Life Expectancy Through Permanently Reducing $PM_{2.5}$ from 2018 Concentrations to the WHO Guideline.



albeit aided by the economic slowdown of the 1970s, the United States recorded a 50 percent decrease in particulate emissions compared to 1970 and a 44 percent decrease in ambient concentrations of SO2, a precursor to PM.[17] Today, on average, Americans are exposed to 62 percent less particulate pollution than they would have been in 1970. And, they're living longer lives because of it, with life expectancy increasing by 1.4 years for the average American from 1970 to today[18]. For those living in the former smog capital of Los Angeles, particulate pollution has declined by almost 57 percent since 1970, extending life expectancy for the average Angeleno by 1.4 years. In Philadelphia and Washington, DC, the gain is 2.6 and 3.3 years.

The history of Europe tells a similar story. Among the policy improvements, the European Environment Agency was created in the mid-1990s to provide independent information to policymakers and the public. In subsequent years, the European Union set emissions targets, created a pollution standard, and introduced a comprehensive clean air program with support measures to ensure that targets are met. The European Union's air pollution regulations, such as fuel emissions standards, have formed the basis of standards in many other countries from Argentina to India to Turkey.

Today on average, Europeans are exposed to 15 percent less particulate pollution than they were two decades ago, gaining 3 months of life expectancy because of it. Areas that were historically more polluted have seen even greater gains.

In the 1990s, Japan tightened its environmental policies, including through the enactment of the Basic Environment Law. An improvement on two earlier rules, the new law included restrictions on industrial emissions and the establishment of environmental pollution control programs, among other changes. Later, in 2001, the country's Environment Agency was promoted to full-fledged Ministry of the Environment.

The people of Japan are now living healthier and longer lives thanks to a 24 percent decline in particulate pollution over the last two decades. The Kagoshima Prefecture, with a population of 1.7 million, has seen the greatest improvement with a 35 percent decline in pollution. As a result of this improvement, the region's residents are living 8 months longer.

Due to the vast improvements in the quality of the air in the United States and Europe, the potential for further progress remains but the potential health benefits are concentrated in specific areas and are limited on average. In the United States, 10 percent of the population lives in areas where particulate pollution exceeds the WHO guideline. Residents of California's Central Valley have consistently been exposed to particulate pollution above both the WHO guideline and the nation's own air quality standard. Those living in this region stand to gain up to 5 months of life expectancy if air quality were kept below the WHO guideline rather than at the 2018 level---a year when California saw intense wildfires that may have contributed to the pollution.

17 Hunt and Lillis (1981)

18 These estimates are based on the 236 US counties for which 1970 PM2.5 concentrations could be estimated. Details on how 1970 particulate pollution concentrations and life expectancy changes since 1970 were estimated are available at aqli.epic.uchicago.edu/policy-impacts.

Figure 16 · Potential Gain in Years of Life Expectancy Through Permanently Reducing $PM_{2.5}$ from 2018 Concentrations to the WHO Guideline

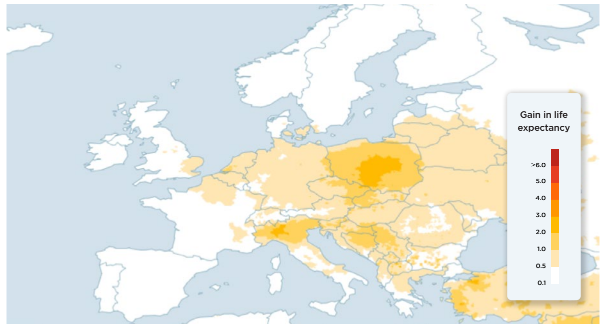


Figure 17 · Potential Gain in Years of Life Expectancy Through Permanently Reducing $PM_{2.5}$ from 2018 Concentrations to the WHO Guideline

The story is broadly similar in Europe. Nearly three-quarters of the population still lives in areas where particulate pollution exceeds the WHO guideline of 10 µg/m3: the average European was exposed to a particulate pollution concentration of 12.2 µg/m3 in 2018, meeting the European Union's air pollution standard of 25 µg/m3 but falling short of WHO guidance. If particulate pollution were to meet the WHO guideline, average life expectancy across Europe would improve by 3 months.

