AQLI Air Quality Life Index®

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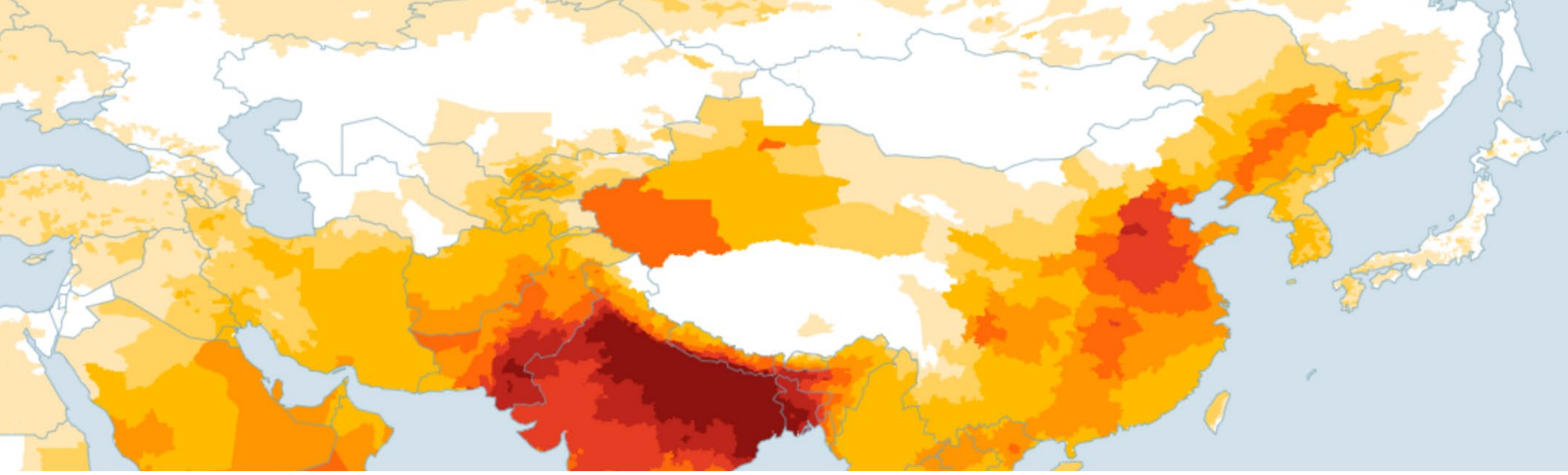
The 2008 Olympics to the 2022 Olympics

China's Fight to Win its War Against Pollution

By Michael Greenstone, Guojun He, and Ken Lee

Early Release



SUMMARY

In the years before the 2008 Beijing Summer Olympics, pollution in China had been sharply climbing. The government responded with quick reforms that temporarily reduced pollution during the games. The reforms, however, only managed to slow the climb in the long run. By 2013, pollution in China had reached record levels. The following year, the same year Beijing applied to host the 2022 Olympic Games, Chinese Premier Li Keqiang declared a "war against pollution" and vowed that China would tackle pollution with the same determination it used to tackle poverty.

Seven years later, pollution has declined dramatically by about 40 percent. In Beijing, there is half as much pollution compared to both 2008 and 2013 levels. In most areas of China, pollution has fallen to levels not seen in more than two decades. To put China's success into context, these reductions account for more than three quarters of the global decline in pollution since 2013. Once the United States started to focus on reducing pollution in the early 1970s, it took several decades and recessions to achieve the same pollution reductions that China has accomplished in seven years. Due to these improvements, the average Chinese citizen can expect to live 2 years longer, provided the reductions are sustained. Residents of Beijing can expect to live 3.7 and 4.6 years longer, since 2008 and 2013 respectively.

Nevertheless, work remains. While China has met its national air quality standard, pollution levels as of 2020 were still six times greater than the World Health Organization (WHO) guideline. To further reduce pollution, China is taking rapid actions ahead of the 2022 Winter Olympics. If those actions were to allow China to permanently reduce pollution to meet the WHO guideline, the average Chinese citizen could expect to gain an additional 2.6 years of life expectancy, on top of the gains since the war against pollution was initiated. Residents of Beijing could gain an additional 3.2 years.

Can China meet and sustain these further pollution reductions? To this point, the country has relied on command-and-control measures to swiftly reduce pollution. While the measures have worked, they have come with significant economic and social costs. As China now enters the next phase of its "war against pollution," the long-run durability of its actions will be enhanced by minimizing the costs. Relying on market-based approaches are one solution that can effectively and inexpensively reduce pollution.

The WHO changed its particulate pollution guidance (from 10 μg/m3 to 5 μg/m3) on September 22, 2021. While the figures in this report reflect the new guidance, the website currently reflects the previous guidance. For more information, visit www.who.int/publications/i/item/9789240034228.

The AQLI will release its full 2020 dataset in early 2022, which will include the WHO update. This is an advanced preview of that data focused on China.

INTRODUCTION

Pollution Before and After the 2008 Beijing Olympic Games

In China, public concern about worsening air pollution began rising in the late-1990s. That concern extended to the international community as the 2008 Beijing Olympic Games drew closer. Chinese officials saw the Olympics as an opportunity to foster a positive image of the nation for the world to see—but air pollution visibly stood in its way.

