中国疾病预防控制中心
CHINESE CENTER FOR DISEASE CONTROL AND PREVENTION

Clean Air Policies and Related Health Benefits in China

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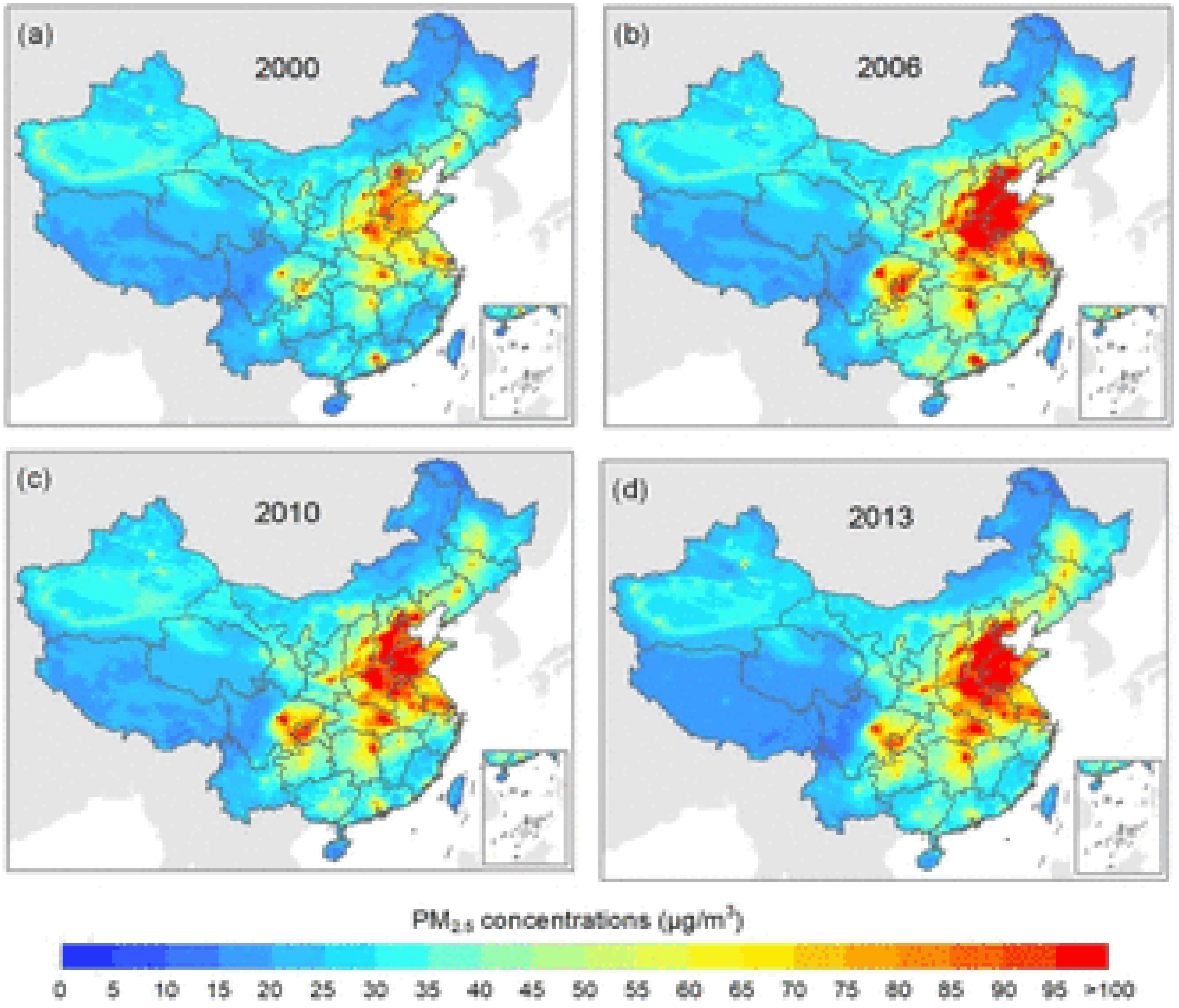
Outlines

1. Clean Air Policies in China
2. Overview of Health Benefits Studies in China
3. Accountability Study in Beijing-Tianjin-Hebei Region
4. Prospects

Clean Air Policies in China

Long-term trend of air pollution in China

The population-weighted $PM_{2.5}$ concentration increased from 36.0μg/m^3 in 1990 to 63.5μg/m^3 in 2005, to 49.9μg/m^3 in 2015.

