



CASE STUDIES IN IMPROVING URBAN AIR QUALITY

2018





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PREFACE

This is the International Gas Union's (IGU) third edition of its Urban Air Quality report series.

The first edition, released at COP 21 in Paris, highlighted the interconnection that exists between reducing greenhouse gas emissions and reducing emissions of other air pollutants. It presented case studies of efforts in four cities — New York, Istanbul, Toronto, and Beijing — to improve urban air quality.

The second edition of the report was released in Strasbourg, during 2016 Gas Week at the European Parliament. It featured efforts to improve air quality in three European cities: Berlin, Dublin, and Krakow; as well as the Port of Rotterdam.

This third edition continues to build on the previous work to highlight the efforts to improve urban air quality. This edition provides an update on efforts in Beijing and includes two additional examples of major actions in the Chinese cities of Urumqi and Shanghai. It also extends to South America, with an example of air quality improvements in Santiago, Chile.

Common Air Pollutants and Their Health Impacts

The major components of outdoor air pollution are a combination of gases and dust particles (particulate matter, or "PM") that have detrimental human health and environmental consequences. Health impacts include lung disease, cardiac disease, cancer, and more. Outdoor air pollution has a variety of human and natural sources, but the most significant human contributor to outdoor air pollution is the combustion of fuels — primarily fossil fuels. A few of the main components of outdoor air pollution, including their health impacts and primary sources are:¹

Particulate Matter (PM): PM consists of sulfate, nitrates, ammonia, sodium chloride, black carbon, mineral dust and water. The most health-damaging particles are those with a diameter of 10 microns or less (PM₁₀), especially fine particles of 2.5 microns or less (PM_{2.5}). PM is generated from human and natural sources, with PM10 and above often coming from dust generated in the environment. Combustion of fossil fuels, particularly coal, fuel oil, and diesel, are a significant source of PM_{2.5}.

There is a close relationship between exposure to high levels of PM and impacts on human health. Long-term exposure to PM_{2.5} is associated with increased mortality due to lung and cardiac issues. The WHO has recognized PM matter as a carcinogen since 2013.² Exposure to PM has health impacts even at very low levels.

Sulphur Dioxide (SO₂): SO₂ is produced from burning fossil fuels (coal and oil) that contain sulphur. It is one of a group of sulphur oxides that are highly reactive gases.³ SO₂ has harmful health effects and is a major contributor to the formation of acid rain. SO₂ can impact the respiratory system, impair lung function, and cause eye irritation. Studies have found that hospital admissions for cardiac events and mortality increase on days of high SO₂ concentration.

Nitrogen Dioxide (NO₂): NO₂ is one of several nitrogen oxides (NO_x) produced during combustion processes, particularly higher temperature combustion associated with burning fossil fuels. NO_x are harmful pollutants that have direct health consequences in humans and contribute to the formation of ground-level ozone and acid rain. NO₂ is linked to reduced lung function and respiratory issues in asthmatic children.

Ozone (O₃): Ground-level ozone is a major component of smog and should not be confused with the ozone layer that filters out UV radiation from the sun. Ground-level (or "tropospheric") ozone is produced when gases such as NO_x or volatile organic compounds are exposed to sunlight.

¹ Information for this overview of air pollutants is drawn from the World Health Organization, <http://www.who.int/mediacentre/factsheets/fs313/en>; and the U.S. Environmental Protection Agency, <http://www.epa.gov/air/urbanair>.

² World Health Organisation. Oct. 17, 2013. "IARC: Outdoor Air Pollution a Leading Environmental Cause of Cancer Deaths," available at: http://www.iarc.fr/en/media-centre/iarcnews/pdf/pr221_E.pdf.

³ Both SO₂ and NO₂ are considered indicators of the presence of the other sulphur oxides and nitrogen oxides, respectively. Rather than set standards for each of the separate gas individually, regulatory bodies typically set standards just for SO₂ and NO₂. Reports of emissions and concentrations of pollutants in the air are sometimes done just for SO₂ or NO₂, and other times are done for the broader group of SO_x and NO_x.



1. INTRODUCTION

Air pollution continues to be “the world’s single greatest environmental risk to health”.⁴ Roughly 87% of the world population lives in areas that exceed the World Health Organisation’s (WHO) air quality guidelines of 10 µg/m₃.⁵

In December 2017, the Ministers of Environment and delegates from over one hundred countries gathered in Nairobi, Kenya for the third United Nations Environmental Assembly, with a theme for the gathering being – “Toward a Pollution Free Planet”. The unsettling statistic that 9 out of 10 people on the planet are breathing air that exceeds WHO standards was a strong unifying factor for building consensus on the urgent need for coordinated action against air pollution.⁶

Another unsettling global statistic is that “(a)mong 5.9 billion people who live in countries where PM readings are available, 4.5 billion are currently exposed to PM concentrations that are at least twice the concentration that the WHO considers safe.”⁷

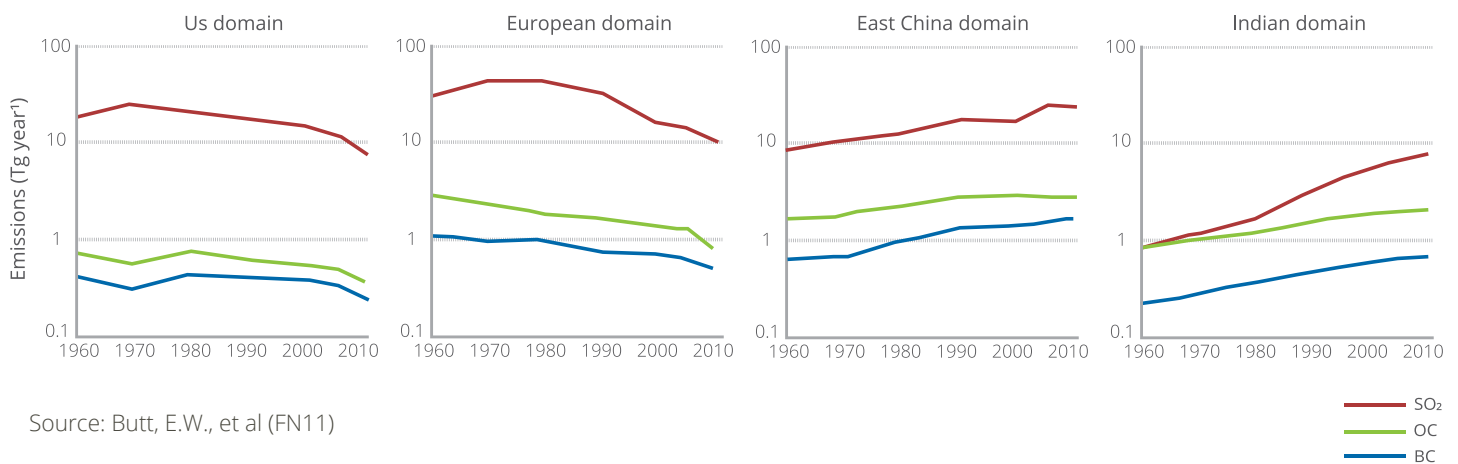
For perspective on the scale of this problem, “air pollution is believed to kill more people globally than AIDS, malaria, breast cancer, or tuberculosis”.⁸ The body of evidence on the harmful impacts of pollution only continues to expand, linking it to issues ranging from birth defects to mental health, and of course quality and length of life.⁹

Air pollution affects the vast majority of global population; however, its burden falls most heavily on the most vulnerable members of society – the elderly, children, and women. It also tends to be much more severe in the developing world.

Between 1960 and 2009, global concentrations of PM_{2.5}¹⁰ grew by 38%, and global PM-attributable deaths grew by about 89-124%. The majority of this growth originated in China and India, while in the United States and Europe the trend was reverse.¹¹

Emissions in the developed world dropped to all-time lows, while emissions over Asia increased sevenfold. These disparate trends are shown on *Figure 1*.

Figure 1. Annual Emissions
(Tg-yr⁻¹ of SO₂, Black Carbon, and Organic Carbon)



Source: Butt, E.W., et al (FN11)

⁴ UNE (2016) Towards a Pollution Free planet; 2018 Environmental Performance Index (<https://epi.envirocenter.yale.edu/2018-epi-report/executive-summary>).

⁵ Butt, E. W., et al., Global and Regional Trends in Particulate Air Pollution and Attributable Health Burden over the Past 50 Years. *Environmental Research Letters*. October, 2017.

