Dangerous Breathing

$PM_{2.5}$: Measuring the human health and economic impacts on China's largest cities

GREENPEACE 绿色和平

1 Background

According to statistics from China's Ministry of Environmental Protection (MEP), cities in China's Yangtze River Delta, Pearl River Delta, and Beijing-Tianjin-Hebei region suffer over 100 haze days every year, with $PM_{2.5}$ (particles with an aerodynamic diameter less than 2.5 μm) concentration two to four times above the World Health Organization guidelines. The effects of $PM_{2.5}$-related air pollution extend beyond haze days, also leading to systemic damage to the health of the human body. At the end of 2011 heated public discussion and media attention over $PM_{2.5}$ led to its installation as a new national indicator for air quality monitoring, in an era of incredibly high pollution levels and an ever-increasing area of contamination. However, the exact sources of, control approach, public health risks and economic loss due to $PM_{2.5}$ had yet to be verified and closely studied .

This study is the first of its kind, based on currently available research findings and data in relation to $PM_{2.5}$ in Shanghai, Guangzhou, Xi'an and Beijing, respectively elected as four major cities in Eastern, Southern, Western, and Northern China. It studies the health risks and economic loss linked to $PM_{2.5}$ in these four cities, and assesses the potential public health and economic benefits given effective improvement of $PM_{2.5}$ pollution control under different scenarios. Due to a lack of available data, we were only able to estimate the health and economic loss brought upon by premature death. We did not include hospital admissions numbers, nor lost work and school days, although $PM_{2.5}$ would have also impacted these numbers. We hope that this study can offer insight into evaluating the economic loss due to China's $PM_{2.5}$ pollution, and look forward to seeing more researchers and policy makers join the research into $PM_{2.5}$ and the discussion of pollution control.

Key Points

$PM_{2.5}$ concentration levels have endangered public health in Beijing, Shanghai, Guangzhou and Xi'an. The $PM_{2.5}$ concentration levels in all four cities exceed World Heath Organisation (WHO) air quality guidelines (AQG). This means higher health risks to the cardiovascular system, cerebrovascular system and an increase in the probability of cancer and premature death.

Supposing if pollution levels remained the same as 2010, 8,572 premature deaths would have been caused by $PM_{2.5}$ in the four cities in 2012, with a total economic loss of 1.08 billion USD .

Supposing if the four cities effectively controlled $PM_{2.5}$ levels and met WHO air quality guidelines in 2012, the number of premature deaths would have decreased by at least 81%, while the economic benefits of reducing these premature deaths in the four cities would amount to 875 million USD.

2 The health risks of $PM_{2.5}$

$PM_{2.5}$ is small in particulate size but as pollution can reach a large surface area. Compared to other particulate matter it is more prone to carrying a variety of toxic heavy metals, acid oxides, organic pollutants and other chemicals, as well as microorganisms such as bacteria and viruses in the air. Therefore, compared to PM_{10} it can be considered more hazardous to human health. Modern toxicology research has proven that the heavy metals and PAHs (polycyclic aromatic hydrocarbons) carried by $PM_{2.5}$ can enter and deposit in human alveoli, causing inflammation and lung diseases. It can also enter the human blood circulation and affect the normal functioning of the human cardiovascular system. Therefore, exposure to $PM_{2.5}$ can lead to significantly increased mortality due to cardiovascular, cerebrovascular and respiratory diseases, as well as greater cancer risks. (See table 1. WHO air quality guidelines and interim targets for particulate matter – annual mean concentrations)

Table 1. WHO air quality guideline and interim targets for particulate matter – annual mean concentrations

	PM_{10} (μg/m^3)	$PM_{2.5}$(μg/m^3)	Basis for selected level
Interim target - 1 (IT-1)	70	35	These levels are associated with about a 15% higher long-term mortality risk relative to the AQG level.
Interim target - 2 (IT-2)	50	25	In addition to other health benefits, these levels lower the risk of premature mortality by approximately 6% [2-11%] relative to the IT-1 level
Interim target -3 (IT-3)	30	15	In addition to other health benefits, these levels lower the mortality risk by approximately 6% [2-11%] relative to the IT-2 level
Air quality guideline (AQG)	20	10	These are the lowest levels at which total, cardiopulmonary and lung cancer mortality have been shown to increase with more than 95% confidence in response to long-term exposure to $PM_{2.5}$

3 Key findings: the health and economic impacts of $PM_{2.5}$ on four major Chinese cities

The cities of Beijing, Xi'an, Shanghai and Guangzhou have been selected for this study. A mathematical model was developed based on $PM_{2.5}$ laboratory monitoring values over the past three to four years in these four cities, as well as local CDC (Centers for Disease Control and Prevention) statistics on related deaths and their causes over the same period. From this a $PM_{2.5}$ exposure relative risk coefficient (RR) was calculated. Total deaths related to $PM_{2.5}$ pollution in 2010 was also estimated based on population sizes and PM_{10} concentration statistics published in the National Statistical Yearbook 2010.

Finally, the study also calculates mortality caused by $PM_{2.5}$ in 2012, together with figures based on potential $PM_{2.5}$ improvement scenarios. Those figures include the projected health benefits to these cities under different air pollution levels, according to national guidelines and the WHO AQG.