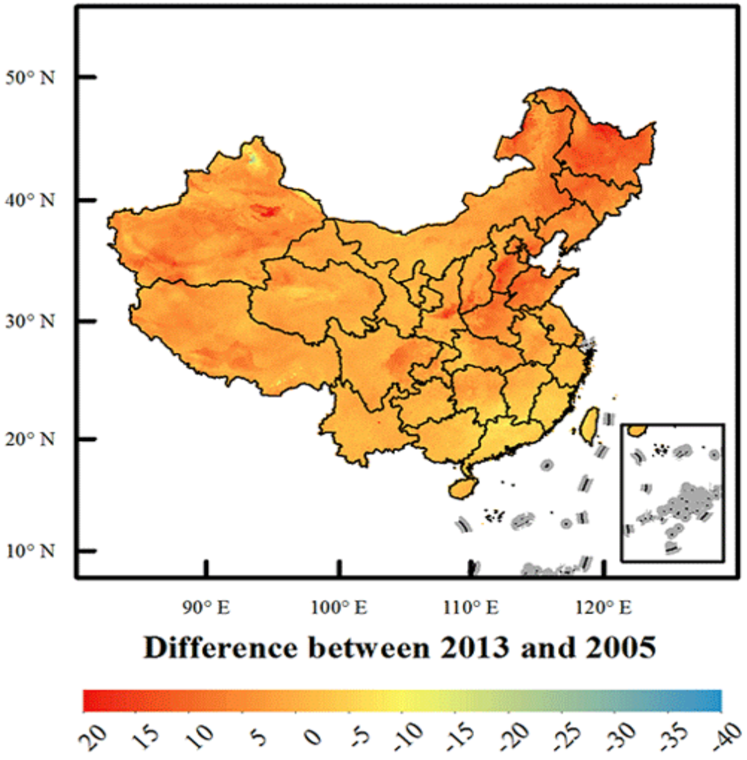


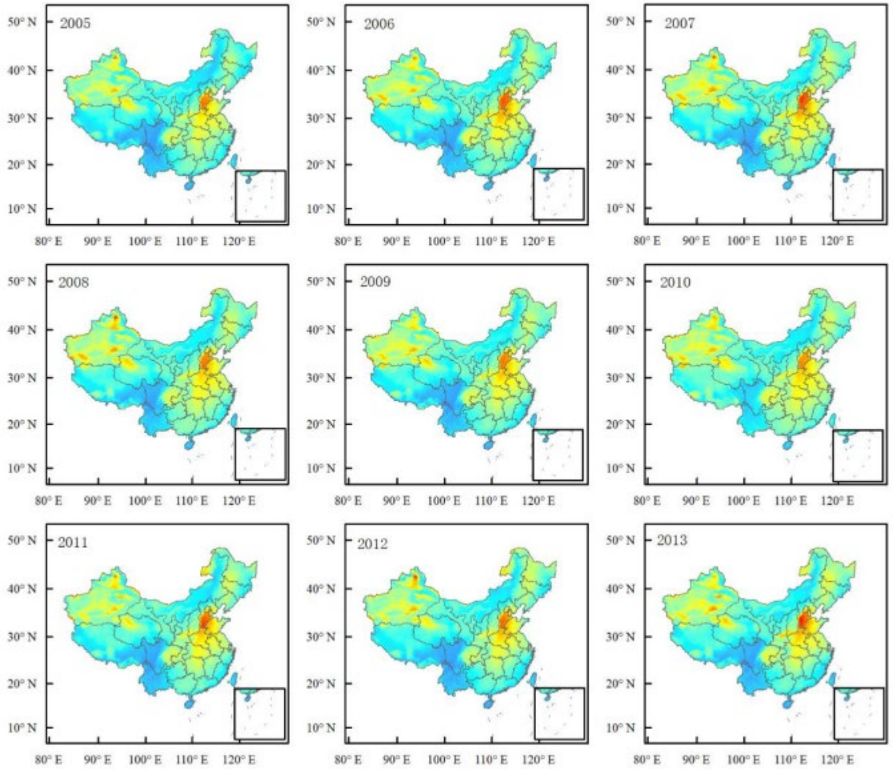
Trend of annual $PM_{2.5}$ concentration during 2000-2013

(Liu et al., *Atmos. Chem. Phys.*, 2020)