⁶ <http://web.unep.org/environmentassembly/assembly>

⁷ Ebenstein, A., et al. *New Evidence on the Impact of Sustained Exposure to Air Pollution on Life Expectancy from China's Huai River Policy*. PNAS. July, 2017.

⁸ Rohde R.A., Muller R.A. (2015) *Air Pollution in China: Mapping of Concentrations and Sources*. PLoS One. 10(8)

⁹ See for example Rees, N. 2017. *Danger in the Air: How Air Pollution can Affect Brain Development in Young Children*. UNICEF.; Ayre, J. Jan. 7, 2018. "Study Links Mother's Air Pollution Exposure Around Time Of Conception With Risk Of Birth Defects In Baby"

[<https://cleantechnica.com/2018/01/07/study-links-mothers-air-pollution-exposure-around-time-conception-risk-birth-defects-baby/>]

¹⁰ Particulate Matter or PM is a mix of solid or liquid inorganic substances linked to major detrimental impacts to health. PM is categorized by size of the particle, as either coarse (above 2.5 µm in diameter) and fine (2.5 µm and smaller). Generally, the finer the particle, the more severe its impact on health.

¹¹ Butt, E. W., et al., Global and Regional Trends in Particulate Air Pollution and Attributable Health Burden over the Past 50 Years. *Environmental Research Letters*. October, 2017.

The share of global deaths attributable to PM_{2.5} in China and India grew from 39% in 1960 to 55% in 2009. In contrast, attributable deaths dropped in the EU and the US by 65.7% and 47.9%, respectively. The US and EU accounted for 27% of global attributable deaths in 1960, falling to around 1% in 2009.

One of the key drivers of that dynamic has been that Asia experienced an immense rate of economic growth, fuelled largely by coal, while policies and regulations to curb an unintended consequence of severe pollution were not in place. On the opposite side, North America and Europe started to develop pollution control policies in the 1970's, and saw emissions drop thereafter.

It should not be concluded from the above however, that the issue of air pollution has been solved in the developed world. Pollution is still a major concern in parts of Europe and North America. 400,000 European deaths are still attributable to pollution every year, and the issue is high on European Commission's agenda¹², which recently held a special Ministerial summit on air quality, as a number of countries remain in breach of the EU nitrogen and particulate matter limits.¹³

Table 1 WHO Guidelines for Ambient Air Pollution Concentrations

PM_{2.5}	10 µg/m ³ annual mean 25 µg/m ³ 24-hour mean
PM₁₀	20 µg/m ³ annual mean 50 µg/m ³ 24-hour mean
Ozone (O₃)	100 µg/m ³ 8-hour mean
NO₂	40 µg/m ³ annual mean 200 µg/m ³ 1-hour mean
SO₂	20 µg/m ³ 24-hour mean 500 µg/m ³ 10-minute mean

Source: World Health Organization

¹² See: European Commission. "Statement by Commissioner Karmenu Vella following Air Quality Ministerial Meeting." (Brussels, Jan. 30, 2018) [http://europa.eu/rapid/press-release_STATEMENT-18-508_en.htm]

¹³ Morgan, S. Jan. 18, 2018. "EU's air pollution pariahs summoned to Brussels." Euractive.com [<https://www.euractiv.com/section/air-pollution/news/eus-air-pollution-pariahs-summoned-to-brussels/>]



2. A LOOK AT CHINA AND THE ROLE OF POLICY

As shown above, China and India represent the biggest portion of the overall increase in global air pollution during the past half century, and this trend is continuing.¹⁴ These extreme levels of pollution have very real societal implications and high costs. In 2015, PM_{2.5} pollution caused 1.6 million deaths in China, which was equivalent to roughly 17% of all deaths in the country, or 4000 deaths per day.¹⁵ A study on the Global Burden of Disease estimated that ambient air pollution in China caused a total economic loss of between 1% and 7% of GDP.¹⁶

China is the biggest producer and consumer of coal in the world (28 billion tons consumed in 2015),¹⁷ and coal combustion is the largest source of PM_{2.5} emissions. As the country's economy, fuelled by coal, grew at colossal speed, so did its air pollution.

China's Pollution Evolution

The identification of air pollution problem in China dates back to the 1970s and 1980s when major cities detected acid rain, caused by SO₂ emissions from coal combustion.

There were generally three eras of pollution growth in China, each adding a new layer to the complex issue:

1970-90: mainly coal from small and big stoves in households, industry and power plants began choking the country;

1990-2000: an exploding number of cars began to exacerbate the problem;

2000-present: the pivotal issue is pollution spread from the megacities to surrounding regions¹⁸

Today, coal burning remains the dominant contributor to primary pollutant emissions on the country level.¹⁹

On a positive note, China has recognized the severity of this problem, and it has been stepping up its efforts to improve air quality. While policies to fight pollution began to develop in the early 1990's, it was the recent government readjustment of focus on achieving results that began to impact tangible reductions.

In 2013, China experienced an extreme pollution crisis, which triggered intensification of anti-pollution policies, marked by the declaration of "war on smog" at the opening of China's National People's Congress in March 2014.²⁰ The Environmental Protection Law was then amended for the first time in 25 years, with some unprecedented regulatory strictness.²¹

The first National Action Plan on Air Pollution Prevention and Control, covering the period of 2013-17 included concrete targets, such as reducing urban concentration of PM₁₀ by 10% below 2012 level, and actions, such as a cap on coal consumption.²² Limiting coal use, and banning its combustion in certain areas altogether, has been a major part of the strategy to reduce pollution.

Perhaps one of the key contributors to increased policy effectiveness was the centralization of emissions data management, where the reported data is now audited and program results are verified. Prior to this, local authorities often misreported results. China adopted the first National Air Quality Standard and began to develop the national Air Reporting System in 2012.²³ Now the system includes 338 cities.²⁴ Regional coordination is another important feature that contributed to effectiveness.²⁵

¹⁴ Ibid.

¹⁵ Rohde R.A., Muller R.A. (2015) *Air Pollution in China: Mapping of Concentrations and Sources*. PLoS One. 10(8)

¹⁶ Jin, Y. et al. (2016) *Air Pollution Control Policies in China: a Retrospective and Prospects*. International Journal of Environmental Research and Public Health. (13)

¹⁷ Ren, Y., et. al. *Changes in Concentration, Composition and Source Contribution of Atmospheric Organic Aerosols by Shifting to Natural Gas in Urumqi*. *Atmospheric Environment*. (148) 306-15. October, 2016.

¹⁸ Jin, Y. et al. (2016) *Air Pollution Control Policies in China: a Retrospective and Prospects*. International Journal of Environmental Research and Public Health. (13)

¹⁹ Ibid.

²⁰ Zhang, D. et al. *Tackling Air Pollution in China – What do We Learn from the Great Smog of 1950s in London*. Sustainability. August, 2014

²¹ Jin, Y. et al. (2016) *Air Pollution Control Policies in China: a Retrospective and Prospects*. International Journal of Environmental Research and Public Health. (13) December, 2016.

²² Ibid.

²³ Rohde R.A., Muller R.A. (2015) *Air Pollution in China: Mapping of Concentrations and Sources*. PLoS One. 10(8)

²⁴ Ministry of Environmental Protection the People's Republic of China. 2016 Report on the State of the Environment in China.

²⁵ Ibid.