In the years leading up to the 2008 Olympics, Chinese leaders began initiating air pollution reduction strategies in Beijing and its neighboring cities. But it wasn't until October 2007 that the State Council of China issued "Measures to Ensure Good Air Quality in the 29th Beijing Olympics and Paralympics"—a series of quick, radical and in many cases temporary actions to confront air pollution. For example, the government temporarily suspended production at many power plants.[1]

Since vehicle exhaust is a primary source of air pollution in large cities, the government's efforts there were especially visible. The government raised gas prices twice, in November 2007 and June 2008, to discourage vehicle usage. During the Olympics, vehicles that failed to meet high emissions standards were banned from Beijing's roads and all other vehicles were subject to an odd-even rule that allowed some cars to operate on odd days with others operating on even days. The Beijing Olympic Committee and Ministry of Environmental Protection (MEP) in China claimed that vehicular emissions decreased by more than 60 percent because of their efforts.[2]

Several studies demonstrate that the combination of air pollution control measures improved pollution in and around Beijing, most noticeably immediately before and after the games. One study, which describes the 2008 Olympic-related air pollution regulations as one of the "largest efforts made in human history to control air quality within a short period of time," found that monthly PM_{10} concentrations declined by 30 percent compared to the previous summer, using data from monitoring sites administered by the MEP.[3] But the pollution policies that China introduced during the 2008 Olympics did not last—and with them went the improved air quality. According to some measures, about 60 percent of the air pollution improvements in Beijing had disappeared a year later.[4]

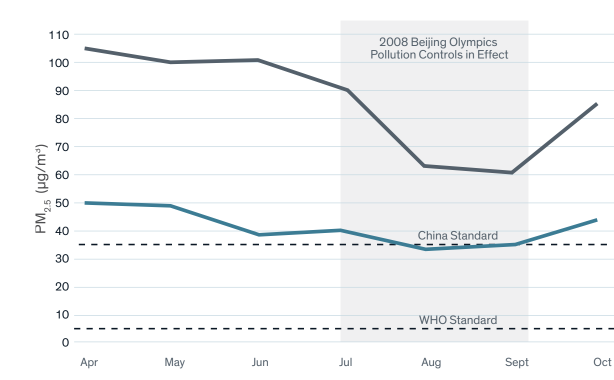
1 Chen et al., 2013a.
2 Chen et al., 2013a.
3 He et al., 2016.
4 Chen et al., 2013a.

Our satellite-derived data show that the population-weighted national annual $PM_{2.5}$ level in China fluctuated between 48 to 53 micrograms per cubic meter (μg/m³) between 2005 and 2014. In Beijing, pollution levels during this period were higher, ranging from 67 to 85 μg/m³. In 2008, satellite-derived monthly PM2.5 levels fell 33 percent from roughly 51 to 34 μg/m³ between June and August, before rising to 44 μg/m³ by October. Data from ground-level monitoring, recorded by the U.S. Embassy in Beijing, illustrate a similar story, with pollution falling from roughly 100 to 63 μg/m³ between June and August (Figure 1).

While pollution ahead of the 2008 Olympics had been rising rapidly, in the years that followed pollution continued to increase but at a slower rate. By 2013, air pollution across China had reached its highest levels on record. In Beijing, the average $PM_{2.5}$ concentration was 85 μg/m³—higher than pre-Olympic levels, well above China's national standard of 35 μg/m³ and 17 times higher than the World Health Organization's (WHO) newly revised guideline for $PM_{2.5}$ of 5 μg/m³. In Shanghai, the average $PM_{2.5}$ concentration was 50 μg/m³, 10 times higher than the current WHO guideline (see Figure 2).[5]

In the summer of that year, EPIC Director Michael Greenstone and three co-authors published a study in the *Proceedings of the National Academy of Sciences (PNAS)* that provided clear evidence

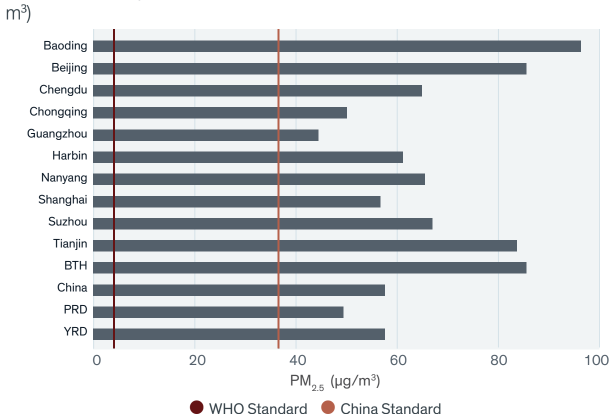
Figure 1 · $PM_{2.5}$ Concentrations in Summer 2008 in Beijing (μg/m³)



Note: We plot average monthly $PM_{2.5}$ concentrations in Beijing during the summer of 2008 using ground-level monitoring data provided by the U.S. State Department, as well as satellites. Both sources suggest there was a temporary improvement in air quality during the 2008 Olympics.

5 An earlier version of this report, released in March 2018, used daily data from more than 200 monitors across the country from 2013 to 2017. In this report, we use population-weighted satellite-derived $PM_{2.5}$ data that excludes mineral dust and sea salt. For more information on our methodology, visit https://aqli.epic.uchicago.edu/about/methodology/.