3.1 Methodology

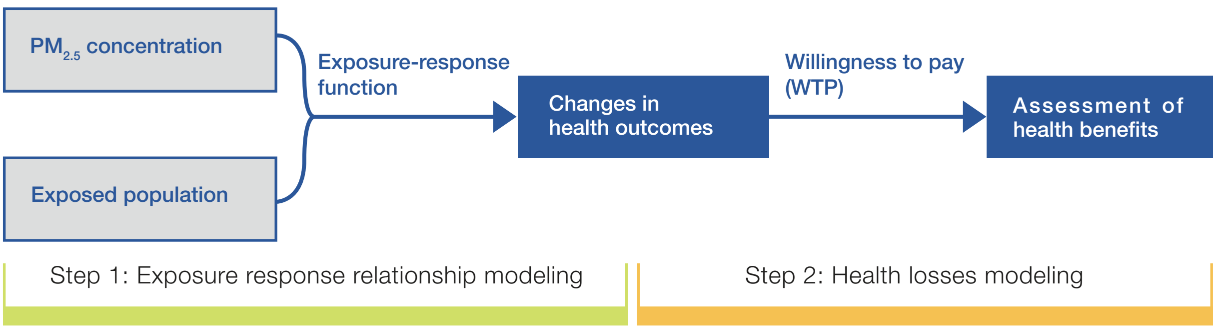


Table 2. $PM_{2.5}$ concentration data used in the exposure response relationship model

City	Monitoring site	Monitored period	Average daily $PM_{2.5}$ concentration during monitored period ($\mu g/m^3$) (standard deviation)
Beijing	Peking University campus	2006 - 2008	83.96 (58.28)
Shanghai	Shanghai Environmental Monitoring Center, Pudong District	2004 - 2005	56.4 (1.34)
Guangzhou	South China Environmental Sciences Institute, Tianhe District	2006 - 2009	59.91 (32.57)
Xi'an	Chinese Academy of Sciences	2004 - 2008	176.7 (103.8)

Table 3. Exposure response relationship coefficient in the four cities

City	Health outcomes	RR (95% CI)	Sources of data
Beijing	Non-accidental deaths	1.002709 (1.000982, 1.004438)	Data for Beijing, 2006 - 2008: Mortality data from National CDC, $PM_{2.5}$ data from Peking University
	Deaths caused by circulatory diseases	1.003465 (1.001034, 1.005903)	
Guangzhou	Non-accidental deaths	1.005648 (1.002182, 1.009125)	Data for Guangzhou, 2006-2009 data: Mortality data from National CDC, $PM_{2.5}$ data from South China Institute of Science
	Deaths caused by circulatory diseases	1.008009 (1.002098, 1.013955)	
	Deaths caused by respiratory diseases	1.00867 (1.001341, 1.016052)	
Shanghai	Non-accidental deaths	1.0036 (1.0011, 1.0061)	Kan Haidong, et al (2007)
	Deaths caused by circulatory diseases	1.0041 (1.0001, 1.0082)	
	Deaths caused by respiratory diseases	1.0095 (0.0016, 0.0173)	
Xi'an	Non-accidental deaths	1.002 (1.0007, 1.0033)	Huang Wei, et al (2012)
	Deaths caused by circulatory diseases	1.0027 (1.0008, 1.0046)	

The data in table 2 shows that the daily average $PM_{2.5}$ concentration far exceeds the national level two, and goes far beyond WHO guidelines. A look at the monitoring results of Xi'an shows levels five times over the national level two standard.

From the RR matrix in table 3 we can see that the levels of hazardous impacts are both high in these four cities.

3.2 2010: the health and economic impacts of $PM_{2.5}$ on four major Chinese cities.

Based on the exposure response relationship coefficient values in different cities, we were able to calculate figures for related deaths in 2010 and economic loss based on population and $PM_{2.5}$ concentration numbers.

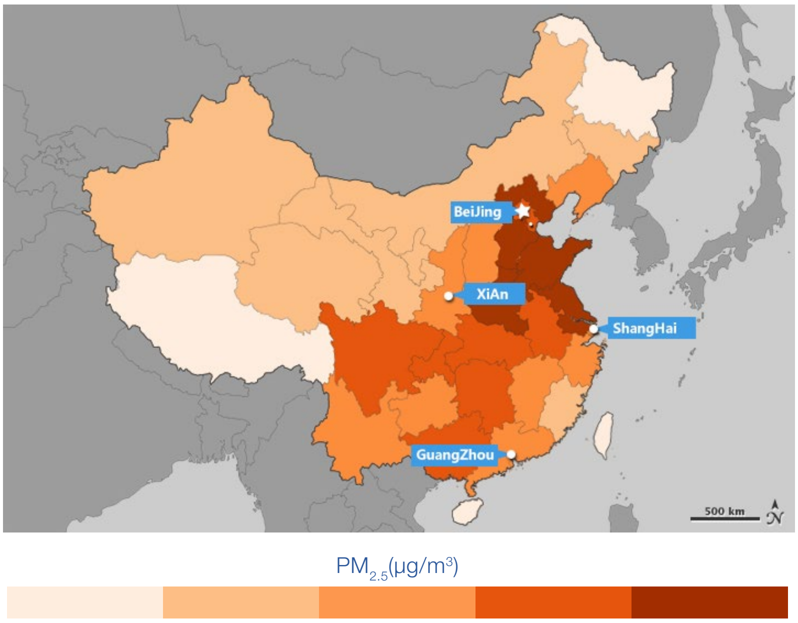
To calculate the number of residents in 2010 exposed to $PM_{2.5}$ air pollution, we used statistics from the population of permanent residents in Beijing, Shanghai, Guangzhou and Xi'an (see appendix table 1, from annual statistics reports of each city). The $PM_{2.5}$ data used is calculated from annual environment communiqués published by the Ministry of Environmental Protection (MEP), with PM_{10} converted to $PM_{2.5}$ concentration numbers using a factor of 0.60.

The 2010 estimation results are as following, seen in table 4. Detailed figures are listed in the appendix, tables 2-5.

Table 4. 2010: $PM_{2.5}$ induced deaths and economic loss estimates

City	$PM_{2.5}$ annual concentration (μg/m^3)	Number of deaths caused by $PM_{2.5}$	Economic loss (million USD)
Beijing	72.6	2349	296
Shanghai	47.4	2980	377
Guangzhou	42	1715	217
Xi'an	78	726	92

3.3 2012: the health and economic impacts of $PM_{2.5}$ on four major Chinese cities