The North-South Divide

Coal combustion is the main source of air pollution in China; it is estimated to produce 87% of SO₂ and 76% of NO_x emissions.²⁶ It is also a key cause of pollution-attributable deaths.²⁷

Coal-fired heating, is a significant culprit for the worsening pollution during the fall and winter months, and something that is known as the Huai River Policy was a major contributor to this outcome. For three decades (1950-80), the Chinese government provided free coal to everyone living north of the Huai River and Qin Mountain Range, because it was selected as the 0°C dividing line between average January temperatures. It was a way to rationing fuel supply. As a result, central coal-fired heating systems developed in the north (and not in the south), creating a certain degree of lock-in.²⁸

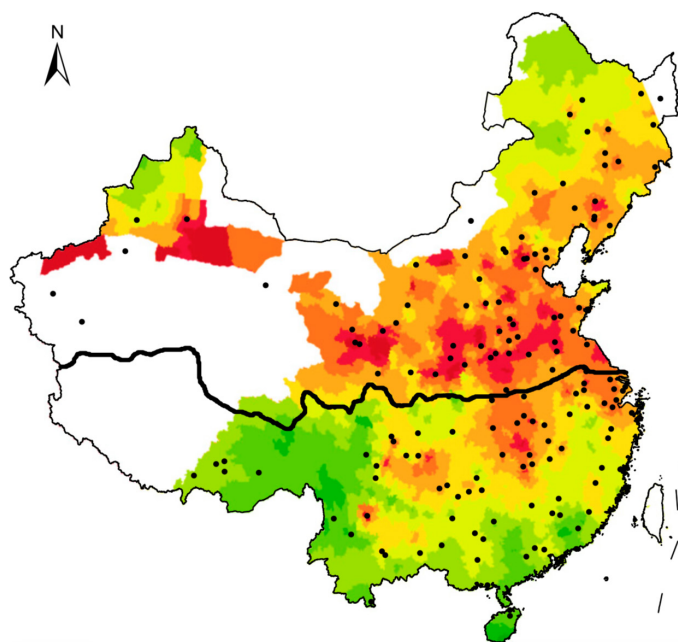
Figure 2 illustrates the division line, and air quality measurements where monitoring was available

This unique scenario allowed researchers to complete a comprehensive analysis of the long-term exposure to PM₁₀ health impacts. They concluded that at concentrations present today in China, PM₁₀ "causes people to live substantially sicker and shorter lives."

The use of coal heating caused a 41.7 mg/m³ increase in PM₁₀ exposure and a decline of 3.1 years in life expectancy north of the river. According to the study's authors, "...bringing all of China into compliance with its Class I²⁹ standards for PM₁₀ would save 3.7 billion life-years."³⁰ Another study concluded that household pollution from heating causes a decrease in life expectancy of ~5.5 years in north China, due to cardiorespiratory mortality.³¹

Figure 2. China's Huai River/Qinling Mountain Range winter heating policy line and PM₁₀ concentrations

Black dots indicate the DSP locations. Coloring corresponds to interpolated PM₁₀ levels at the 12 nearest monitoring stations, where green, yellow, and red indicate areas with relatively low, moderate, and high levels of PM₁₀, respectively. Areas left in white are not within an acceptable range of any station.



Source: Ebenstein, A., et al. (FN 30)

²⁶ Zhang, D. et al. *Tackling Air Pollution in China - What do We Learn from the Great Smog of 1950s in London*. Sustainability. August, 2014

²⁷ Edward Wong. Aug., 2016. *Coal Burning Causes the Most Air Pollution Deaths in China, Study Finds*. New York Times.

<https://www.nytimes.com/2016/08/18/world/asia/china-coal-health-smog-pollution.html>

²⁸ Ebenstein, A., et al. *New Evidence on the Impact of Sustained Exposure to Air Pollution on Life Expectancy from China's Huai River Policy*. PNAS. July, 2017.

²⁹ 50 µg / m³

³⁰ Ebenstein, A., et al. *New Evidence on the Impact of Sustained Exposure to Air Pollution on Life Expectancy from China's Huai River Policy*. PNAS. July, 2017.

³¹ Ren, Y., et al. *Changes in Concentration, Composition and Source Contribution of Atmospheric Organic Aerosols by Shifting to Natural Gas in Urumqi*.

Atmospheric Environment. (148) 306-15. October, 2016.



3. CASE STUDIES

3.1 Revisiting BEIJING

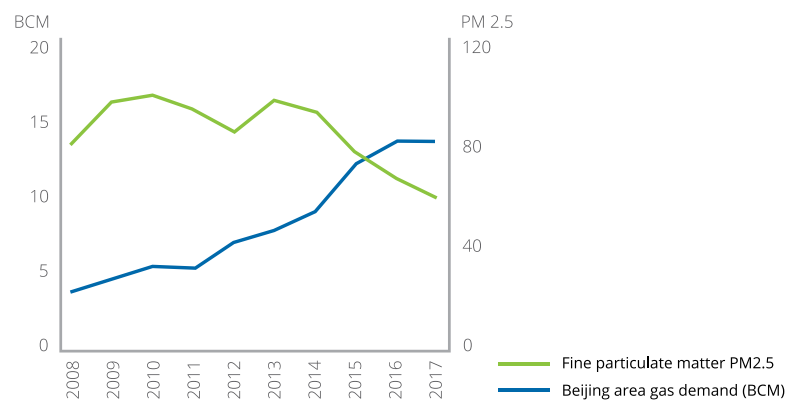
As the capital city, Beijing was one of the early targets in the government’s fight against pollution. In the 2015 edition of this report, the IGU featured Beijing’s aggressive coal to gas substitution policy.³² At the end of 2017, the city has achieved notable positive results. PM_{2.5} levels in Beijing fell by 54% from the previous year, and these air quality gains “show urgent need to reduce coal burning while at the same time ensuring everyone has access to adequate heating.”³³



In 2017, Beijing shut 4,453 coal-fired boilers, and since 2013 it switched about 900,000 households off coal.³⁴ Figure 3 illustrates the inverse relationship between particulate matter emissions and the growth in natural gas consumption.

As Greenpeace notes in its report, however, the dramatic air quality gains in Beijing-Tianjin-Hebei-Shanxi region were somewhat offset by a rebound of pollution in central and southern China (see Figure 4).³⁵ Much work still remains to be done in Beijing and the rest of the country to bring it in line with the WHO standards; however, its success to date should be commended.

Figure 3. Correlation between Coal to Gas Switch and Reduction in PM_{2.5}



Source: Shell, 2017

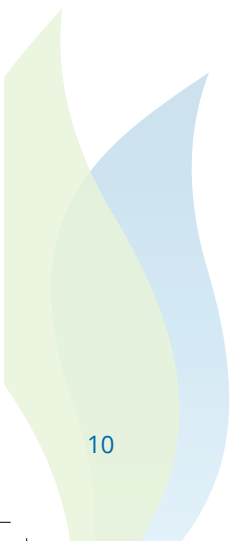
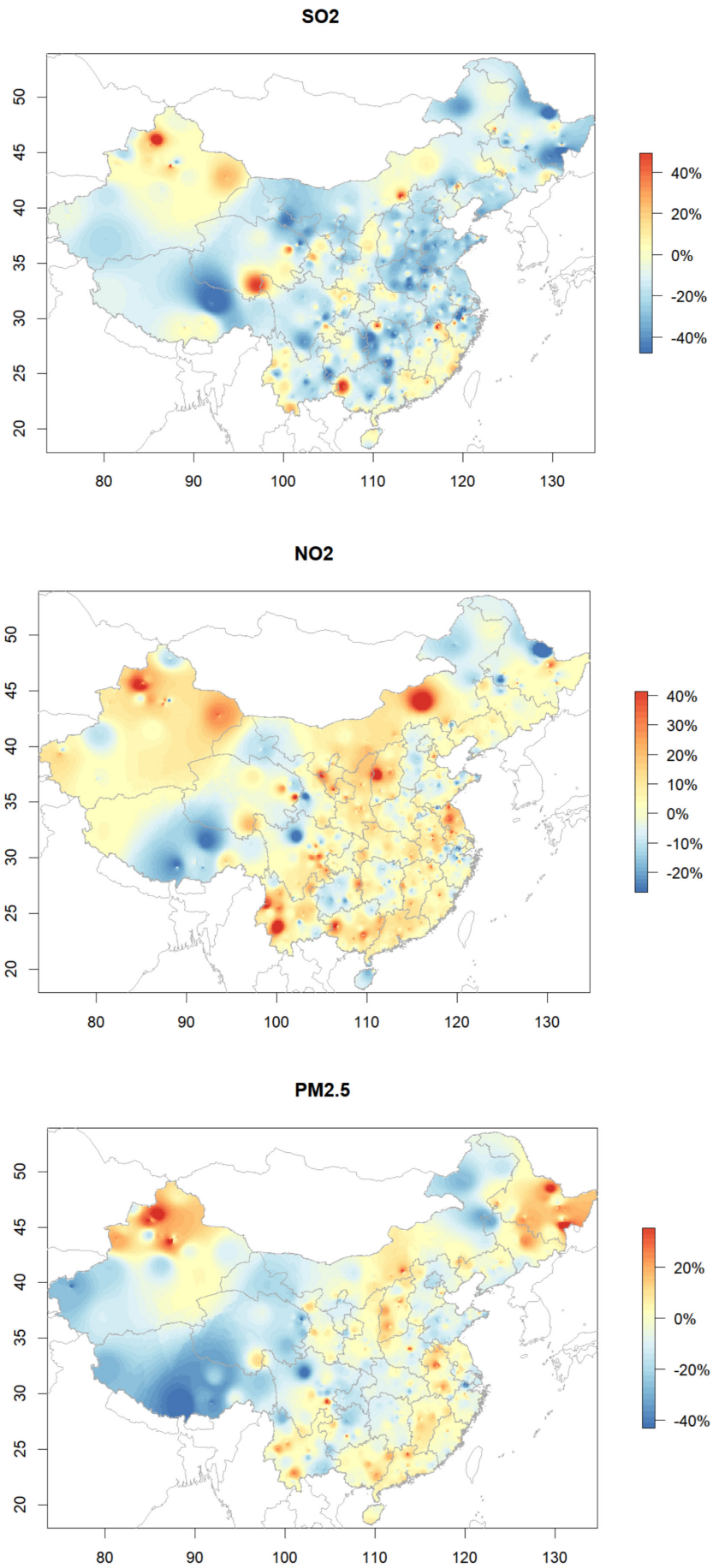
³² IGU. 2015. Case Studies in Improving Air Quality. http://www.igu.org/sites/default/files/node-document-field_file/IGU_Urban%20Air%20Quality%20FINAL%20for%20web%20etc.pdf