Figure 2 · PM$_{2.5}$ Concentrations Across Mainland China in 2013 (μg/m³)



Note: "BTH" refers to the Beijing-Tianjin-Hebei region, "PRD" refers to the Pearl River Delta, and "YRD" refers to the Yangtze River Delta, Suzhou refers to the prefecture in the Jiangsu province. The cities shown in this figure are the ten most populous prefectures in our data.

of the health impacts of that high air pollution.[6] They found that sustained exposure to higher levels of air pollution had cut the lifespans of people living just north of the Huai River—where coal was supplied for winter heating—by about five years compared to those living just to the south. The implications for life spans across China were immediate and striking. Consequently, the study's findings drew coverage from every major international media outlet, creating a buzz both within China and abroad and attracting the attention of Chinese leaders.

Evidence of the human health toll of air pollution added to a broader, growing public concern. Stories began to circulate of foreigners leaving the country due to health concerns; news reports from Beijing referred to daily conversations about air quality as a "national pastime amongst expats and Chinese locals alike;" blogs and parenting forums became inundated with discussions about which air filters to purchase and where to vacation for cleaner air; and so on.[7]

China Begins its War Against Pollution

6 Chen et al., 2013b.

7 The Guardian, December 16, 2014.

China responded to the rising public concern with concrete policy initiatives. The government initiated a National Air Quality Action Plan in the fall of 2013, laying out specific targets to improve air quality by the end of 2017. The plan included a $270 billion initiative to reduce annual average PM$_{2.5}$ concentrations in the densely populated Beijing-Tianjin-Hebei area by 25 percent, and in the Pearl and Yangtze River Delta regions by 15 and 20 percent, respectively. Beijing, which had set aside an additional $120 billion to fight pollution, targeted a reduction in its average PM$_{2.5}$ level to below 60 μg/m³ (equivalent to a 36 percent decline from its 2013 level of 94 μg/m³).

At the next annual meeting of the People's Congress in March 2014, Premier Li Keqiang declared a "war against pollution" (this was the same year the country applied to host the 2022 Winter Olympics). The timing of this declaration—at the kickoff of a nationally-televised conference typically reserved for discussing key economic targets—marked an important shift in the country's long-standing policy of prioritizing economic growth over concerns about environmental protection.[8] It also marked an important change in the government's official rhetoric about the country's air quality. In the past, state media had deflected concerns about air quality by claiming that poor visibility was due to "fog" and that emissions had no effect on smog. Now, the government stressed environmental responsibility, stating that the country could not "pollute now and clean up later" and would fight pollution with "an iron fist."

To meet the goals laid out in its National Air Quality Action Plan, the government began implementing many of the reforms that had been introduced ahead of the 2008 Olympics but at a larger scale. For example, large cities such as Beijing, Shanghai, and Guangzhou again reduced vehicle emissions by restricting the number of cars on the road. In the industrial sector, iron- and steel-making capacity was reduced. During the Olympics, many coal power plants were suspended. Now, new plants were banned in the Beijing-Tianjin-Hebei, Pearl River Delta and Yangtze River Delta regions. Existing plants were mandated to reduce their emissions or switch to natural gas and other renewable energy sources. Other plants were closed or relocated.

Much focus was directed towards replacing the coal-fired boilers

8 Greenstone et al., 2021.

Table 1: China National Action Plan on Air Pollution Prevention and Control

Goal 1	Lower urban concentrations of PM$_{10}$ by 10 percent relative to 2012 levels; gradually increase the number of days with fairly good air quality.
Goal 2	Reduce concentrations of PM$_{2.5}$ In the Beijing-Tianjin-Hebei, Pearl River Delta, and Yangtze River Delta by 25 percent, 20 percent, and 15 percent, respectively.
Goal 3	Reduce the annual PM$_{2.5}$ concentrations in Beijing to below 60 μg/m³.

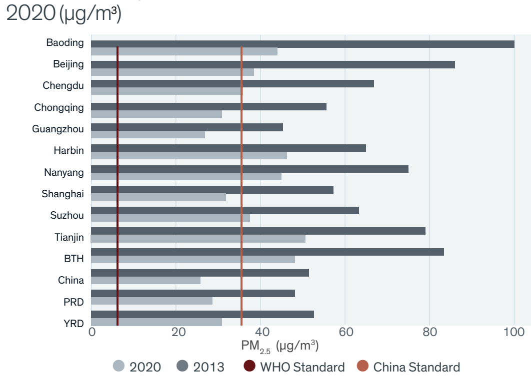
used for heating homes in the north—the same coal boilers that were the primary source of the striking difference in air pollution in the Chen et al. (2013) *PNAS* paper—with gas or electric heaters. The government also increased transparency in its reporting of air quality statistics, broadened its nationwide network of air quality monitors, and made its data publicly available.[9] In short, the stage was set for China to finally begin addressing its decades-long struggle to control its air pollution.