The most polluted area of Europe is the eastern part of the continent, where the entire populations of Poland, Belarus, Slovakia, the Czech Republic, Slovenia, Hungary, Lithuania, Armenia, Belgium, Germany, Moldova, Cyprus, and Ukraine, as well as the Netherlands and San Marino do not meet WHO's guideline. Poland is the most polluted country in Europe and areas surrounding Warsaw and Łódź suffer particularly high levels of particulate pollution. If pollution were to improve to meet the WHO guideline, residents in Warsaw would gain 11 months of life expectancy. Silesia, the hub of Poland's coal mining industry, is the country's third most polluted province. Though air quality has been improving there, the average resident still stands to gain 1.2 year of life expectancy if particulate pollution were to meet the WHO guideline on a permanent basis.

Outside of Eastern Europe, high pollution remains in areas such as Italy's Po Valley, including the city of Milan, as well as the industrial center of Bursa in Turkey. In Milan and Bursa, residents would gain over 1 year if particulate pollution levels met the WHO guideline.

In Japan, 90 percent of the population lives in a region with pollution levels that exceed the WHO guideline, and about 40 percent lives in a region where the pollution is higher than the national standard. The city of Kumamoto could stand to benefit the most from reducing pollution to meet the WHO guideline, which would add a year onto the lives of the 700,000 people living there.

Conclusion

The Air Quality Life Index shows that particulate pollution is the world's greatest threat to human health. South Asia is consistently the most polluted region, with people there seeing their lives shortened by an average of five years relative to what it would be if the region met the WHO guideline —and even more in the most polluted part of the region, northern India. While South Asian countries are beginning to pay due attention to the severity of the problem, pollution remains largely unacknowledged in Central and West Africa, where the life expectancy impact is on par with the more well-known threats of malaria and HIV/AIDS. Meanwhile, China made extraordinarily rapid gains, cutting pollution by 28 percent in about five years and extending lives by 1.4 years if the reductions are sustained. The country not only joins Europe and the United States in stablishing strong policies to confront pollution, but is achieving gains at an even quicker pace. The United States, Europe and China provide lasting examples to more polluted regions that the threat of air pollution can be tackled through serious, sustained public policy.

Appendix Table

Country	$PM_{2.5}$ Concentration, 2018 (µg/m³)	National Standard (µg/m³)	Additional Years of Life Expectancy if $PM_{2.5}$ is Reduced to: WHO Guideline**	National Standard
Afghanistan	31	10	2.1	2.1
Akrotiri and Dhekelia	11	*	0.1	*
Albania	13	15	0.3	0.0
Algeria	8	*	0.0	*
American Samoa	1	*	0.0	*
Andorra	6	25	0.0	0.0
Angola	15	*	0.5	*
Anguilla	1	*	0.0	*
Antigua and Barbuda	1	*	0.0	*
Argentina	7	15	0.0	0.0
Armenia	17	*	0.6	*
Aruba	2	*	0.0	*
Australia	4	8	0.0	0.0
Austria	14	25	0.4	0.0
Azerbaijan	10	*	0.1	*
Bahamas	4	*	0.0	*
Bahrain	38	*	2.8	*
Bangladesh	78	15	6.7	6.2
Barbados	1	*	0.0	*
Belarus	14	15	0.4	0.0
Belgium	14	25	0.3	0.0
Belize	10	*	0.0	*
Benin	41	*	3.0	*
Bermuda	2	30	0.0	0.0
Bhutan	36	*	2.6	*
Bolivia	13	10	0.3	0.3
Bonaire, Sint Eustatius	2	*	0.0	*
Bosnia and Herzegovina	17	25	0.7	0.0
Botswana	9	*	0.0	*
Brazil	8	*	0.1	*
British Virgin Islands	1	*	0.0	*
Brunei	12	*	0.2	*
Bulgaria	13	25	0.4	0.0
Burkina Faso	15	*	0.5	*
Burundi	17	*	0.7	*
Cambodia	19	*	0.8	*
Cameroon	31	10	2.1	2.1
Canada	9	10	0.0	0.0
Cape Verde	3	*	0.0	*
Caspian Sea	8	*	0.0	*
Cayman Islands	7	*	0.0	*
Central African Republic	32	*	2.2	*
Chad	19	*	1.0	*