³³ Greenpeace, 2017. [<https://secured-static.greenpeace.org/eastasia/Global/eastasia/publications/campaigns/Climate%20and%20Energy/Analysis%20of%20air%20quality%20trends%20in%202017.pdf>]

³⁴ <https://www.shine.cn/archive/nation/How-Beijing-is-improving-its-air-quality/shdaily.shtml>

³⁵ Ibid.

Figure 4. Year on Year Changes January to December 2017.





The city has come a long way to reach this point. The trigger for action was China's 2013 PM crisis.

In the fall of 2013, with the start of the heating season, Beijing and other northern cities experienced an unprecedented pollution event, dubbed by some as "airpocalypse." Over half of total days that year were ranked unhealthy, or worse, for air quality.³⁶

In 2014, the average ambient PM_{2.5} concentration in Beijing was 85.9 µg/m³, which is almost 2.5 times the National Ambient Air Quality Standard (35 µg /m³) and almost 9 times the WHO guidelines (10 µg /m³).³⁷ At the end of 2017, it was 58 µg /m³, still above the national air quality target, but well within the city target reduction to be achieved by the end of that year.³⁸

Coal-Fired Boilers

Industrial

As of 2015, China's industrial boiler systems consumed 700 million tons of coal annually, and accounted for 18% of the nation's coal consumption, and were the cause of 33% of its soot and 27% sulphur dioxide emissions.

China's legacy industrial coal boilers are mostly small size (over 70% are 20 t/h), lower efficiency, lacking automation and advanced emissions control. Natural gas is the primary option for fuel-switching. The government has been implementing a number of measures to encourage the switch, from infrastructure development, to providing incentive, and attempts at market reform for improved pricing mechanisms.

As of 2013, coal provided roughly 80% and oil 15% of fuel for the industrial boiler systems.³⁹

Residential

Even though residential coal consumption accounts for just 12% of total use, residential stoves and boilers are also a lot less efficient, usually not equipped with any exhaust control technology, and often use the cheapest low-grade coal. Between the years 2000 and 2012, residential boilers made a significant impact on wintertime emissions, accounting for 11.6% of PM₁₀, 27.5% of PM_{2.5}, 2.8% of SO₂, and 7.3% of CO.⁴⁰

Gas-fuelled Boilers

Aside from solving the air pollution issue, gas-fuelled boilers offer a plethora of operational advantages, including: high efficiency, rapid ignition, fast ramp-up, flexibility, low maintenance costs, and smaller footprint.⁴¹

³⁶ Zhang, D. et al. *Tackling Air Pollution in China – What do We Learn from the Great Smog of 1950s in London*. Sustainability. August, 2014

³⁷ Ibid.

³⁸ Reuters. Jan. 3, 2018. "Beijing meets 2017 air pollution target set under 2013 clean-up plan." [<https://www.reuters.com/article/us-china-pollution-beijing/beijing-meets-2017-air-pollution-target-set-under-2013-clean-up-plan-idUSKBN1ES0J6>]

³⁹ Shen, B. et al., *Curbing Air Pollution and Greenhouse Gas Emissions from Industrial Boilers in China*. Lawrence Berkeley National Lab. October, 2015.

⁴⁰ Xue, Y., et al. *Trends of Multiple Air Pollutants Emissions from Residential Coal Combustion in Beijing and its Implication on Improving Air Quality for Control Measures*. *Atmospheric Environment*. (142) 303-312. August, 2016.

⁴¹ Shen, B., et al. 2015. *Curbing Air Pollution and Greenhouse Gas Emissions from Industrial Boilers in China*. Ernest Orlando Berkeley National Laboratory.

3.2 URUMQI: Household Heating Coal to Gas Conversion

Urumqi is the capital city of the gas-rich Xinjiang province in northwest China, with estimated population of 3.5 million. Surrounded by mountains, it also had one of the worst air quality rankings in the country.⁴² Coal combustion, traffic, and biomass burning were the major sources of harmful aerosols emissions in the city.⁴³

This effort was supported by the World Bank, which provided funding support for a district heating project, to replace inefficient and polluting coal fired boilers with efficient Combined Heat and Power (CHP) plants.⁴⁴



In late 2012, in an effort to tackle air pollution, the city began a major transformation of its energy system. It set out to convert all of its heating systems from coal to natural gas. In a period of 6 months, Urumqi replaced 12,900 coal boilers with gas.⁴⁵ The replacement was completed in 2014.

Prior to the 2012 policy announcement, the presence of natural gas heating in the city was insignificant, compared to the dominant fuel – coal. By 2012-13 heating season, natural gas grew to become the dominant heating fuel, representing 76% of total, and by 2014, natural gas heating largely replaced coal.

This rapid switch allowed for a focused analysis of the impact on air quality, including major reductions in particulate matter emissions and toxic aerosols.

As coal consumption dropped, so did the SO₂ emissions; during the 2012-13 heating season, a 5 million tons reduction in coal consumption was accompanied by a 35,000-ton reduction in SO₂ emissions and 17,000 tons drop in soot.

⁴² Ren, Y., et. al. *Changes in Concentration, Composition and Source Contribution of Atmospheric Organic Aerosols by Shifting to Natural Gas in Urumqi*. *Atmospheric Environment*. (148) 306-15. October, 2016.

⁴³ Ibid.

⁴⁴ see World Bank, Urumqi District Heating Project: <http://projects.worldbank.org/P120664/urumqi-district-heating-project?lang=en&tab=overview>

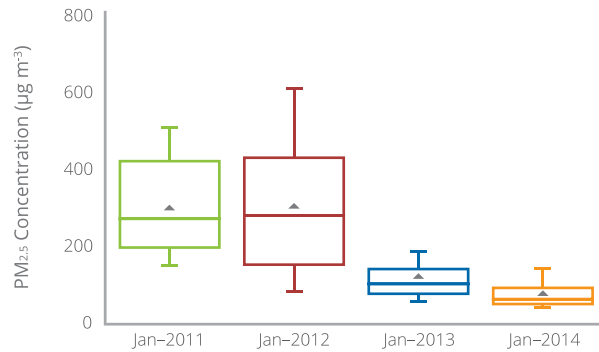
⁴⁵ Ibid.



Monthly mean $PM_{2.5}$ concentrations decreased by 62.8% in January 2013, and by 75.5% in January 2014. Furthermore, concentrations of heavy metals also dropped significantly. For example, coal combustion was a major source of lead in the atmosphere, and burning natural gas does not produce any lead emissions, so after the switch the presence of lead traces in the air was largely gone.⁴⁶

Figures 5, 6, 7 demonstrate the significant improvements in air quality that occurred with the switch.

Figure 5. Comparison of the monthly mean $PM_{2.5}$ concentrations in January 2011, 2012, 2013 and 2014.



Note: The lines inside the box and triangles represent median and mean values. Lower and Upper edges represent 25th and 75th percentiles. Bars with forks outside of boxes show the 5th and 95th percentiles

Figure 6. Concentrations of water-soluble inorganic ions in $PM_{2.5}$ at the SDS site during January 2011, January 2012, January 2013 and January 2014 in Urumqi.