RESULTS

Progress Since the War Against Pollution

Today, seven years after the start of China's "war against pollution," the impacts are persistent and tangible. As revealed in satellite-derived PM$_{2.5}$ data, the air quality in China's most populated cities has improved dramatically since 2013. Figures 3 and 4 compare PM$_{2.5}$ concentrations in 2013 and 2020 across various regions. Across the board, air pollution fell significantly by 2020, and in many instances surpassed the targets set in the National Air Quality Action Plan. Countrywide PM$_{2.5}$ levels fell from 52 μg/m³, on average, to 32 μg/m³ in just seven years—a 40 percent decline since 2013, and a 37 percent decline since 2008. Beijing experienced the largest decline in air pollution over this period, with PM$_{2.5}$ levels falling from 85 to 38 μg/m³ in just seven years—a 55 percent decline. Relative to 2008 levels, pollution in Beijing decreased by 50 percent.

Figure 3 · PM$_{2.5}$ Concentrations Across Mainland China, 2013 vs. 2020 (μg/m³)



Note: The estimated life expectancy gains are based on a pair of studies published in the *Proceedings of the National Academy of Sciences* (Chen et al. 2013; Ebenstein et al. 2017) which estimate the impact of long-term exposure to fine particulate matter on life expectancy. For more information on our methodology, visit https://aqli.epic.uchicago.edu/about/methodology/.

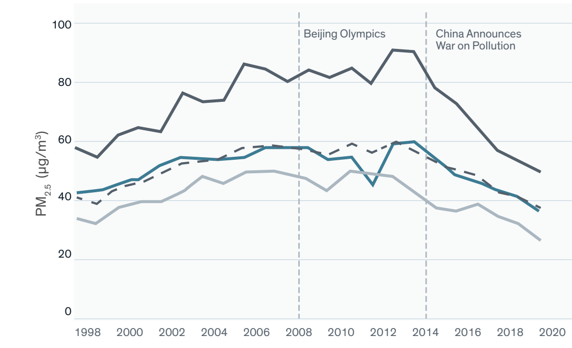
9 Greenstone et al., forthcoming.

Figure 4 · Change in PM$_{2.5}$ concentrations in Mainland China, 2013 vs. 2020

More broadly, in the Beijing-Tianjin-Hebei ("BTH") region, arguably the epicenter of the air pollution crisis, PM$_{2.5}$ concentrations fell by 48 percent since 2013 and 40 percent since 2008. In the Pearl River Delta ("PRD") and Yangtze River Delta ("YRD") regions, PM$_{2.5}$ concentrations fell by 49 percent and 41 percent, respectively, since 2013. As Figure 5 illustrates, average annual PM$_{2.5}$ in China's major regions fell to levels not seen since 2000.

This trajectory is significant because the measures implemented prior to the 2008 Summer Olympics were meant to be radical, but while they targeted pollution in the short run, the changes were not permanent. The policies put in place since 2013 appear to have created more long-lasting improvements.

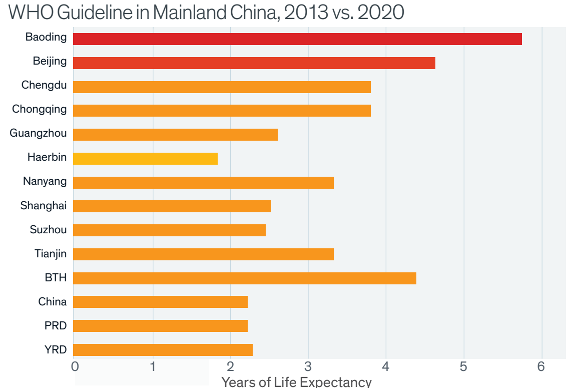
Figure 5 · PM$_{2.5}$ Concentrations in Major Regions in Mainland China Over Time



Note: "BTH" refers to the Beijing-Tianjin-Hebei Region, "PRD" refers to the Pearl River Delta, and "YRD" refers to the Yangtze River Delta.

Figures 6 and 7 translate these air quality improvements into the number of additional years that an average person would live, assuming these reductions are sustained. For instance, in Beijing, where the annual $PM_{2.5}$ concentration fell from 85 to 38 µg/m³, the AQLI suggests that the average person could expect to live 4.6 years longer as a result, assuming the reduction is permanent. In Shanghai, where $PM_{2.5}$ fell from 50 to 28 µg/m³, the average person could expect to live 2.2 years longer. Across the country, the life expectancy gain is 2 years longer relative to 2013, or 1.8 years longer relative to 2008. (Appendix Table 1 lists the specific gains for the 50 most populated prefectures for which data is available.)

Figure 6 · Potential Gain in Life Expectancy from Reducing $PM_{2.5}$ to the WHO Guideline in Mainland China, 2013 vs. 2020



Note: The estimated life expectancy gains are based on a pair of studies published in the *Proceedings of the National Academy of Sciences* (Chen et al. 2013; Ebenstein et al. 2017) which estimate the impact of long-term exposure to fine particulate matter on life expectancy. For more information on our methodology, visit https://aqli.epic.uchicago.edu/about/methodology/.