Country	$PM_{2.5}$ Concentration, 2018 (µg/m³)	National Standard (µg/m³)	Additional Years of Life Expectancy if $PM_{2.5}$ is Reduced to: WHO Guideline**	National Standard
Chile	12	20	0.3	0.0
China	38	35	2.7	0.7
Christmas Island	4	*	0.0	*
Cocos Islands	2	*	0.0	*
Colombia	22	25	1.2	0.1
Comoros	3	*	0.0	*
Cook Islands	1	*	0.0	*
Costa Rica	6	*	0.0	*
Croatia	15	25	0.5	0.0
Cuba	6	*	0.0	*
Curaçao	2	*	0.0	*
Côte d'Ivoire	32	*	2.1	*
Democratic Republic of the Congo	29	*	1.9	*
Denmark	11	25	0.1	0.0
Djibouti	21	*	1.0	*
Dominica	2	*	0.0	*
Dominican Republic	7	15	0.0	0.0
Ecuador	13	15	0.3	0.1
Egypt	15	*	0.5	*
El Salvador	13	15	0.3	0.0
Equatorial Guinea	25	*	1.4	*
Eritrea	16	*	0.6	*
Estonia	8	25	0.0	0.0
Ethiopia	16	*	0.6	*
Falkland Islands	1	*	0.0	*
Faroe Islands	2	*	0.0	*
Fiji	1	*	0.0	*
Finland	6	25	0.0	0.0
France	10	25	0.1	0.0
French Guiana	9	*	0.0	*
French Polynesia	1	*	0.0	*
French Southern	4	*	0.0	*
Gabon	22	*	1.1	*
Gambia	9	*	0.0	*
Georgia	13	*	0.3	*
Germany	13	25	0.3	0.0
Ghana	36	*	2.6	*
Gibraltar	7	*	0.0	*
Greece	11	25	0.1	0.0
Greenland	1	*	0.0	*
Grenada	1	*	0.0	*
Guadeloupe	1	25	0.0	0.0
Guam	2	12	0.0	0.0
Guatemala	17	10	0.7	0.7