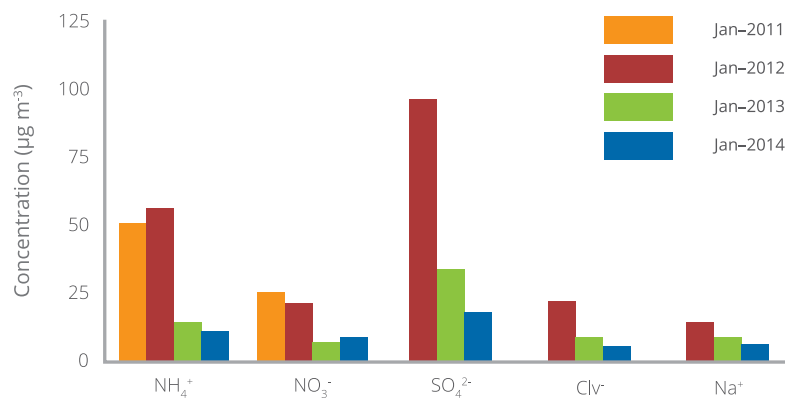
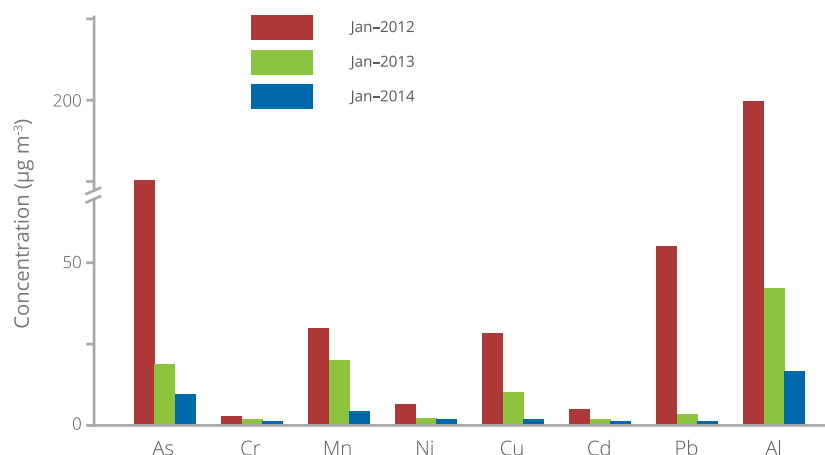


Figure 7. Concentrations of metal elements in $PM_{2.5}$ during January 2012, January 2013 and January 2014 in Urumqi.

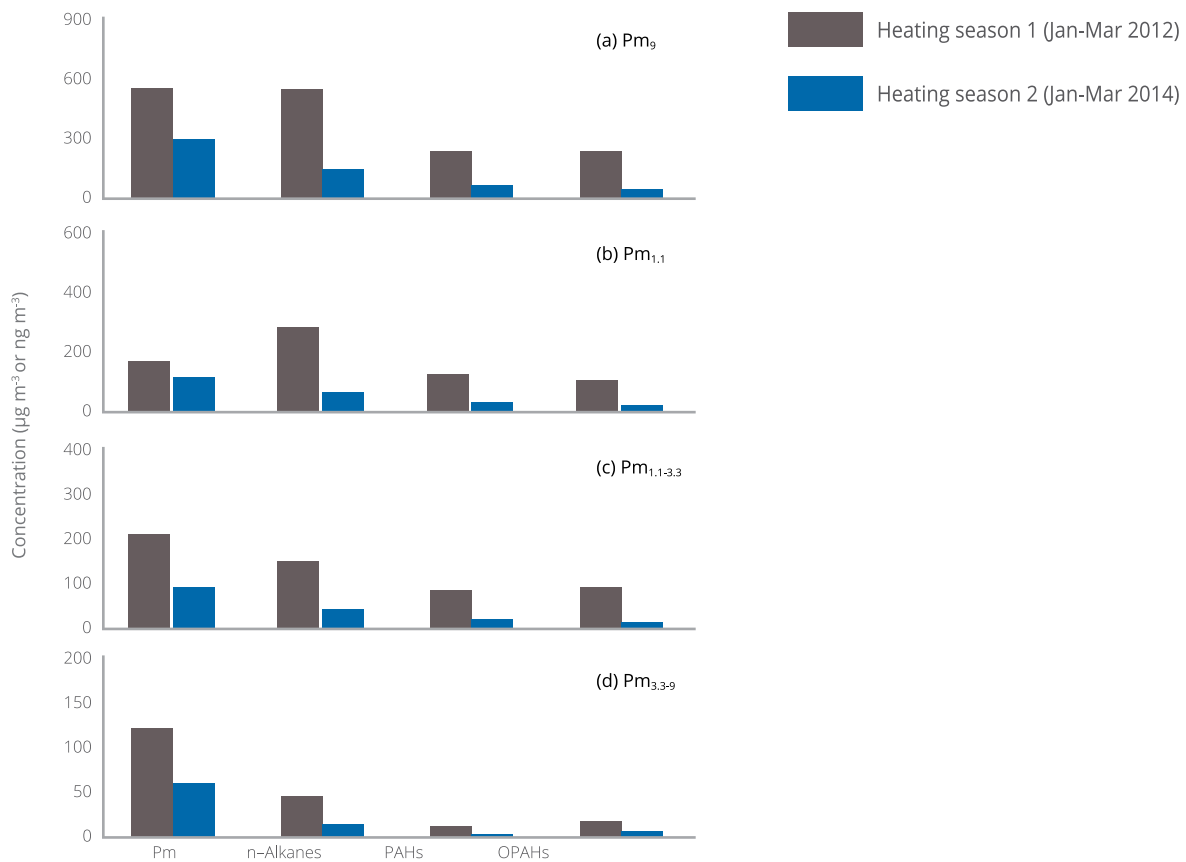


⁴⁶ Song, W. et. al. A Multiyear Assessment of Air Quality Benefits from China's Emerging Shale Gas Revolution: Urumqi as a Case Study. Environmental Science and Technology. (49) 2066-72. January, 2015.

In addition to the inorganic pollutants (SO₂, NO_x, fly ash), coal combustion releases toxic material, such as polycyclic aromatic hydrocarbons (PAH's). A study that compared aerosol and toxic pollutant emissions between pre- and post-conversion heating periods, found significant reductions after the conversion: PM₉ concentration decreased by 45%, SO₂ by 50% (from 58 to 25 mg/m³). Concentration of airborne particulate organic matters and the carcinogenic PAH's decreased by about 70%.⁴⁷

Figure 8 demonstrates these changes.

Figure 8 Concentrations of PM, n-alkanes, PAHs, and OPAHs in different size of particles during the heating seasons in Urumqi, China



Source: Song, W. et al. (FN 48)

The air quality improvements also translated into a 73% reduction in pollution-related lung cancer:

...due to the implementation of the project of shifting coal to natural gas, the number of lung cancer related to PAHs exposure in Urumqi decreased by 73% from 63 persons in heating season 1 to 17 persons in heating season 2, demonstrating a significant improvement of human health by using natural gas for house heating in the city.⁴⁹

One of the studies concluded that if consumption of natural gas were increased in China to the world average of 23.9%, consumption of coal would be reduced by 751 mt, and that would reduce emissions by 4.57 million tons for SO₂, 2.87 million tons for NO_x, and 734 thousand tons of dust.⁵⁰

⁴⁷ Ren, Y., et al. *Changes in Concentration, Composition and Source Contribution of Atmospheric Organic Aerosols by Shifting to Natural Gas in Urumqi. Atmospheric Environment.* (148) 306-15. October, 2016.

⁴⁸ Fig. 8. Concentrations of PM, n-alkanes, PAHs and OPAHs in different size of particles during the heating seasons in Urumqi, China (Concentration unit for PM is mg m⁻³ and others are ng m⁻³; PM₉; the sum of the three grouped size ranges; The mean values with statistic difference (p < 0.05) are labeled with a and b, while those with no statistic difference are labeled with a and a).

⁴⁹ Ibid.

⁵⁰ Song, W. et. al. A Multiyear Assessment of Air Quality Benefits from China's Emerging Shale Gas Revolution: Urumqi as a Case Study. *Environmental Science and Technology.* (49) 2066-72. January, 2015.