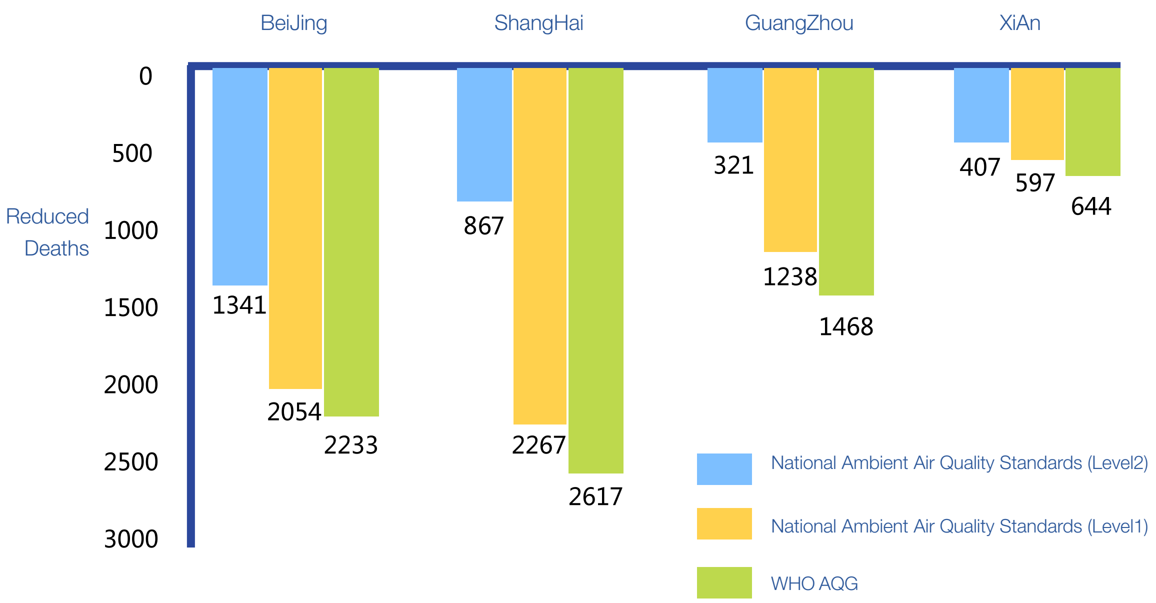
Graph 1. $PM_{2.5}$ concentration levels of Chinese major regions

Based on the demographic changes of the four cities in 2012, we can calculate deaths and economic loss caused by different levels of $PM_{2.5}$ in 2012. Since PM_{10} statistics are taken from the MEP annual environmental communiqués, and those from 2011 and 2012 have yet to be published, we are using 2010 $PM_{2.5}$ levels as a reference to calculate the impact in 2012. We are supposing $PM_{2.5}$ in these cities didn't improve in the past two years.

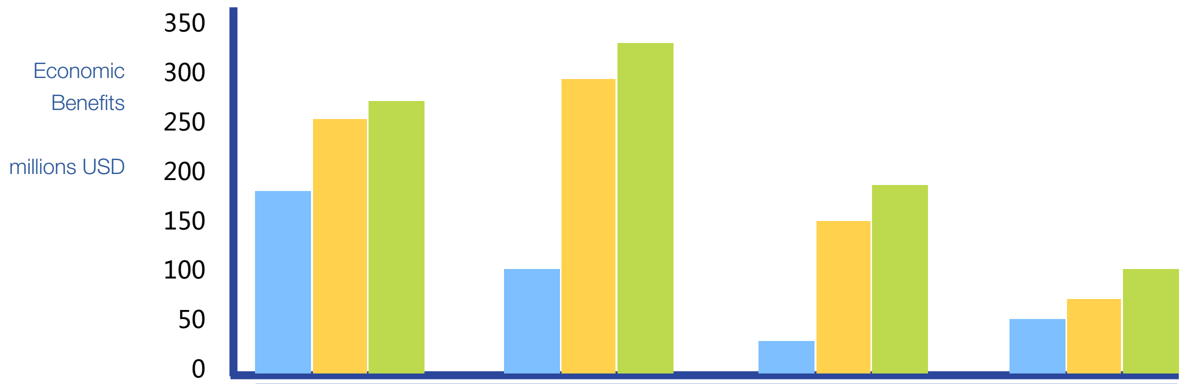
Table 5. 2012: $PM_{2.5}$ induced deaths and economic loss estimates if pollution remained at 2010 level

City	Number of deaths caused by $PM_{2.5}$	Economic loss (million USD)
Beijing	2589	328
Shanghai	3317	420
Guangzhou	1926	244
Xi'an	739	94

We can also calculate the potential death and economic loss reduction of different air quality improvement scenarios compared to no improvement in 2012 (graphs 2 and 3). The hypothetical air quality levels accord with national standards and the WHO guideline. Detailed figures are listed in the appendix, tables 6-9.



Graph 2. Reduction of premature death caused by $PM_{2.5}$ pollution in 2012 under different improvement scenarios



	BeiJing	ShangHai	GuangZhou	XiAn
National Ambient Air Quality Standards (Secondary)	170	110	41	52
National Ambient Air Quality Standards (Primary)	260	287	157	76
WHO AQG	283	331	186	82

Graph 3. Economic loss reductions under different $PM_{2.5}$ improvement scenarios .scenarios

In conclusion, if these cities can effectively lower their $PM_{2.5}$ level and meet level one or two of the national air quality guidelines, $PM_{2.5}$-induced deaths would be reduced by a significant degree compared to no improvement in 2012. If the cities can meet the WHO AQG such deaths would be reduced by at least 81%, and the economic loss reduction of these four cities could reach in total of up to 868 million USD .

Further detailed scenarios for each city

A

If the pollution level remains at the 2010 level, the total number of deaths resulted from $PM_{2.5}$ pollution in Beijing in 2012 would be 2,589, and related economic loss would reach nearly 328 million USD. If Beijing can meet level 2 or level 1 of national AQG or the WHO AQG in 2012, such deaths would be reduced by 1,341, 2,054, and 2,233 respectively. There would also be a decrease of 51.7%, 79% and 86.2% respectively over no $PM_{2.5}$ concentration improvement made (2,589 deaths). And the economic benefits would reach 170, 260 and 283 million USD respectively.

B

If the pollution level remains at the 2010 level, the total number of deaths resulted from $PM_{2.5}$ pollution in Shanghai in 2012 would be 3,317, and related economic loss would reach nearly 420 million USD. If Shanghai can meet level 2 or level 1 of national AQG or the WHO AQG in 2012, such deaths would be reduced by 867, 2,267 and 2,617 respectively. There would also be a decrease of 26.1%, 68.3% and 78.9% respectively over no $PM_{2.5}$ concentration improvement made (3,317 deaths). And the economic benefits would reach 110, 287 and 331 million USD respectively.