Long-term trend of air pollution in China

Annual mean $PM_{2.5}$ concentration in China, 2005-2013



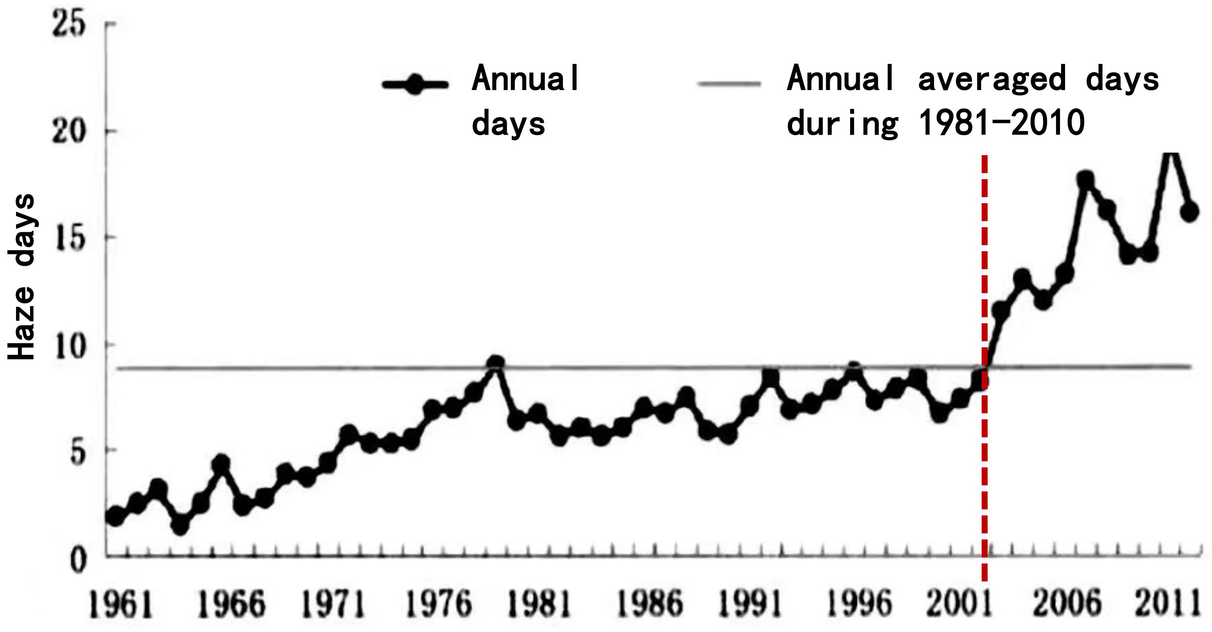


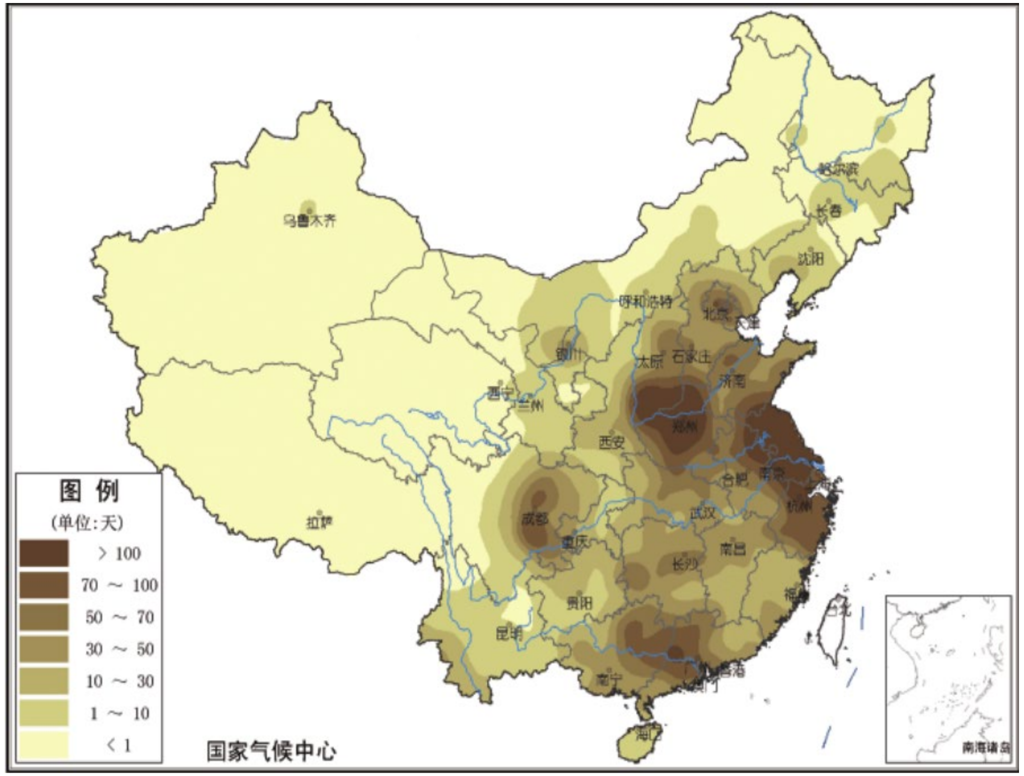
Relative to 2005,

- **$PM_{2.5}$ concentration increased by 2.60 μg/m³ in 2013 averaged across China**
- **$PM_{2.5}$ concentration increased by 8.75 and 1.07 μg/m³ in BTH and YRD in 2013, respectively**

(Ma et al. *ESSD*, 2022)

Heavy-polluted weather appealed nation-wide attention





Distribution of Haze Days in 2013

Summary of China Air Pollution Control Actions since 2013

Implementation period (2013–2020)		Targeted precursor					Sector				
Action	Years	PM	SO_2	NO_x	VOC	NH_3	PP	IN	TR	DO	AR
→12th FYP	2013–2015	√	√	√			√	√	√		
→Air Pollution Prevention and Control Action Plan	2013–2017	√	√	√	√		√	√	√		
→Enhancing air pollution control in the energy industry	2014–2017	√	√	√	√		√	√	√	√	
→Action Plan for Retrofitting and Upgrading of Coal-Fired Power Plants	2014–2020	√	√	√	√		√				
→Industrial Green Development Plan	2015–2020		√	√	√			√			
→The Plans for the Protection of the Ecological Environment in Beijing–Tianjin–Hebei Coordinated Development	2015–2020	√	√	√	√		√	√	√	√	
→Action Plan on VOC Reduction in Key Industries	2016–2020				√			√			
→Comprehensive Work Plan for Energy Conservation and Emission Reduction	2017–2020		√	√	√		√	√	√	√	
→Three-Year Action Plan	2018–2020	√	√	√	√	√	√	√	√	√	√

PP: power plants;
IN: industry;
TR: transport;
DO: domestic sector;
AR: agriculture.

Nationwide | Key regions (e.g., BTH, YRD) | Nationwide with more efforts in key regions

The policy framework shows a trend of gradually involving more $PM_{2.5}$ precursors and emission sectors.

(Lu, et al. 2020)

Air Pollution Prevention and Control Action Plan: 2013–2017

ENGLISH.GOV.CN
THE STATE COUNCIL
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Launched by Sep 10th, 2013
10 main measures

1. Increase effort of control and reduce emission of multi-pollutants
2. Optimize the industrial structure, promote industrial restructure