3.3 SHANGHAI: Coal to Gas Boiler Retrofit

As with Beijing, the importance of Shanghai as one of China's megacities and the urgency to address its air quality issues have been top of mind for the city and national authorities, since the late 1990's.

In 1998 the State Council named Shanghai as one of China's key regions required to reduce SO₂ emissions.⁵¹

Shanghai became the first city in China to embark on a coal-fired boiler retrofit program.

In 2000, there were more than 3,800 industrial boilers in operation, and the citywide boiler density was 0.6 units per km², reaching 6.2 units in downtown core. That year, Shanghai emitted 464,000 tons of SO₂ and 141,200 tons of smoke and dust (PM) from industrial sources.⁵²



The first phase in Shanghai's boiler replacement program was between 2000 and 2012, and it mainly focused on enabling the supply of natural gas. The West-East gas transmission pipeline was completed and began supplying Shanghai in 2004. In 2009, Shanghai accelerated the construction of the Phase 2 of the Shanghai Section of the Natural Gas Backbone Network and the terminal station of Sinopec Sichuan-East Gas Transmission Project, enabling it to access Sichuan gas. Simultaneously, the municipal authorities continued to accelerate the development of citywide gas delivery infrastructure. These were pivotal enabling steps, which allowed for the next phase of policy efforts to be effective in meeting the boiler retrofit targets.⁵³

At the start of second policy period in 2012, Shanghai government completed a work plan for replacing the remaining coal-fired boilers; created a special fund for financing the initiative; and passed "Coal-free areas and Mostly-Coal Free Areas Implementation Plan."

In its Clean Air Action Plan of Shanghai Municipality (2013-2017), the city committed to specific targets of: replacing or eliminating "more than 2,500 boilers and more than 300 furnaces fired by high polluting fuels such as coal (heavy oil)," and to closing "most scattered facilities fired by coal or other high-polluting fuels, such as commercial small drinking water boilers and small stoves." Further, the plan committed to retrofit "all coal-fired facilities, such as co-generation units and central heating boilers, into clean energy ones, and (...) shut down scattered coal fired facilities" by 2017.

⁵¹ Fu, L. et. al. *China Air 2016 Air Pollution Prevention and Control Progress in Chinese Cities*. Clean Air Asia.

⁵² Ibid.

⁵³ Ibid.

In 2015, Shanghai issued a series of intensification measures, including strengthening the formulation of the implementation plan. It required that by the end of 2015, “the entire Shanghai metropolitan region should be coal-free” and 2,898 coal fired units should be replaced with clean energy.

The government used a number of tools, from incentives, to stricter punishment for non-compliance to accelerate the transition. For example, Shanghai offered tiered financial subsidies, with the amount tied to implementation date, the earliest adopters receiving the largest amounts. The city also increased financial support for gas and power supply projects and related facilities, and simplified the application and approval processes.

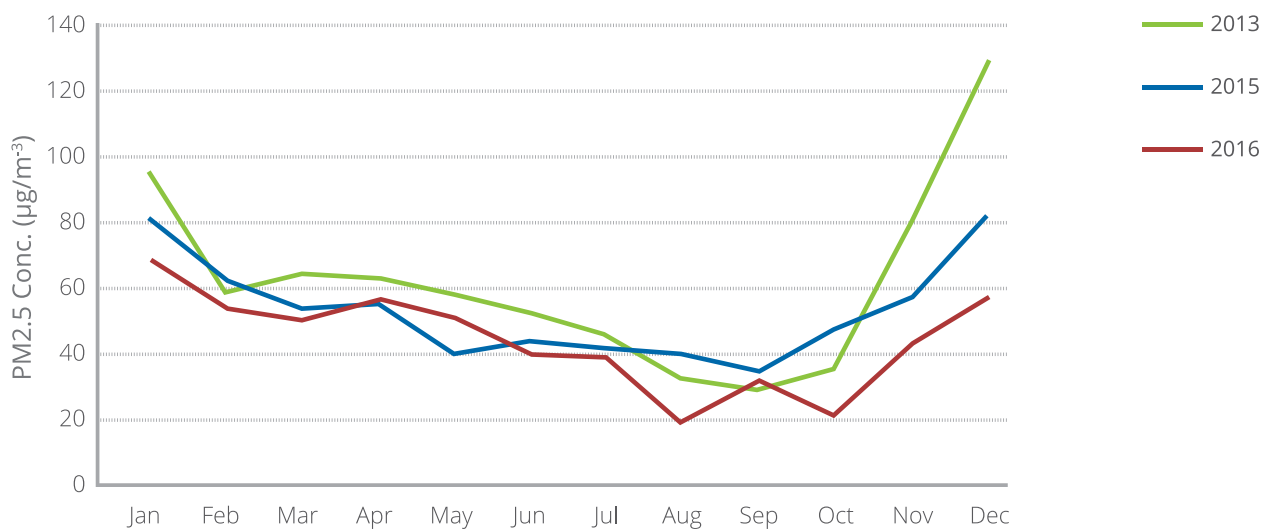
Measures to encourage investment in CHP (combined heat and power) facilities were implemented. For instance, in order to encourage the transition of central heating and larger cogeneration units, the municipal plan requires that electric utilities: “should enhance the coordination and communication with power grid planning, municipal road and other authorities at the district / county level to include gas-fired co-generation with regional grid planning,” to accommodate gas co-generation. Companies that are retrofitting for gas-fired co-generation were exempt from certain charges (reserve capacity). Legal and regulatory provisions ensured stricter enforcement, including very large fines for non-compliance and forced operation shutdown.

The results of these consecutive policy efforts were notable. During 2001-2005, more than 2000 boilers and furnaces were retrofitted and the area of mostly coal-free zones reached 321 km² (double the original goal of 150). By the end of 2015, Shanghai fully completed the replacement of small and medium size coal-, or heavy oil-fired boilers and furnaces, and outlawed 3,626 commercial small boilers and stoves.⁵⁴

The city achieved a significant drop in coal to gas consumption ratio of 10%, between 2013 and 2016 (see Figure 12). These notable efforts helped Shanghai to reduce all major air pollutants, though similarly to other cities in China, the work that lies ahead remains considerable.

According to Shanghai’s Environmental Protection Bureau, in 2016, Shanghai’s PM_{2.5} concentration improved by 15.1%, compared to the previous year, and 27.4%, compared to 2013. PM₁₀ concentrations dropped by 14.5%, from the year before.⁵⁵ These are demonstrated in Figures 9, 10 and 11 below.

Figure 9. Variations in Monthly Avg. Concentrations of PM_{2.5} from 2015 to 2016 compared with 2013



⁵⁴ Ibid

⁵⁵ Shanghai Environmental Protection Bureau. 2017. *Shanghai Environmental Bulletin* 2016.