C

If the pollution level remains at the 2010 level, the total number of deaths resulted from $PM_{2.5}$ pollution in Guangzhou in 2012 would be 1,926, and related economic loss would reach nearly 244 million USD. If Guangzhou can meet level 1 or level 2 of national AQG or the WHO AQG in 2012, such deaths would be reduced by 321, 1,238 and 1,468 respectively. There would also be a decrease of 16.6%, 62.4% and 76.2% respectively over no $PM_{2.5}$ concentration improvement made (1,926 deaths). And the economic benefits would reach 41, 157 and 186 million USD respectively.

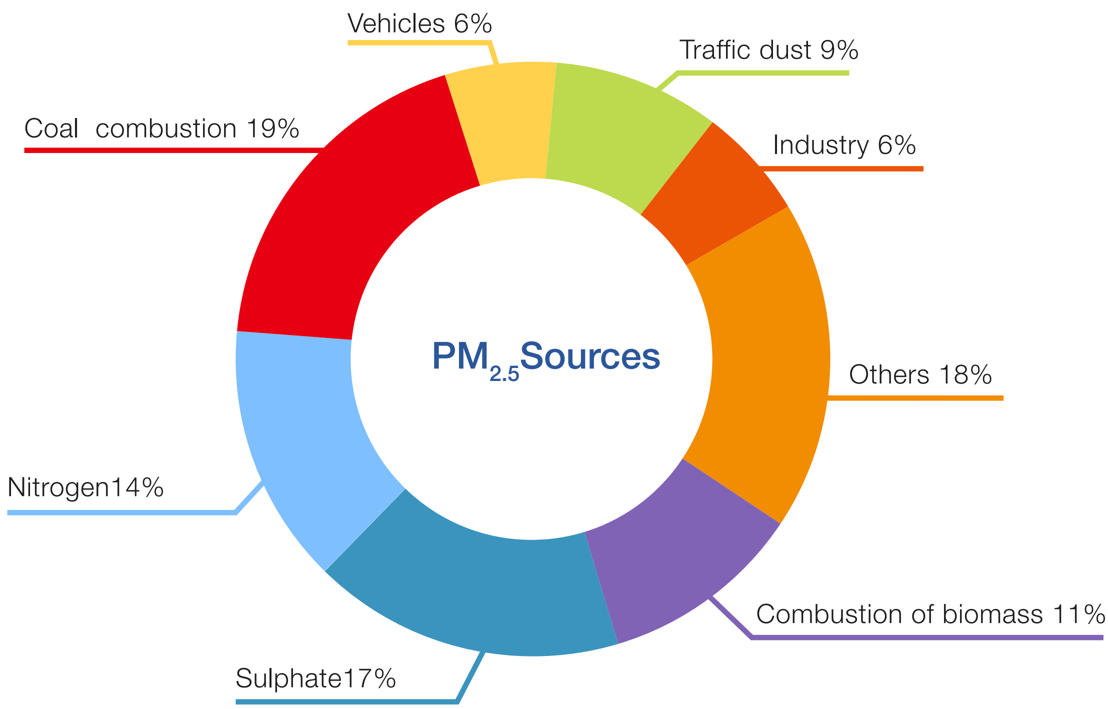
D

If the pollution level remains at the 2010 level, the total number of deaths resulted from $PM_{2.5}$ pollution in Xi'an in 2012 would be 739, and related economic loss would reach nearly 94 million USD. If Xi'an can meet level 1 or level 2 of national AQG or the WHO AQG in 2012, such deaths would be reduced by 407, 597 and 644 respectively. There would also be a decrease of 55.1%, 80.8% and 87.1% respectively over no $PM_{2.5}$ concentration improvement made (739 deaths). And the economic benefits would reach 52, 76 and 82 million USD respectively.

4 $PM_{2.5}$ source analysis and control strategy

4.1 Sources of $PM_{2.5}$

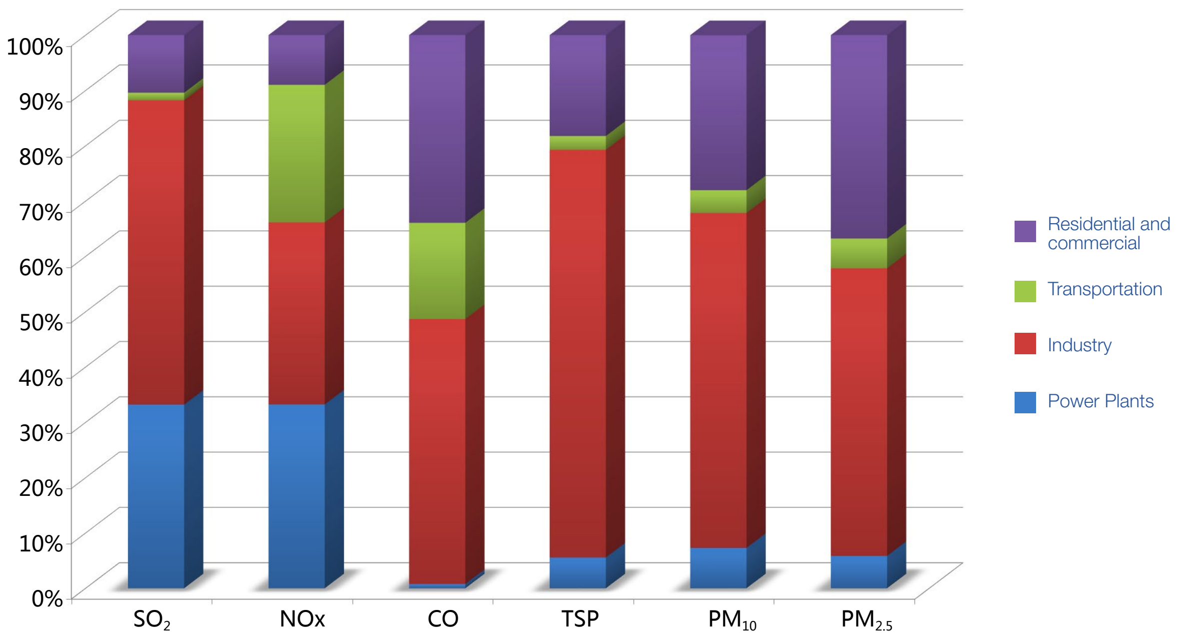
The composition of $PM_{2.5}$ is relatively complex, including direct emissions of fine particles of the combustion process (primary $PM_{2.5}$ particles), and secondary particles generated by multiphase chemical reactions (ie. gases are converted into solids through chemical reactions, such as how sulfur dioxide and nitrogen oxide are converted into sulfates and nitrates) of atmospheric pollutants. Early $PM_{2.5}$ research focused on $PM_{2.5}$ sources apportionment for counter measures. A number of studies show that the proportion of primary $PM_{2.5}$ particles has been on the decrease while that of secondary particles are on the rise.1 Graph 4 shows the analytical results of $PM_{2.5}$ sources in Beijing by the Chinese Academy of Sciences in 2006. We can see that the emissions of motor vehicles contribute about 6%, the combustion of coal remains the most important source of primary particulate matters, accounting for 19%, and that secondary particles carried by nitrates and sulfates also take a large proportion with 14% and 17%, respectively. This illustrates the significance of pollution caused by secondary particles, especially nitrates and sulfates.