3. Accelerate the technology transformation, improve the innovation capability
4. Adjust the energy structure and increase the clean energy supply
5. Strengthen environmental thresholds and optimize industrial layout
6. Better play the role of market mechanism and improve environmental economic policies
7. Improve law and regulation system, carry on law-based supervision and management
8. Establish the regional coordination mechanism and the integrated environmental management
9. Establish monitoring and warning system, cope with heavy pollution weather
10. Clarify the responsibilities of the government, enterprise and society.

➢ **Overall goal:**

- the overall national air quality shall be improved;
- heavily polluted days shall be reduced dramatically;
- regional air quality in Beijing-Tianjin-Hebei, Yangtze River delta and Pearl River delta will be turned better.

➢ **Specific goals:**

- By 2017, the urban PM_{10} concentration shall decrease by **10%** compared with 2012;
- Annual number of days with fairly good air quality will gradually increase;
- Concentration of $PM_{2.5}$ shall fall by:
  25% in Beijing-Tianjin-Hebei,
  20% in Yangtze River Delta,
  15% in Pearl River Delta
- Fine particulate matter annual concentration in Beijing shall be controlled below **60**$\mu g/m^3$

Three-Year Action Plan for Winning the Blue Sky Defense Battle: 2018

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THE PEOPLE'S REPUBLIC OF CHINA

Launched by July 3rd, 2018
6 main measures

1. Adjust and optimize the industrial structure and promote the green industrial development.
2. Accelerate the adjustment of the energy mix and establish a clean, low-carbon, and efficient energy framework.
3. Adjust the transportation structure and develop green transport system.
4. Optimize and adjust the land use structure and press ahead with the control of pollution from non-point sources.
5. Launch major campaigns to substantially reduce pollutants.
6. Strengthen regional cooperation on control of heavy air pollution.