Figure 7 · Change in Potential Gain in Life Expectancy from Reducing $PM_{2.5}$ to the WHO Guideline in Mainland China, 2013 vs. 2020

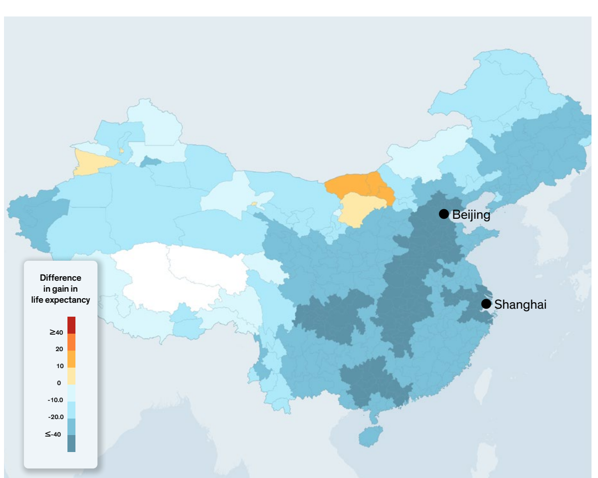
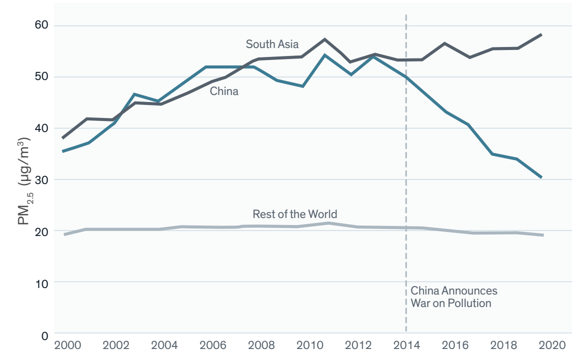


Figure 8 · Pollution Trends in China, South Asia, and the Rest of the World



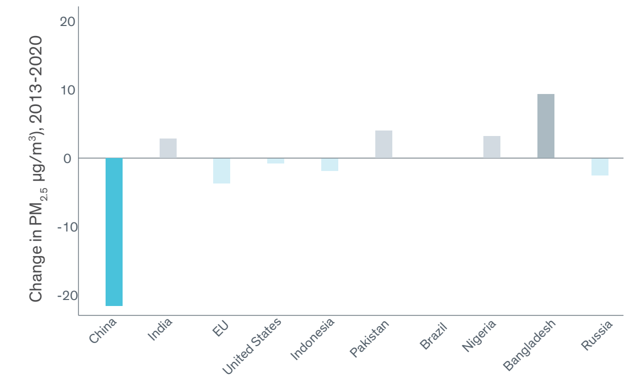
Overall, China's progress in its "war against pollution" has been remarkable, particularly when placed in a global context (Figure 8). Between 2013 and 2020, China accounted for more than three quarters of the population-weighted global decline in particulate pollution.[10] At the same time, several of China's neighbors in South and Southeast Asia saw their pollution rise over this period (Figure 9). India, for instance, saw its pollution rise and accounted for roughly 44 percent of the global increase in pollution.

China is an important model showing that bold and effective policies can produce sharp reductions in pollution in short order. However, the country's extraordinarily successful "war against pollution" has been implemented with significant and unnecessary economic and social costs. These costs are due largely to a "command-and-control" approach deeply rooted in its governance structure. For example, when the Beijing-Tianjin-Hebei region was not on track to meet its goals as late as summer 2017, just months before the targeted deadline, the government responded with an aggressive 143-page "battle plan" released in August 2017 that called for major reductions in industrial and residential coal consumption through March of the following year. The ensuing campaign included the removal of coal-fired boilers in some cases before the natural gas or electric replacements were available, leaving some households in large northern cities without winter heat.

This is one concrete example of the high cost of one policy. But almost all of the policies come from a "command and control" playbook that generally does not consider how to minimize the costs of achieving their goals. Thus, the Chinese government closed, relocated, and reduced the production capacity of a large

10 This is due to China's large population as well as its sizable reduction in its average $PM_{2.5}$ concentration.

Figure 9 · Change in Average $PM_{2.5}$ Concentrations Since 2013 in the 10 Most Populous Regions Across the World



Country	$PM_{2.5}$ 2013	$PM_{2.5}$ 2020	Change (µg/m³)	Change (%)
China	52.4	31.6	-20.7	-39.6
India	53.2	55.8	2.6	4.8
EU	13.1	9.6	-3.4	-26.3
US	7.7	7.1	-0.7	-8.8
Indonesia	18.9	17.0	-1.9	-10.2
Pakistan	40.4	44.2	3.8	9.3
Brazil	10.1	10.0	-0.2	-1.7
Nigeria	20.5	23.7	3.2	15.5
Bangladesh	65.6	75.8	10.2	15.5
Russia	12.0	10.0	-2.0	-16.8

Note: In 2013, the average $PM_{2.5}$ in China and India was 52 and 53 µg/m³, respectively. In the EU and the US, it was 13 and 8 µg/m³, respectively.