Graph 4. $PM_{2.5}$ source analysis

4.2 The electric power sector and industrial sectors are the main sources of air pollution

Source apportionment method allows for a qualitative analysis of $PM_{2.5}$ control, with the control of secondary particulate matters being at its core. For pollution control measures, the most crucial approach is to have an inventory of pollutants discharged by different sectors and enterprises. Although there isn't such an official inventory at the national level in China, scholars have tried several ways to produce one such at both national and regional levels as an important basis for regional joint prevention and control of air pollution. According to the findings published by Zhao Yu et al in 2012[1] , the country's emissions by sector are shown in graph 5, and the emissions in the Pearl River Delta (PRD) and the Yangtze River Delta (YRD)shown in graph 6[2] and graph 7[3] . Both the national and regional emission inventories indicate that the electric power sector and industrial sectors are the main sources of SO_2, NOx, which are precursors to primary and secondary $PM_{2.5}$ particles. Such a phenomenon is largely attributed to China's excessive dependence on coal consumption.

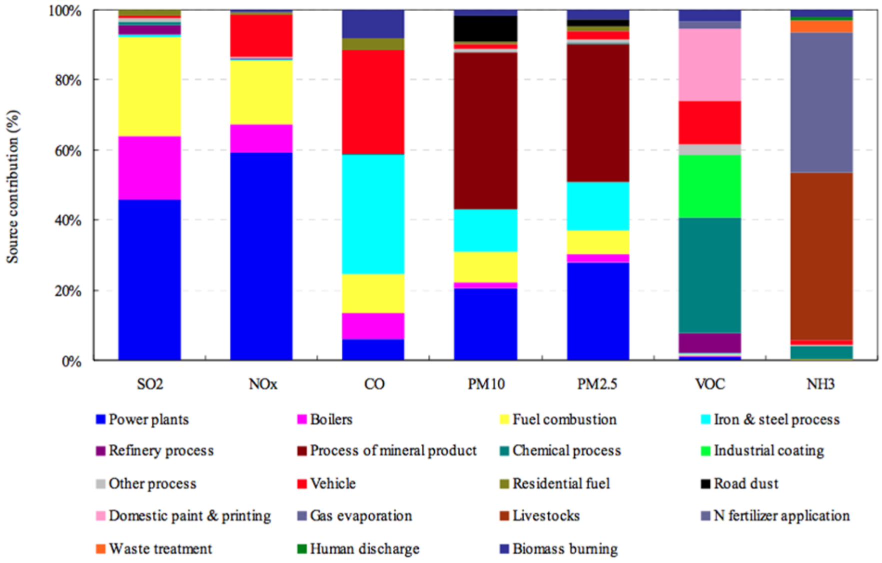


Graph 5. National inventory of different air pollutants in 2010

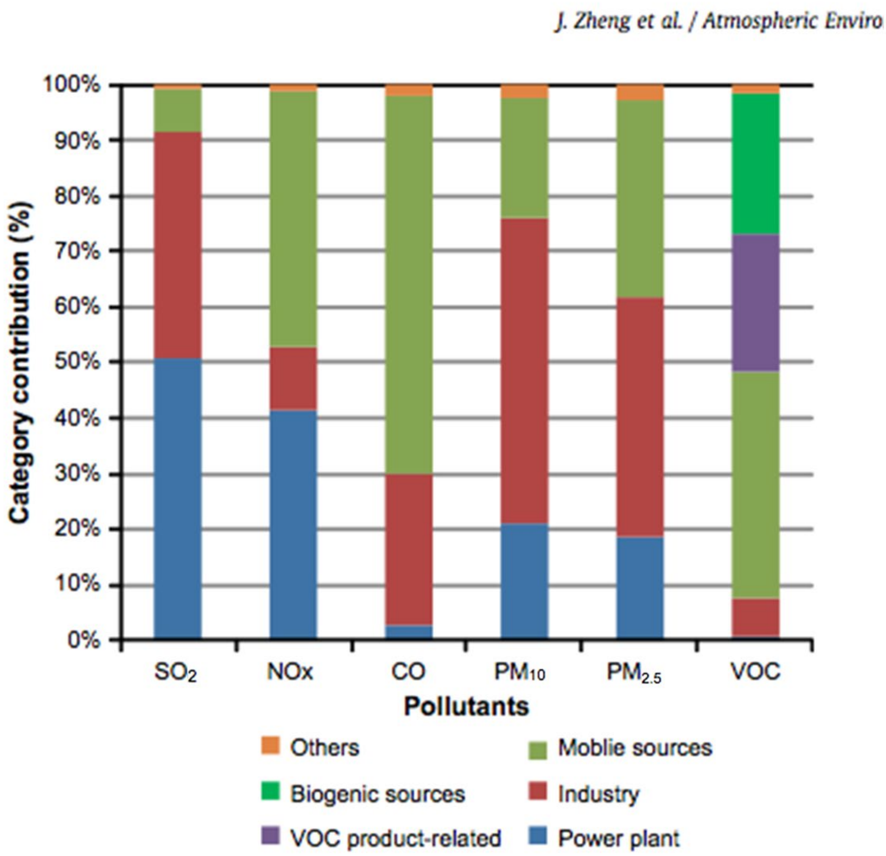
[1] Zhao, Y., Zhang, J., and Nielsen, C. P.: The effects of recent control policies on trends in emissions of anthropogenic atmospheric pollutants and CO2 iin China, Atmos. Chem. Phys. Discuss., 12, 24985-25036, doi:10.5194/acpd-12-24985-2012, 2012