* No national standard specified ** 10 µg/m³

Country	$PM_{2.5}$ Concentration, 2018 (μg/m³)	National Standard (μg/m³)	Additional Years of Life Expectancy if $PM_{2.5}$ is Reduced to:	
			WHO Guideline**	National Standard
Guernsey	7	*	0.0	*
Guinea	18	*	0.8	*
Guinea-Bissau	13	*	0.3	*
Guyana	6	*	0.0	*
Haiti	8	*	0.0	*
Honduras	12	*	0.2	*
Hungary	14	25	0.4	0.0
Iceland	2	*	0.0	*
India	75	40	6.3	3.4
Indonesia	30	*	2.0	*
Iran	20	10	1.0	1.0
Iraq	19	*	0.9	*
Ireland	4	25	0.0	0.0
Isle of Man	5	*	0.0	*
Israel	14	25	0.4	0.0
Italy	14	25	0.4	0.0
Jamaica	9	15	0.0	0.0
Japan	14	15	0.4	0.1
Jersey	7	*	0.0	*
Jordan	15	15	0.5	0.1
Kazakhstan	13	*	0.4	*
Kenya	9	35	0.1	0.0
Kiribati	13	*	0.6	*
Kosovo	16	*	0.5	*
Kuwait	35	15	2.5	2.0
Kyrgyzstan	23	*	1.3	*
Laos	23	*	1.3	*
Latvia	11	25	0.1	0.0
Lebanon	14	*	0.4	*
Lesotho	7	*	0.0	*
Liberia	26	*	1.5	*
Libya	9	*	0.1	*
Liechtenstein	11	*	0.1	*
Lithuania	13	25	0.3	0.0
Luxembourg	11	25	0.1	0.0
Macedonia	16	*	0.6	*
Madagascar	4	*	0.0	*
Malawi	9	8	0.0	0.1
Malaysia	23	35	1.3	0.0
Mali	9	*	0.1	*
Malta	8	*	0.0	*
Marshall*Islands	0	*	0.0	*
Martinique	2	25	0.0	0.0
Mauritania	4	*	0.0	*
Mauritius	1	*	0.0	*
Mayotte	3	25	0.0	0.0
Mexico	12	15	0.3	0.1
Micronesia	1	*	0.0	*
Moldova	12	*	0.2	*
Monaco	10	*	0.0	*
Mongolia	9	25	0.2	0.0
Montenegro	12	20	0.2	0.0
Montserrat	2	*	0.0	*
Morocco	7	*	0.0	*
Mozambique	7	*	0.0	*
Myanmar	23	*	1.3	*
Namibia	8	*	0.0	*
Nauru	1	*	0.0	*
Nepal	62	*	5.1	*
Netherlands	13	25	0.3	0.0
New Caledonia	2	25	0.0	0.0
New Zealand	3	*	0.0	*
Nicaragua	8	*	0.0	*
Niger	14	*	0.4	*
Nigeria	40	*	2.9	*
Niue	1	*	0.0	*
Norfolk Island	1	*	0.0	*
North Korea	22	*	1.2	*
Northern Cyprus	11	*	0.1	*
Northern Mariana Islands	2	*	0.0	*
Norway	6	15	0.0	0.0
Oman	21	*	1.1	*
Pakistan	54	15	4.3	3.8
Palau	1	*	0.0	*
Palestina	14	*	0.4	*
Panama	9	*	0.0	*
Papua New Guinea	6	*	0.0	*
Paraguay	7	15	0.0	0.0
Peru	32	15	2.3	2.0
Philippines	10	25	0.3	0.0
Poland	19	25	0.9	0.0
Portugal	5	25	0.0	0.0
Puerto Rico	2	15	0.0	0.0
Qatar	36	*	2.6	*
Republic of Congo	30	*	2.0	*
Reunion	2	*	0.0	*
Romania	13	25	0.3	0.0
Russia	12	25	0.2	0.0

* No national standard specified   ** 10 μg/m³

Country	$PM_{2.5}$ Concentration, 2018 (μg/m³)	National Standard (μg/m³)	Additional Years of Life Expectancy if $PM_{2.5}$ is Reduced to:	
			WHO Guideline**	National Standard
Rwanda	20	*	1.0	*
Saint Helena	1	*	0.0	*
Saint Kitts and Nevis	2	*	0.0	*
Saint Lucia	2	*	0.0	*
Saint Pierre and Miquelon	2	*	0.0	*
Saint Vincent and the Grenadines	2	*	0.0	*
Saint-Barthélemy	2	*	0.0	*
Saint-Martin	1	*	0.0	*
Samoa	1	*	0.0	*
San Marino	12	*	0.2	*
Saudi Arabia	27	15	1.7	1.2
Senegal	7	*	0.0	*
Serbia	16	25	0.6	0.0
Seychelles	2	*	0.0	*
Sierra Leone	22	*	1.1	*
Singapore	40	12	3.0	2.8
Sint Maarten	2	*	0.0	*
Slovakia	16	25	0.5	0.0
Slovenia	15	*	0.5	*
Solomon Islands	3	*	0.0	*
Somalia	10	*	0.3	*
South Africa	10	20	0.2	0.0
South Korea	23	25	1.3	0.0
South Sudan	20	*	1.0	*
Spain	7	25	0.0	0.0
Sri Lanka	25	25	1.5	0.1
Sudan	14	*	0.4	*
Suriname	9	*	0.0	*
Swaziland	9	*	0.0	*
Sweden	7	25	0.0	0.0
Switzerland	12	*	0.2	*
Syria	15	*	0.5	*
São Tomé and Príncipe	11	*	0.1	*
Taiwan	16	15	0.6	0.2
Tajikistan	26	*	1.6	*
Tanzania	9	*	0.1	*
Thailand	22	25	1.2	0.1
Timor-Leste	9	*	0.0	*
Togo	39	*	2.8	*
Tonga	1	*	0.0	*
Trinidad and Tobago	2	15	0.0	0.0
Tunisia	8	*	0.0	*
Turkey	15	*	0.5	*
Turkmenistan	11	*	0.2	*
Turks and Caicos Islands	3	25	0.0	0.0
Tuvalu	1	*	0.0	*
Uganda	19	*	0.8	*
Ukraine	13	*	0.3	*
United Arab Emirates	26	*	1.6	*
United Kingdom	10	25	0.1	0.0
United States	8	12	0.0	0.0
Uruguay	4	*	0.0	*
Uzbekistan	24	*	1.4	*
Vanuatu	3	*	0.0	*
Vatican City	13	*	0.3	*
Venezuela	10	*	0.2	*
Vietnam	24	25	1.3	0.3
Virgin Islands, U.S.	2	12	0.0	0.0
Wallis and Futuna	1	*	0.0	*
Western Sahara	5	*	0.0	*
Yemen	21	*	1.1	*
Zambia	11	*	0.2	*
Zimbabwe	8	*	0.0	*
Åland	5	*	0.0	*