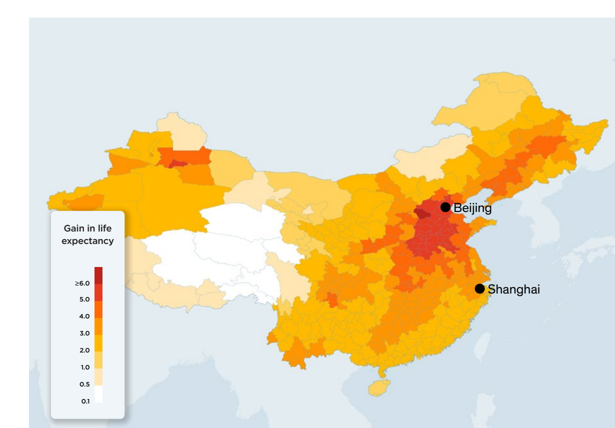
number of polluting firms, enforced tighter emission standards across many industries, assigned binding abatement targets to local governments, and sent thousands of discipline teams to inspect local environmental performances. These measures, while being effective in reducing the total emissions in the country, ignored the significant differences in the abatement costs across firms, industries, and regions, and led to large economic and administrative costs in achieving the policy goal. They also led to social media complaints from stakeholders that environmental regulations are too stringent, protests from workers being laid off by the polluting firms, and resistance from local governments for enforcing tighter environmental standards.

The 2022 Winter Olympics and the Work Ahead

Going into the 2022 Winter Olympics, China has continued a targeted approach, like that used ahead of the 2008 Olympics, as well as the command-and-control tactics used in their "war against pollution." For instance, Tangshan, China's biggest steel hub, which accounts for 8 percent of global steel output, extended its curbs on steel mills until March 2022. This move is expected to lower air pollution by 40 percent when the Games begin.[11] Beijing has also heavily invested in green technology, such as hydrogen vehicles, claiming 85 percent of vehicles used for the Games will run on either electricity or hydrogen.[12] And, while coal still powers around 60 percent of China's energy—making up more than half of the world's total coal consumption—officials in China claim the Olympic venues will be fully powered by renewable energy and that the Games will be "carbon neutral" for the first time.[13] Further, the Chinese government is enforcing action against polluters and increasing the accountability of government officials.

Looking forward, the challenge of achieving 'Olympic Blue', i.e. blue skies and better air quality, on a permanent basis remains. While pollution levels are now on par with its national standards, they are still six times greater than the WHO guideline of 5 µg/m³ as of 2020. Using an international lens, Beijing is still three times more polluted than Los Angeles, the most polluted city in the United States. If China were to reduce pollution to meet the WHO guideline, and those reductions were sustained

Figure 10 · Potential Gain in Years of Life Expectancy Through Permanently Reducing $PM_{2.5}$ from 2020 Concentrations to the WHO Guideline in Mainland China



11 Bloomberg, August 10, 2021.

12 CBS News, January 3, 2022.

13 BBC, November 2, 2021.

permanently, the health benefits would be substantial. For example, the average Chinese citizen could expect to gain 2.6 years onto their lives, as compared to air pollution concentrations remaining at their 2020 levels (Figure 10). The expected gains are even larger in the more heavily polluted provinces of Hebei, Henan and Tianjin, where residents stand to gain up to 4.1 additional years of life expectancy from clean air, respectively. Residents of Beijing stand to gain 3.2 years.

How can China achieve these large health benefits in the coming decades? While the command-and-control approach has worked well at reducing pollution to date, the economic costs of abating emissions continues to rise and is unnecessarily high. Consequently, leaders are facing increasing challenges in balancing the needs of different stakeholders. As such, it is becoming increasingly important for China's leaders to better balance the needs for continued economic growth and environmental quality.

As China enters the next phase of its "war against pollution," the country has an opportunity to place more emphasis on market-based approaches in order to more sustainably reduce pollution at a lower cost and without intense stakeholder pressure. Such approaches at reducing pollution have been successful in other parts of the world. One of the largest programs in history, the U.S. sulfur dioxide emissions trading scheme, reduced pollution by 40 percent between 1980 and 2003. Analysts have shown that the program's benefits exceeded its costs by a 40:1 ratio. Meanwhile, the government of Gujarat, India, implemented the world's first emissions trading market for particulate pollution in 2019 in the industrial city of Surat. Evidence suggests that participating factories have reduced pollution by about 24 percent without any measured increase in their operating costs. China's introduction of a national carbon market in July 2021, which upon completion will be the largest such market in the world, positions the country well for the adoption of a particulate pollution and/or sulfur dioxide market.

CONCLUSION

While policy actions to reduce pollution ahead of the 2008 Beijing Summer Olympics improved air quality during the games and managed to slow the climb in the years after, pollution levels reached a record high by 2013. Since that time, China has engaged in a war against pollution that—seven years into the war—has led to a staggering decline in pollution, making up the vast majority of global progress on air pollution in recent years and extending the lives of its citizens by about 2 years if reductions are sustained. Residents of Beijing are breathing air half as polluted as it was in both 2008 and 2013, allowing them to live almost 5 years longer.

Nevertheless, pollution levels were still six times greater than the WHO guideline as of 2020. If China were to meet that guideline, its residents could expect to gain an additional 2.6 years onto their lives. Residents of Beijing could gain 3.2 years. However, political support for a continued focus on cleaning the air is likely to require finding less expensive approaches to reducing air pollution. Thus, as China enters the next phase of its "war against pollution," there are appealing opportunities to move to a greater reliance on market-based approaches to environmental regulation that better accommodate the needs for cleaner air and rapid economic growth.