[2] C . Huang et al : Emission inventory of anthropogenic air pollutants and VOC species in the Yangtze River Delta region, China , Atmos. Chem. Phys., 11, 4105–4120, 2011

[3] Junyu.Zheng et al:A highly resolved temporal and spatial air pollutant emission inventory for the Pearl River Delta region, China and its uncertainty assessment, Atmospheric Environment 43 (2009) 5112–5122



Graph 6. Yangtze River Delta inventory of different air pollutants in 2007

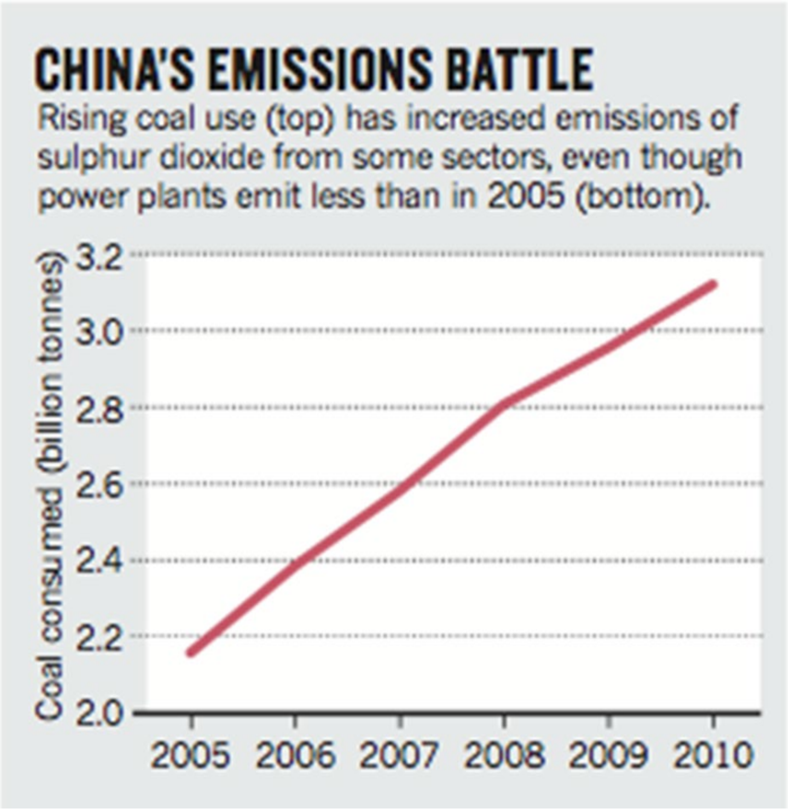


Graph 7. Pearl River Delta inventory of different air pollutants in 2006

4.3 Growing energy consumption is the main reason for worsening air pollution

A number of studies have shown that worsening urban air pollution and deteriorating regional air quality is closely related to China's over-reliance on coal consumption. Managing $PM_{2.5}$ pollution must begin with replacing urban coal consumption with clean alternative energy sources, control of regional total coal consumption, as well as control and treatment of pollutants from coal combustion.

China has been making unremitting efforts to do end of pipe air pollution control while developing its economy. However, in spite of such efforts, environmental pressures brought about by drastically increased energy consumption are still looming large. For example, during the 11th Five-Year Plan period, China's coal consumption increased by 44% (graph 8), accounting for one quarter of the world's total coal consumption in 2010 . Although desulfurization efforts in the power sector have allowed China to meet its sulfur dioxide emission reduction targets, it still failed to implement de-nitrification plans, which resulted in a 20% increase of nitrogen oxide emission during the 11th Five-Year Plan. This means the only way China's total nitrogen oxide emissions can return to its 2005 level by 2020 is if the country meets its 10% emission cut targets for both the 12th and 13th Five-Year Plan periods. Which would mean the timeline to control NOx has been postponed by 15 years.



Graph 8. Energy consumption during 11th Five-Year Plan

5 Our policy suggestions

To effectively combat $PM_{2.5}$ pollution, to meet China's new air quality standards, and to protect China's public health from experiencing further negative impacts due to $PM_{2.5}$ pollution, we are making the following policy recommendations:

1 Cap regional coal consumption

To cope with severe air pollution, it would not be enough to simply do end of pipe pollution control. If rapid coal consumption increases cannot be curbed, gains made by the effort to control end of pipe pollutants such as sulfur dioxide and nitrogen oxides emissions during the 12th Five-Year Plan will probably be offset. As China's coal consumption continues to grow, other pollutants of coal combustion will exacerbate air pollution and interfere with $PM_{2.5}$ improvements in the long-term.

At present, leading cities like Beijing and Guangzhou have already announced their coal consumption reduction target during the 12th Five-Year Plan. The coal consumption growth cap has been introduced to Tianjin, Shanghai and some Yangtze River Delta region cities (such as Wuxi, Changzhou and Ningbo). However, the severe regional pollution diffusion cannot be tackled as fragmented cities. Therefore a control of coal consumption in the region as a whole is urgently needed particularly in areas already heavily polluted by $PM_{2.5}$. Here regional zero coal consumption growth targets are required, or even coal consumption reduction targets developed in cities and regions with good facilities.