Figure 10. Annual Concentrations of PM₁₀

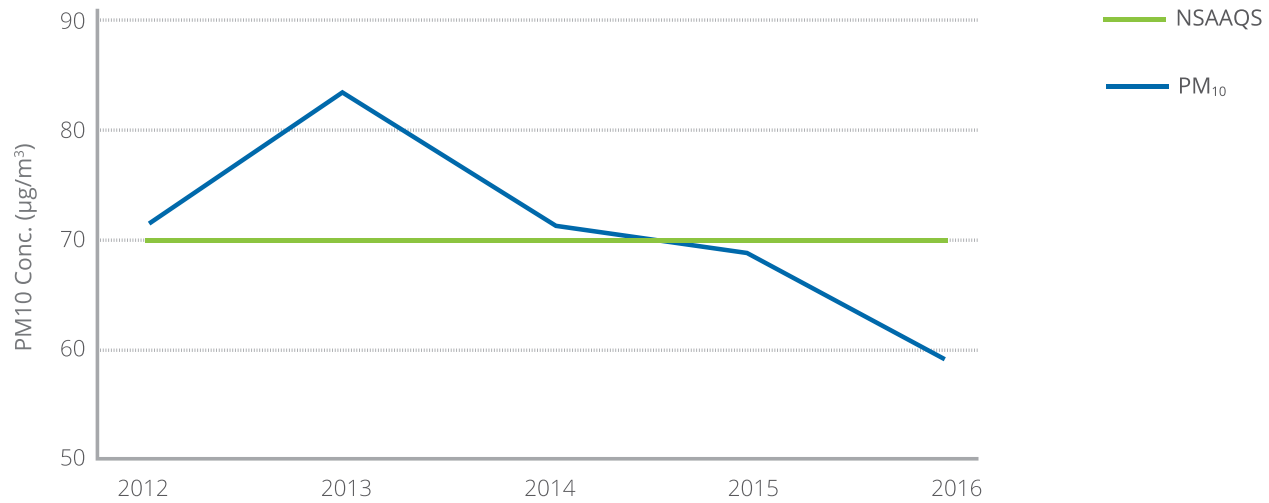
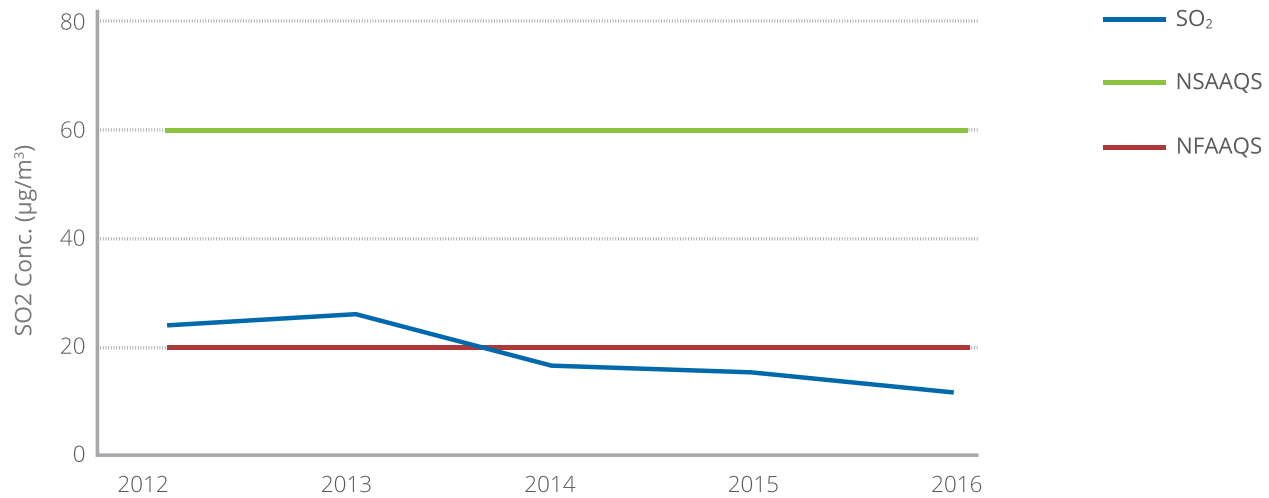
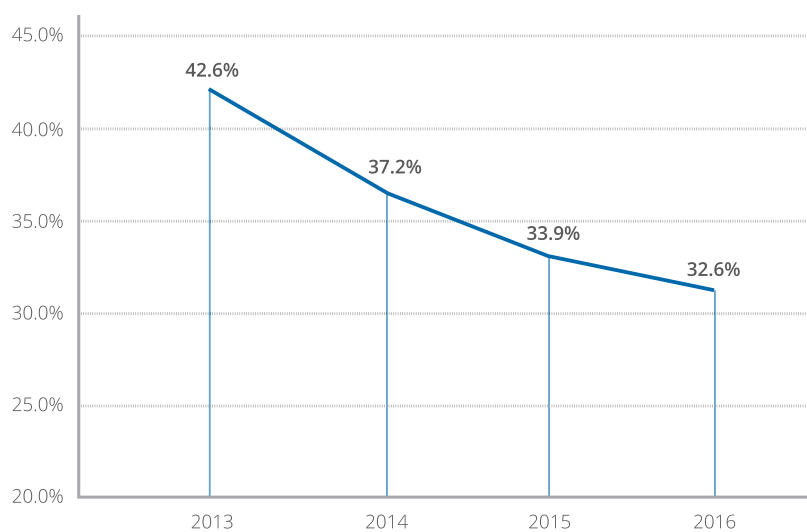


Figure 11. Annual Concentrations of SO₂



NSAAQS: National Ambient Air Quality Standard NFAAQS: National First Ambient Air Quality Standard
Source: Shanghai Environmental Protection Bureau. 2017. Shanghai Environmental Bulletin 2016.

Figure 12. Ratio of coal to natural gas consumption



Source: Data collected and provided by Beijing Gas.

3.4 Santiago - A Look at Chile



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In 1989, Santiago Chile's $PM_{2.5}$ concentration was registered at $68.9 \mu\text{g}/\text{m}^3$, nearly seven times the recommended WHO level. The main causes of air pollution were wood burning for residential heating, transport activity, and the use coal, fuel oil, and diesel by industry.⁵⁶ Santiago, is also located in a basin with poor atmospheric ventilation; its geography and climate are unfavourable to the diffusion of air pollutants, making the issue worse.⁵⁷

Chile became acutely aware of Santiago's severe air quality problem in the 1970s, after the installation of air quality monitoring stations. In 1978, the government introduced the first air quality norms, regulating total suspended particles and other pollutants, but it was not until the 1990s that deliberate environmental management policy started to take root with the creation of dedicated government departments and new stricter regulations.



In 1994, the government enacted the Law for the Environment, immediately followed by the implementation of the Protocol for Natural Gas Integration between Chile and Argentina in 1995. As a result, the industrial and residential sectors started using natural gas, instead of coal, provided through the new infrastructure facilitating imports from Argentina.

Research shows that, according to the annual averages recorded by Santiago's monitoring stations, between 1990 and 2016, there was a reduction of 39% in PM_{10} and 58% reduction in $PM_{2.5}$. Furthermore, results show a reduction of $2.63 \mu\text{g}/\text{m}^3$ in PM from industrial sources during the study period, largely due to fuel switch toward natural gas⁵⁸

⁵⁶ Villalobos, A., Barraza, F., Jorquera, H., and Schauer, J.: *Chemical speciation and source apportionment of fine particulate matter in Santiago, Chile, 2013*, *Science of the Total Environment*, 512-513, 133-142, doi:10.1016/j.scitotenv.2015.01.006, 2015.

⁵⁷ Muñoz, R. and Alcañiz, R. I.: *Variability of urban aerosols over Santiago, Chile: Comparison of surface PM_{10} concentrations and remote sensing with ceilometer and lidar*, *Aerosol and air quality research*, 12, 8-19, 2012. doi:10.1016/j.scitotenv.2015.01.006, 2015.

⁵⁸ Barraza F., Lambert F., Jorquera H., Villalobos A.M., Gallardo L. 2017. *Temporal evolution of main ambient $PM_{2.5}$ sources in Santiago, Chile, from 1998 to 2012*. *Atmos. Chem. Phys. Discuss.*, doi:10.5194/acp-2017-18.



Policy Context

Reacting to the problematic pollution situation, the government undertook a number of measures to improve air quality, including: a ban of controlled biomass burning in the agriculture sector, mandating the retirement of old buses, requiring catalytic converters for vehicles, issuing a ban on domestic wood burning, and introducing a sulphur content limit for diesel. Table 1 presents the evolution over time of selected drivers of anthropogenic emissions.