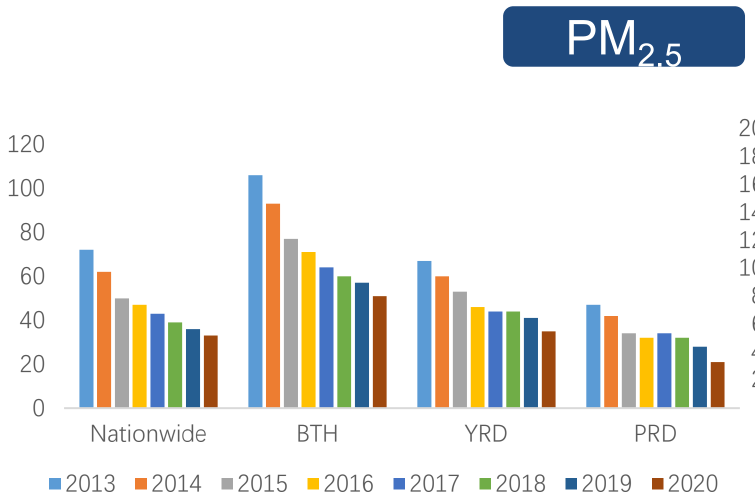
➢ **Overall goal:**

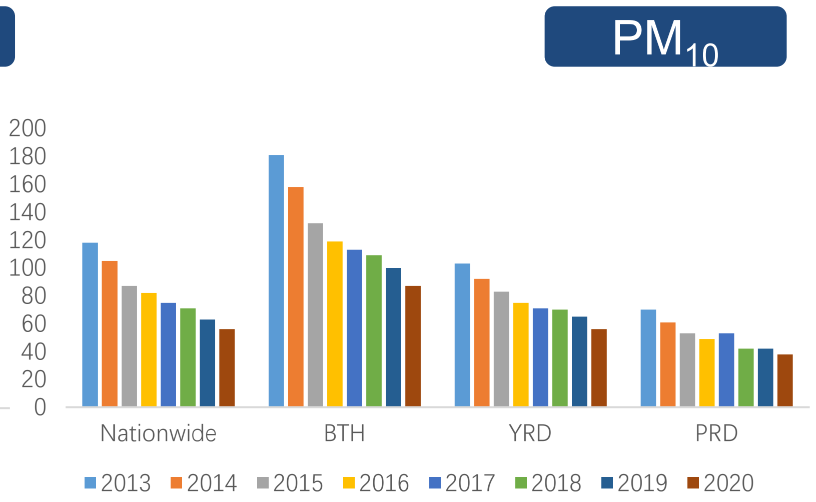
- the total load of main air pollutants will have been significantly reduced, along with less greenhouse gas emissions
- the concentration of $PM_{2.5}$ will be notably lowered down
- remarkably improved air quality, and much greater sense of happiness for the people from the sight of blue skies.