2 De-NOx retrofit for existing coal-fired power plants

During the 11th Five-Year Plan period, China's increased its power generation capacity by 80%, accompanied by a radical surge in nitrogen oxides emissions, one of the major sources of $PM_{2.5}$. In September 2011 the state released thermal power industry pollution emission standards (GB3096-2012) that require all existing power plants to meet tighter pollutant emissions limits by 2014. Although almost half of this transitional period has already passed only a small portion of the existing power plants have actually carried out the De-NOx retrofit. The De-NOx subsidizing scheme related to existing power plants should be announced as soon as possible, together with a binding target for reduction of NOx emissions, as applied to the big power companies.

3 Shutdown inefficient coal-fired industrial boilers

At present the coal consumption of coal-fired industrial boilers still accounts for more than half of China's total coal consumption. They burn coal less efficiently and have more dirty emissions than the power sector. We suggest the immediate promotion of De-SOx and De-NOx schemes for coal-fired industrial boilers, or that they should be replaced with clean-energy industrial boilers in developed areas.

4 Improving environmental policies

China's current charges for atmospheric pollutants are far lower than the operational costs of end of pipe pollution control. This has, to some extent, discouraged many enterprises from making changes, and made it hard to clearly define legal and illegal pollutant discharging. A hike in pollution discharging charges and strengthened supervision efforts could help make illegal discharges unaffordable. Also recommended is an improvement of environmental policies, bringing total pollutants and their transactions under better control, and encouraging enterprises to cut pollution.

On December 5, 2012 the MEP officially announced their 12th Five-Year Plan for prevention and control of atmospheric pollution in major regions (hereby referred to as 'the plan'). The plan requires 47 cities (14% of China's land area) to accomplish the $PM_{2.5}$ target with a drop of 5% before 2015. And for those cities that are unable to meet national air pollution standards, a specific air quality improvement plan to achieve the standard should be drawn up. The plan also includes active content such as De-NOx retrofits for coal-fired power plants and reconstruction for coal-fired industrial boilers as we suggested earlier.

The target of 5% is set based on estimations that coal consumption and vehicle consumption will increase by 30% and 50% respectively in the major regions during the 12th Five-Year Plan period. If we take this dramatic increase into consideration, it is obvious that even with the most restrictive pollution emission standards (terminal pollutant control technology), the best outcome for air pollution improvement that China can expect in 2015 is 5%. The reality is that most Chinese cities have exceeded the new standard, with huge public health loss. And with this increase in the consumption speed of coal and vehicles, big challenges lie in the way of China's path to a clearer sky. Capping the coal consumption in these major regions is a crucial step, and definitive action must be taken.

We hope that local governments in key regions will go beyond the plan, and take ambitious steps to set up specific air quality improvement planning, including detailed $PM_{2.5}$ pollution improvement timelines. And while drafting regulations, both information disclosure and public participation should be encouraged.

Advanced regional areas like Jing-Jin-Ji, Yangtze River Delta, and Pearl River Delta should take the lead and announce a regional coal consumption cap. Local environmental protection bureaus and health departments should promote public health education of air pollution issues, as well as remind the public to take proper health protection against air pollution. Meanwhile local governments should actively advocate eco-friendly lifestyles, and welcome public participation in improving urban air quality.

Appendix

Table 1. A demographic and economic overview of the four cities, 2010

City	Population(10 thousand)	Area(km2)	GDP(billion RMB)
Beijing	1961	16410.54	14113.58a
Xi'an	847	10108	3241.69b
Guangzhou	1107	7434.4	10748.28c
Shanghai	2303	6340.5	17165.98d

a:2011 Beijing Statistical Yearbook; b:2011 Shaanxi Statistical Yearbook; c:2011 Guangzhou Statistical Yearbook;
d:2011 Shanghai Statistical Yearbook;

Table 2. Estimated deaths and economic loss caused by $PM_{2.5}$ pollution in Beijing, 2010

Types of diseases	Number of deaths	Economic loss (10 thousand RMB)
Heart diseases	755(229,1265)	60057
Cerebrovascular diseases	685(208,1147)	54439
Total deaths	2349(862,3802)	186754

Table 3. Estimated deaths and economic loss caused by $PM_{2.5}$ pollution in Shanghai, 2010

Types of diseases	Number of deaths	Economic Loss (10 thousand RMB)	Total	
			Deaths	Economic loss (10 thousand RMB)
Circulatory system diseases	1195(30,2344)	94964(2360,186376)	2980(921,4992)	236924(73247,396831)
Respiratory diseases	826(144,1423)	65676(11472,115513)		
Total deaths	2980(921,4992)	236924(73247,396831)		

Table 4. Estimated deaths and economic loss caused by $PM_{2.5}$ pollution in Guangzhou, 2010

Types of diseases	Number of deaths	Economic loss (10 thousand RMB)
Circulatory system diseases	1145(304,1933)	91040
Respiratory diseases	310(48,556)	24613
Total deaths	1715(683,59183)	136332

Table 5. Estimated deaths and economic loss caused by $PM_{2.5}$ pollution in Xi'an, 2010

Types of diseases	Number of deaths	Economic loss (10 thousand RMB)
Cardiovascular and cerebrovascular diseases	436(131,733)	34692
Total deaths	726(257,1186)	57724

Table 6. An estimation of deaths and economic loss caused by $PM_{2.5}$ pollution in Beijing, 2012

Scenarios	Types of diseases	Number of deaths	Economic Loss (10 thousand RMB)	Deaths
Scenario 1	Heart diseases	114.72(34.83,192.12)	9120.20(2769.26,15273.53)	356.73 (130.92 ,577.31)
	Cerebrovascular diseases	103.99(31.58,174.15)	8267.12 (2510.23,13844.89)	
	Total deaths	356.73 (130.92,577.31)	28360.39(10408.49,45896.20)	
Scenario 2	Heart diseases	172.08(52.25,1106.61)	13680.29 (4153.89,22910.29)	535.10 (196.39,3325.31)
	Cerebrovascular diseases	155.98 (47.36,1003.10)	12400.68(3765.34,79746.57)	
	Total deaths	535.10 (196.39,3325.31)	42540.58 (15612.74,264362.12)	
Scenario 3	Heart diseases	401.52(121.92,672.42)	31920.69(9692.40,53457.35)	1248.57 (458.24,2020.59)
	Cerebrovascular diseases	363.96 (110.51,609.52)	28934.92 (8785.80,48457.12)	
	Total deaths	1248.57(458.24,2020.59)	99261.35 (36429.73,160636.70)	
Scenario 4	Heart diseases	832.86 (252.89,1394.79)	66212.62 (20104.81,110885.82)	2589.89 (950.51,4191.28)
	Cerebrovascular diseases	754.96(229.24,1264.33)	60019.30(18224.27,100513.90)	
	Total deaths	2589.89 (950.51,4191.28)	205896.41(75565.67,333206.42)	

Based on average population growth rate of 5.0% between 2006 and 2010, and unchanged population structure and adaptability.