China & The United States: Comparing Two Pollution Wars

Today, particulate air pollution is not a major problem in most parts of the United States. But that wasn't always the case. Our coal-driven industrialization was largely unfettered by concern for health or the environment. Following World War II, American industry rebounded from the Great Depression, the population grew as the "baby boom" generation was born, the first highways were built, and droves of Americans fled for the suburbs for new homes outfitted with modern appliances. With home and industrial energy consumption increasing, and more vehicles on the roads, pollution began to increase. New research continues to raise our estimates of the severity of air pollution in those times.

The impacts of this intense pollution began to make their mark on American consciousness. In 1948, an episode of heavy smog in the industrial town of Donora, Pennsylvania killed more than 20 people and made half the population severely sick in less than a week. More people died the following months and higher-than-usual mortality rates continued in subsequent years.

The Donora Smog is an extreme but vivid example of how industrialization was largely unfettered by concern for health or the environment. Over time, it caused Americans to wake up to the fact that everyday pollution levels across the country were hazardous to their health. By 1970, the Steubenville, Ohio metropolitan area had particulate pollution concentrations like those in Beijing in 2001. Los Angeles had become known as the smog capital of the world, and other large metropolitan areas weren't far behind.

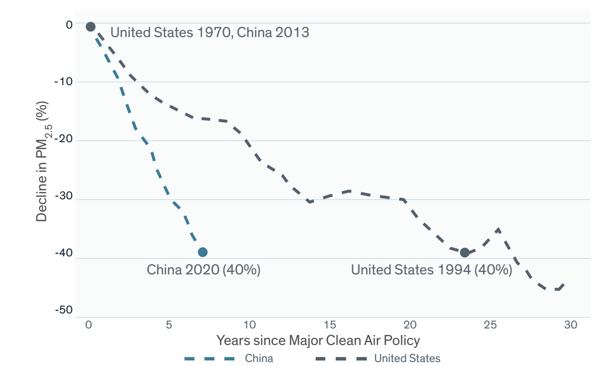
By the late 1960s pollution was a part of everyday life for many Americans and citizens had enough—not unlike the people of China in recent years. Millions across the country marched for a cleaner environment on the first Earth Day in April 1970. Just months later, the Environmental Protection Agency was formed and Congress passed the Clean Air Act. This law, and subsequent amendments, fostered the creation of federal and state level regulations to tackle sources of air pollution, establish air quality standards, and punish violators, all of which led to a substantial decrease in ambient air pollution.

The Clean Air Act quickly made an impact on the quality of the air Americans breathed. By 1980, the average $PM_{2.5}$ concentration level nationwide had fallen by about 20 percent. Today, on average, the $PM_{2.5}$ pollution that Americans are exposed to is only about one-third of what it was in 1970.

While progress in reducing pollution in the United States is helping residents live longer lives, the improvements came much quicker in China. It took over two decades and multiple recessions for the United States to reduce its average air pollution by 40 percent—a feat that China achieved in just seven years while its economy continued to grow at a good clip (Figure 11). China's ability to reduce pollution so quickly offers optimism to other countries with high pollution. But it also must be taken in context. China was able to reduce pollution so quickly because of some harsh tactics, such as at one point removing coal boilers from homes during winter before the natural gas or electric replacements had arrived.

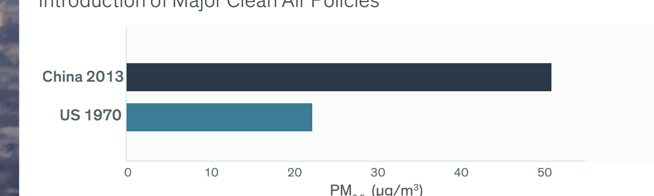
It also should be noted that except for some extreme instances in the United States, China's pollution levels were higher before they began making reductions (Figure 12). The average $PM_{2.5}$ concentration in the United States in 1970 was roughly 24 µg/m³, well below the average concentration of 52 µg/m³ in China in 2013. This has allowed China to see greater gains in life expectancy. A 63 percent reduction in air pollution in the United States has led Americans to live 1.5 years longer four decades after beginning their "war." That's compared to a gain of 2 years of life expectancy in China, and it took far less than a decade to achieve. While China's harsh tactics certainly played a role, it may also be easier to reduce a high amount of pollution at first. Bringing down the remaining pollution may prove harder to achieve.

Figure 11 · Pollution Reductions in the United States and China Following Major Clean Air Policies



Note: This figure compares the cumulative percentage decline in average $PM_{2.5}$ in the US since 1970 and in China since 2013. For China, we use satellite-derived measurements of $PM_{2.5}$. US data is derived from EPA data on Total Suspended Particulates (TSPs). Using these data, we impute $PM_{2.5}$ values for the period spanning 1970 to 1997 by assuming a constant ratio between $PM_{2.5}$, $PM_{1.0}$, and TSPs. For consistency with the satellite measurements (which are available from 1998 onwards), we then scale these imputed values by the average ratio of satellite to monitor measurements. This approach should be interpreted with caution as it is less reliable than the satellite-derived measurements that are available in the years following 1998. For further information, see the Technical Appendix available at https://aqli.epic.uchicago.edu/policy-impacts/united-states-clean-air-act/.