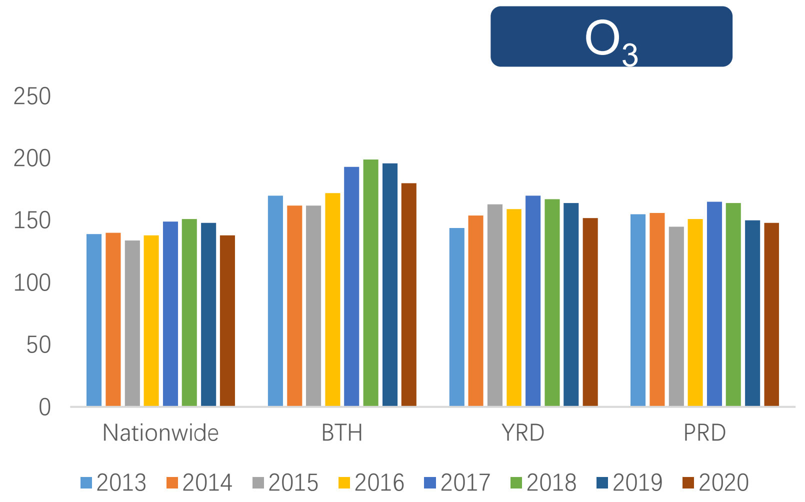
➢ **Specific goals:**

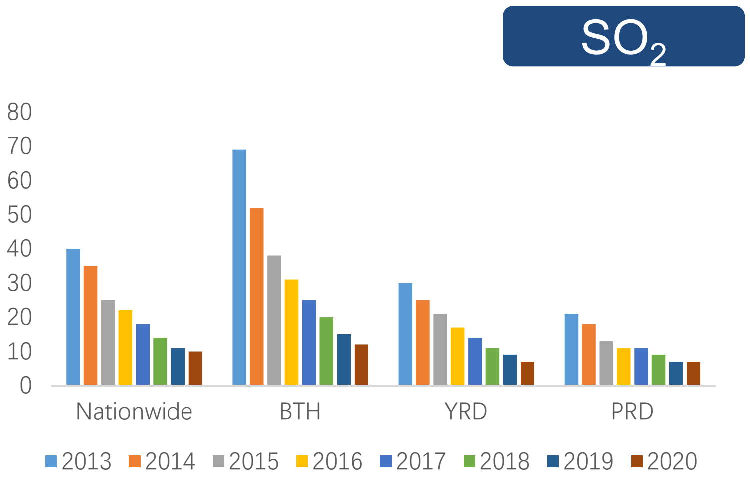
- The total emission of SO_2 and NO_2decreased by more than **15%**
- The $PM_{2.5}$ in nonattainment cities at or above the prefectural level will have been down over **18%**
- The cities at or above prefectural level will have recorded clean or fairly clean air during **80%** of the days across the year
- The number of the days with heavy or severe pollution will have dropped over **25%**

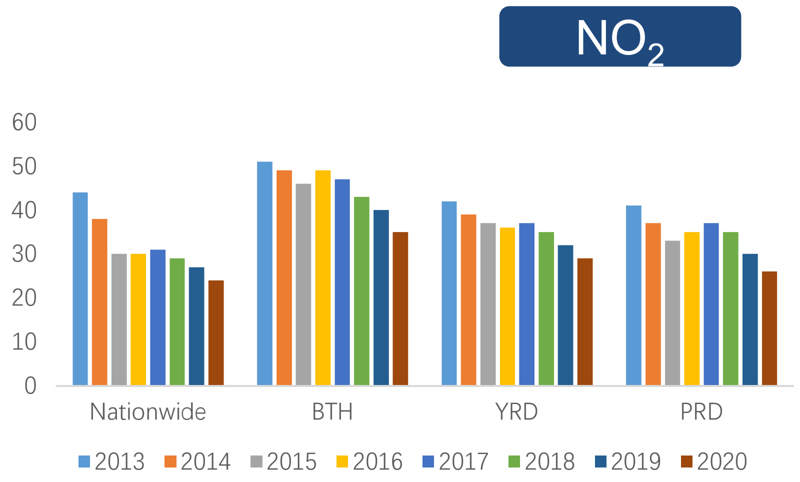
Air Quality Improvement: 2013–2020

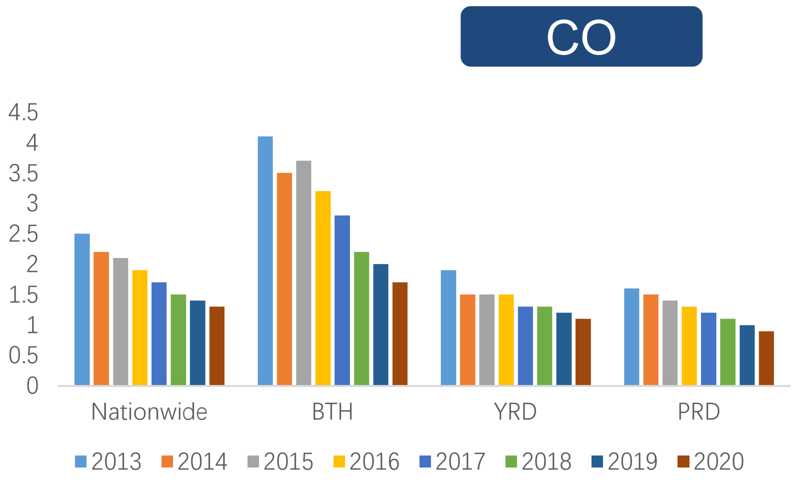












Bulletin of the State of the Ecological Environment. 2015-2020. Bulletin of Guangdong Province's Ecological Environment.2018-2020