Table 7. An estimation of deaths and economic loss caused by $PM_{2.5}$ pollution in Shanghai, 2012

Scenarios	Types of diseases	Number of deaths	Economic Loss (10 thousand RMB)	Deaths
Scenario 1	Circulatory system diseases	280.49 (6.97,550.49)	22299.09(554.19,43763.88)	699.79(216.35,1172.10)
	Respiratory diseases	193.98 (33.89,341.18)	15421.73(2693.87,27124.16)	
	Total deaths	699.79 (216.35,1172.10)	55633.41(17199.49,93182.05)	
Scenario 2	Circulatory system diseases	420.74(10.46,825.73)	33448.63(831.28,65645.82)	1049.69(324.52,1758.15)
	Respiratory diseases	290.98(50.83,511.78)	23132.6(4040.81,40686.24)	
	Total deaths	1049.69(324.52,1758.15)	83450.12(25799.24,139773.1)	
Scenario 3	Circulatory system diseases	981.72(24.40,1926.71)	78046.8(1939.66,153173.6)	2449.27(757.21,4102.35)
	Respiratory diseases	678.94(118.60,1194.15)	53976.06(9428.55,94934.56)	
	Total deaths	2449.27(757.21,4102.35)	194717(60198.23,326137.2)	
Scenario 4	Circulatory system diseases	1329.53(33.04,2609.32)	105697.7(2626.848,207440.8)	3317.01(102548,5555.76)
	Respiratory diseases	919.48(160.62,1617.21)	73099(12768.95,128568.5)	
	Total deaths	3317.01(1025.48,5555.76)	263702.4(81525.6,441682.9)	

Table 8. An estimation of deaths and economic loss caused by $PM_{2.5}$ pollution in Guangzhou, 2012

Scenarios	Types of diseases	Number of deaths	Economic Loss (10 thousand RMB)	Deaths
Scenario 1	Circulatory system diseases	306.36(81.41,517.11)	24355.41(6472.096,41110.57)	458.77(182.78,15832.92)
	Respiratory diseases	82.82(12.76,148.81)	6584.487(1014.302,11830.36)	
	Total deaths	458.77(182.78,15832.92)	36471.94(14531,1258717)	
Scenario 2	Circulatory system diseases	459.54(122.12,775.67)	36533.11(9708.14,61665.85)	688.15(274.17,23749.38)
	Respiratory diseases	124.24(19.14,223.21)	9876.73(1521.45,17745.54)	
	Total deaths	688.15(274.17,23749.38)	54707.91(21796.5,1888076)	
Scenario 3	Circulatory system diseases	1072.25(284.94,1809.90)	85243.93(22652.34,143887)	1605.68(639.73,55415.23)
	Respiratory diseases	289.88(44.65,520.83)	23045.71(3550.058,41406.26)	
	Total deaths	1605.68(639.73,55415.23)	127651.8(50858.49,4405511)	
Scenario 4	Circulatory system diseases	1286.70(341.92,2171.88)	102292.7(27182.8,172664.4)	1926.82(767.68,66498.27)
	Respiratory diseases	347.86(53.59,625.00)	27654.85(4260.069,49687.51)	
	Total deaths	1926.82(767.67,66498.27)	153182.2(61030.19,5286613)	

Based on average population growth rate of 6.0% between 2006 and 2010, and unchanged population structure and adaptability

Table 9. An estimation of deaths and economic loss caused by $PM_{2.5}$ pollution in Xi'an, 2012

Scenarios	Types of diseases	Number of deaths	Economic Loss (10 thousand RMB)	Deaths
Scenario1	Cardiovascular and cerebrovascular diseases	56.96(17.13,95.65)	4528.162(1361.44,7604.28)	94.77(33.50,154.83)
	Total deaths	94.77(33.50,154.83)	7534.33(2663.61,12308.75)	
Scenario2	Cardiovascular and cerebrovascular diseases	85.44(25.69,143.48)	6792.24(2042.16,11406.41)	142.16(50.26,232.24)
	Total deaths	142.16(50.26,232.24)	11301.49(3995.41,18463.12)	
Scenario3	Cardiovascular and cerebrovascular diseases	199.35(59.94,334.78)	15848.57(4765.03,26614.96)	331.70(117.27,541.89)
	Total deaths	331.70(117.27	26370.14(9322.62,43080.61)	
Scenario4	Cardiovascular and cerebrovascular diseases	444.27(133.58,746.08)	35319.66(10619.22,59313.34)	739.22(261.34,1207.65)
	Total deaths	739.22(261.33,1207.65)	58767.75(20776.15,96008.21)	

Based on average population growth rate of 0.9% between 2006 and 2010, and unchanged population structure and adaptability

Table 10 Different $PM_{2.5}$ concentration scenario definition and reference(μg/m³)

Scenario	$PM_{2.5}$annual concentration	Reference
S1	10	WHO AQG
S2	15	Level 1 of China national air quality standard
S3	35	Level 2 of China national air quality standard
S4	Aa	The concentration remain the same

a: $PM_{2.5}$ concentration level remains the same with 2010

100% Recycled Paper

GREENPEACE 绿色和平

3F, Julong Office Building, Block 7, Julong Garden,
68 Xinzhong Street, Dongcheng, Beijing 100027

Tel：86(10) 65546931
Fax : 86(10) 65546932
www.greenpeace.cn