Table 1 Drivers for reduction in anthropogenic emissions in the Santiago Metropolitan Region

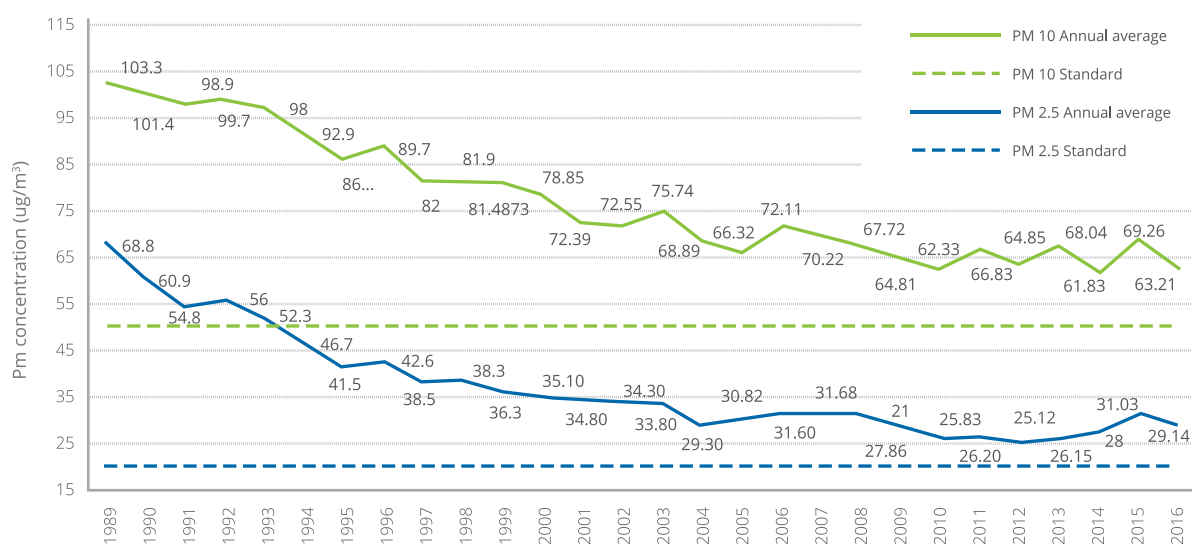
Activity	1994	2004	2014
Industrial Fuel Switching	Wood, coal and fuel oil	Natural gas and diesel 50 ppm sulphur	Natural gas and diesel 50 ppm sulphur
Electricity generation fuel switching	Coal	Natural gas	Natural gas
Number of public transport buses	14,000, 15 average years	7,500, 10 average years	6,500
Vehicle diesel quality	5,000 ppm sulphur	50 ppm sulphur	15 ppm sulphur
Vehicle petrol quality	All unleaded	All unleaded	All unleaded
Private vehicle technology	100% conventional	25% conventional 75% catalytic	3% conventional 97% catalytic

Source: Authors' elaboration using data from CONAMA Metropolitana, INE, ENAP and Decree 60/2013 from the Ministry of Energy.

The first regulations of PM₁₀ emissions were issued in 1992, followed by the Ministry of Environment's issuing of a decontamination plan for the Metropolitan Region in 1998, and in 2011, the first air quality norm for PM_{2.5}.

Figure 13 shows the evolution of PM₁₀ and PM_{2.5} concentrations between 1989 and 2016 as averages recorded at monitoring stations, and the respective primary norms. The curves show a steady decrease as a result of the policy measures implemented, even though economic activity has increased.

Figure 13 Evolution of annual average concentrations for PM₁₀ and PM_{2.5} in Santiago.



Source: data from SINCA.⁵⁹

⁵⁹ SINCA 2017, Sistema de Información Nacional de Calidad del Aire, Ministerio del Medioambiente, Chile. Información histórica estaciones públicas de monitoreo en la Región Metropolitana, available at <http://sinca.mma.gob.cl/index.php/region/index/id/M>.

Industrial Emissions

Based on the analysis of PM filters from 1998 to 2012, it can be concluded that the introduction of mass use of natural gas replacing diesel in the industrial sector has had a positive impact on PM_{2.5} concentrations from industrial sources.

The pipeline infrastructure to export gas from Argentina to Chile was built in 1995, and the first gas-fired thermal electric power plant began generating electricity in 1998. Natural gas became an important source of energy for industrial and residential sectors in the Santiago Metropolitan Region, with a peak consumption of 783 bcm in 2004 (70% industrial and 24% residential).

However, in 2004, Chile began experiencing interruptions of Argentine gas supply, causing shortages. During that temporary interruption, the industry was forced to switch back to dirtier fuels, and there was a corresponding increase in industrial emissions. Analysis of source-specific pollution changes showed that between 2005 and 2007, the contributions to PM concentration from industrial sources increased significantly, coinciding with the gradual reduction in imports of gas from Argentina and its replacement by diesel or fuel oil.

In response to the disruption of supply, Chile's large natural gas importers collaborated to construct a gas terminal at the port of Quintero. The Quintero gas terminal started operations in 2009, with new imported natural gas supplies helping to overcome dependence on gas from Argentina and restoring security of supply.

This resumption in stable natural gas supply caused a significant shift back from diesel to natural gas and a consequent reduction in industrial emissions.⁶⁰ PM_{2.5} concentration in the Metropolitan Region reduced by 1.76 µg/m³, compared to the 2004-2008 period.⁶¹

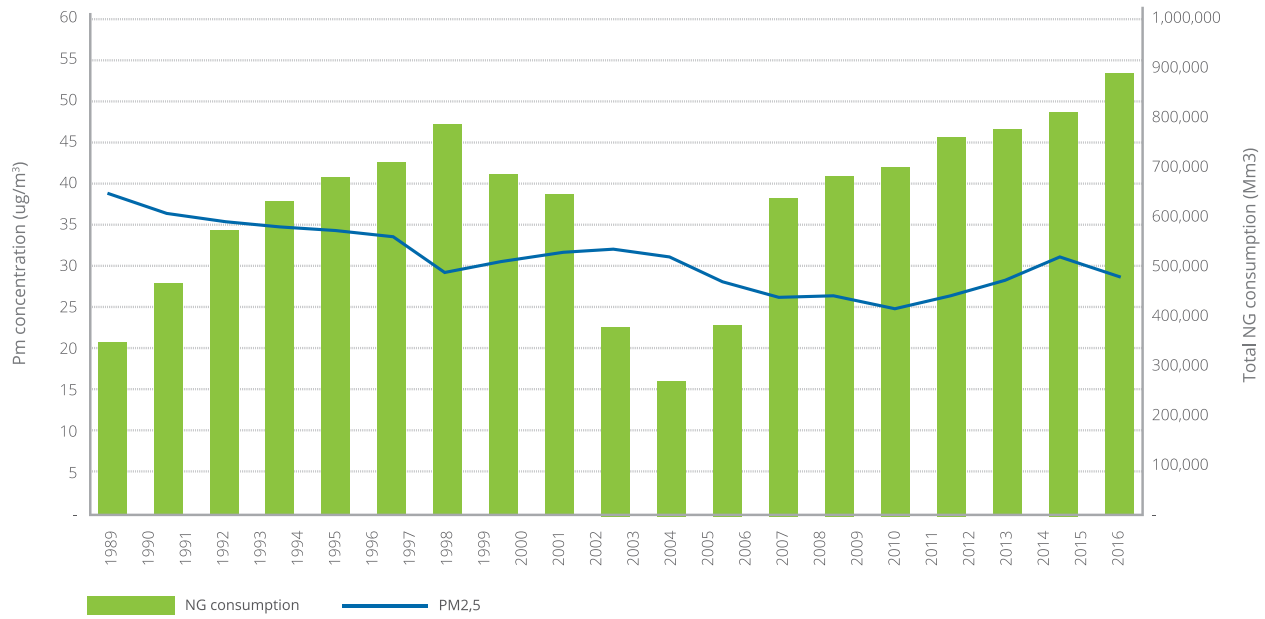
Figure 14 depicts natural gas consumption versus variations in the concentrations of PM_{2.5} in the Metropolitan Region between 1998 and 2016. There is an overall downward trend in PM emissions, coinciding with an upward trend in gas consumption, with the exception of a slight reverse between 2012 and 2015. The latter could be explained by a number of factors, such as growth of transport activity, without the corresponding strengthening of emissions regulations. The separate analysis of industrial emissions, referenced above demonstrated that industrial emissions dropped during that time, as they used more gas.

⁶⁰ Figueroa, E., et al, 2013. *Develando econométricamente los impactos sobre la concentración atmosférica de material particulado de un proyecto de remodelación del transporte urbano: El caso del Transantiago en Chile*. *Estud. Econ.* 40, 53-79, doi:10.4067/S0718-52862013000100003; Mena-Carrasco M., Oliva E., Saide P., Spak S.N., de la Maza C., Osses M., Tolvett S., Campbell J.E., Chi-Chung T., Molina L.T., 2012. *Estimating the health benefits from natural gas use in transport and heating in Santiago, Chile*. *Science of the Total Environment* 429, 257-265.

⁶¹ Barraza F., Lambert F., Jorquera H., Villalobos A.M., Gallardo L. 2017. *Temporal evolution of main ambient PM_{2.5} sources in Santiago, Chile, from 1998 to 2012*. *Atmos. Chem. Phys. Discuss.*, doi:10.5194/acp-2017-18.



Figure 14. Natural gas consumption trends and annual average concentrations of PM_{2.5} in the Metropolitan Region.



Source: data from SINCA, SEC, METROGAS

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