* No national standard specified   ** 10 μg/m³

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Michael Greenstone

Michael Greenstone is the Milton Friedman Professor in Economics, the College, and the Harris School, as well as the Director of the Becker Friedman Institute and the interdisciplinary Energy Policy Institute at the University of Chicago. Greenstone's research, which has influenced policy globally, is largely focused on uncovering the benefits and costs of environmental quality and society's energy choices. As the Chief Economist for President Obama's Council of Economic Advisers, he co-led the development of the United States Government's social cost of carbon. Additionally, he has been researching the impacts of particulate pollution on human well-being for more than two decades, including work that plausibly quantified the causal relationship between long-term human exposure to particulate pollution and life expectancy. This work is the basis of the Air Quality Life Index.

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Qing (Claire) Fan is a Pre-Doctoral Fellow with the Energy Policy Institute at the University of Chicago (EPIC), where she works for Director Michael Greenstone on a variety of energy and environmental economics projects. She earned her bachelor's in mathematics with a minor in economics in 2018 from Pomona College in California. While at Pomona, Claire conducted a field study on attitudes toward sustainable agriculture in farming communities in Punjab, India, and worked on research in applied mathematics and on the economics of social enterprise. Claire is interested in the intersection of environmental and development economics, including the social impacts of climate change, and food and agriculture.

ABOUT THE AIR QUALITY LIFE INDEX

The AQLI is a pollution index that translates particulate air pollution into perhaps the most important metric that exists: its impact on life expectancy. Developed by the University of Chicago's Milton Friedman Dinstinguished Service Professor in Economics Michael Greenstone and his team at the Energy Policy Institute at the University of Chicago (EPIC), the AQLI is rooted in recent research that quantifies the causal relationship between long-term human exposure to air pollution and life expectancy. The Index then combines this research with hyper-localized, global particulate measurements, yielding unprecedented insight into the true cost of particulate pollution in communities around the world. The Index also illustrates how air pollution policies can increase life expectancy when they meet the World Health Organization's guideline for what is considered a safe level of exposure, existing national air quality standards, or user-defined air quality levels. This information can help to inform local communities and policymakers about the importance of air pollution policies in concrete terms.

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ABOUT EPIC

The Energy Policy Institute at the University of Chicago (EPIC) is confronting the global energy challenge by working to ensure that energy markets provide access to reliable, affordable energy, while limiting environmental and social damages. We do this using a unique interdisciplinary approach that translates robust, data-driven research into real-world impacts through strategic outreach and training for the next generation of global energy leaders.

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*This document replaces an earlier version that erroneously used satellite data that did not include PM2.5 from biomass burning sources.