Figure 12 · Pollution Levels in the United States and China at the Introduction of Major Clean Air Policies



Appendix Table | Pollution and Life Expectancy Gains in China's Most Populated Prefectures

		$PM_{2.5}$ Concentrations (μg/m³)			Percent Reduction in $PM_{2.5}$ Concentration		Gain in Years of Life Expectancy		
Prefecture	Population in 2019 (Millions)	2008	2013	2020	Between 2008 and 2020	Between 2013 and 2020	Between 2008 and 2020	Between 2013 and 2020	If 2020 Levels are Reduced to the WHO Guideline (5 μg/m³)
Chongqing	30.0	56.5	56.2	29.0	49	48	2.7	2.7	2.3
Shanghai	24.1	47.5	50.2	28.1	41	44	1.9	2.2	2.3
Beijing	20.5	75.7	85.2	37.9	50	55	3.7	4.6	3.2
Chengdu	13.9	66.3	70.3	35.4	47	50	3.0	3.4	3.0
Tianjin	13.6	72.5	77.6	47.4	35	39	2.5	3.0	4.2
Guangzhou	13.2	47.8	45.5	22.8	52	50	2.4	2.2	1.7
Baoding	11.6	79.3	101.2	46.2	42	54	3.2	5.4	4.0
Harbin	11.1	46.1	59.5	40.7	12	32	0.5	1.8	3.5
Suzhou	10.8	54.8	57.3	31.2	43	46	2.3	2.6	2.6
Nanyang	10.8	38.3	37.2	19.1	50	49	1.9	1.8	1.4
Shenzhen	10.7	57.7	69.0	39.0	32	43	1.8	2.9	3.3
Shijiazhuang	10.6	81.4	109.2	56.0	31	49	2.5	5.2	5.0
Linyi	10.5	64.9	65.6	43.5	33	34	2.1	2.2	3.8
Wuhan	10.1	68.9	77.5	36.9	46	52	3.1	4.0	3.1
Handan	9.5	75.4	96.2	48.5	36	50	2.6	4.7	4.3
Weifang	9.5	60.9	61.1	42.8	30	30	1.8	1.8	3.7
Wenzhou	9.5	42.6	37.5	24.3	43	35	1.8	1.3	1.9
Zhoukou	9.3	64.6	71.6	47.0	27	34	1.7	2.4	4.1
Hangzhou	9.1	55.8	51.4	28.6	49	44	2.7	2.2	2.3
Qingdao	9.1	50.8	51.0	34.0	33	33	1.7	1.7	2.8
Zhengzhou	9.0	70.4	83.6	47.3	33	43	2.3	3.6	4.1
Xuzhou	8.9	68.2	69.3	48.9	28	29	1.9	2.0	4.3
Xi'an	8.9	55.3	61.8	44.5	19	28	1.1	1.7	3.9
Ganzhou	8.7	40.8	39.7	21.3	48	46	1.9	1.8	1.6
Heze	8.6	70.4	77.4	51.2	27	34	1.9	2.6	4.5
Dongguan	8.6	43.6	42.1	22.1	49	48	2.1	2.0	1.7
Shenyang	8.5	32.4	26.9	18.3	43	32	1.4	0.8	1.3
Quanzhou	8.5	61.5	56.6	41.6	32	27	1.9	1.5	3.6
Nanjing	8.3	60.2	59.0	34.8	42	41	2.5	2.4	2.9
Hefei	8.0	61.1	62.0	36.7	40	41	2.4	2.5	3.1
Changchun	8.0	49.3	56.5	40.8	17	28	0.8	1.5	3.5
Fuyang	8.0	58.9	63.1	43.2	27	31	1.5	1.9	3.7
Shaoyang	7.9	54.4	50.1	30.5	44	39	2.3	1.9	2.5
Ningbo	7.9	44.5	43.4	23.0	48	47	2.1	2.0	1.8
Tangshan	7.7	77.3	77.1	42.9	45	44	3.4	3.4	3.7
Shangqiu	7.6	65.6	72.8	49.7	24	32	1.6	2.3	4.4
Yancheng	7.6	48.2	49.5	31.3	35	37	1.7	1.8	2.6
Nantong	7.6	48.6	51.1	29.6	39	42	1.9	2.1	2.4
Foshan	7.6	50.1	47.5	23.5	53	50	2.6	2.3	1.8
Zhumadian	7.5	63.2	67.5	42.9	32	36	2.0	2.4	3.7
Cangzhou	7.5	72.8	92.7	48.1	34	48	2.4	4.4	4.2
Hengyang	7.5	57.6	53.5	32.5	44	39	2.5	2.1	2.7
Xingtai	7.4	80.8	107.2	52.1	36	51	2.8	5.4	4.6
Fuzhou	7.4	30.1	26.2	17.7	41	32	1.2	0.8	1.2
Changsha	7.3	63.9	61.4	35.3	45	43	2.8	2.6	3.0
Zhanjiang	7.3	36.7	33.9	19.1	48	44	1.7	1.5	1.4
Jining	7.3	76.6	75.3	50.9	34	32	2.5	2.4	4.5
Yantai	7.3	42.7	40.6	30.2	29	26	1.2	1.0	2.5
Jinan	7.1	70.0	72.5	46.3	34	36	2.3	2.6	4.0
Nanning	6.9	48.1	48.7	24.6	49	50	2.3	2.4	1.9

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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 Distinguished 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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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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