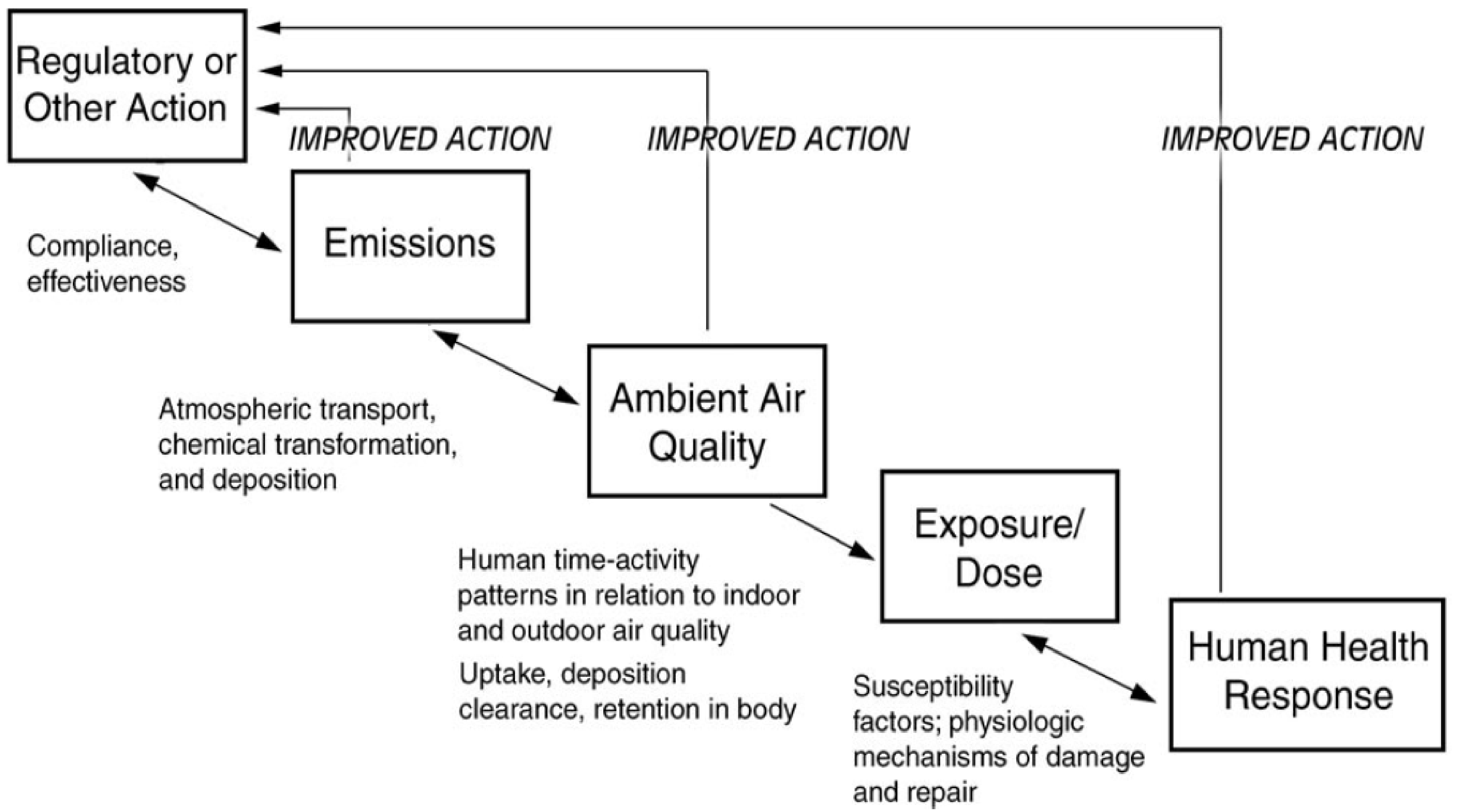
Questions

Could the rapid air quality improvement driven by the clean air actions in China bring any beneficial effects on population health?

Overview of Health Benefits Studies in China

Accountability Study: Concepts and Methods

- **HEI proposed the concepts and methods for Accountability Research to assess health impact of air quality regulations**



Chain of accountability

(HEI Accountability Working Group, 2003; Baker, et al., 2008)

Accountability Study in China:

health risk assessment based method

Rapid improvement of the $PM_{2.5}$ concentration and decline in premature death

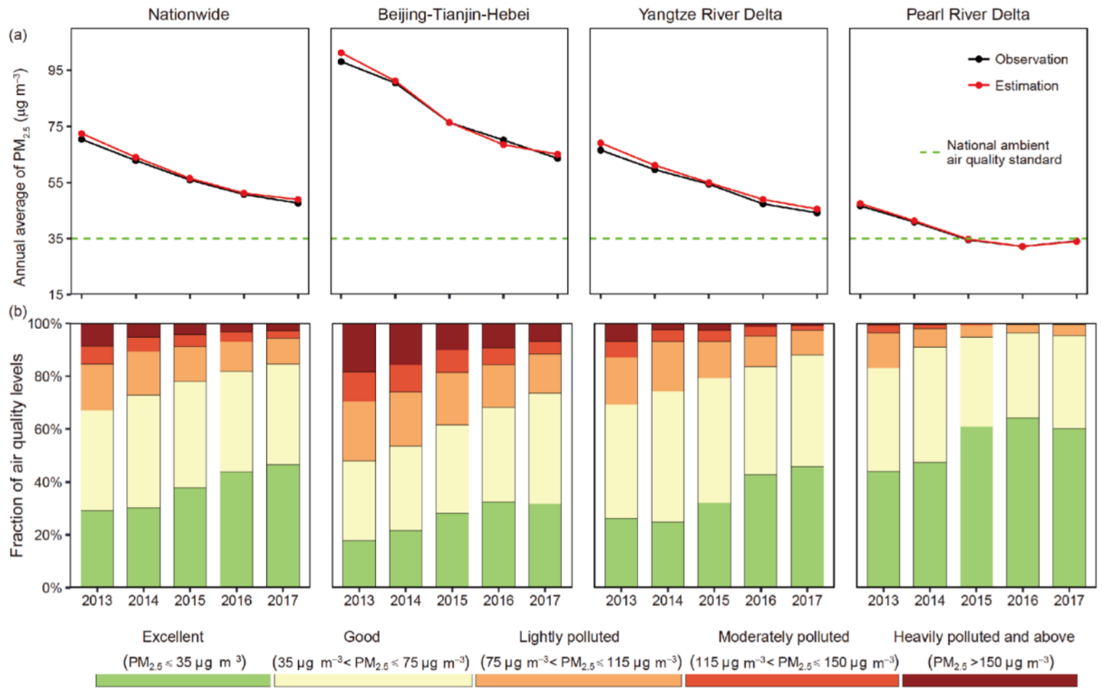
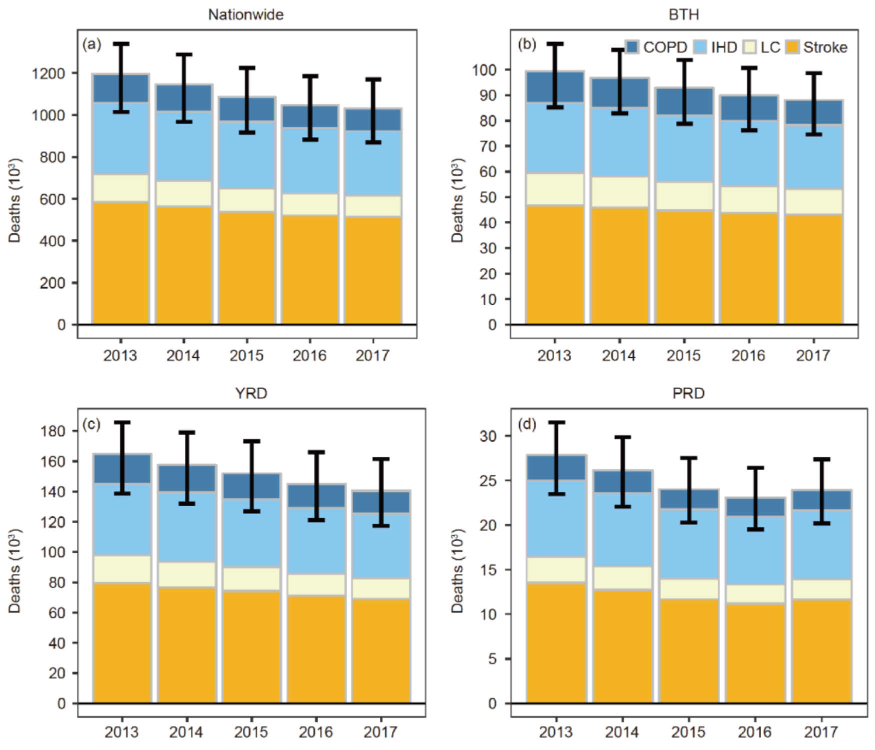


Figure 1 National and regional annual mean fine particulate matter ($PM_{2.5}$) concentrations (a) and daily pollution levels (b) during 2013–2017.



- The national annual population-weighted $PM_{2.5}$ concentrations decreased from 67.4 μg/m^3 in 2013 to 45.5 μg/m^3 in 2017, with a linearly reducing trend of 4.4 μg/m^3 /year.
- In comparison, premature deaths in 2017 were reduced by 14% (95% CI: 11%, 16%) due to reductions in long-term exposure to $PM_{2.5}$

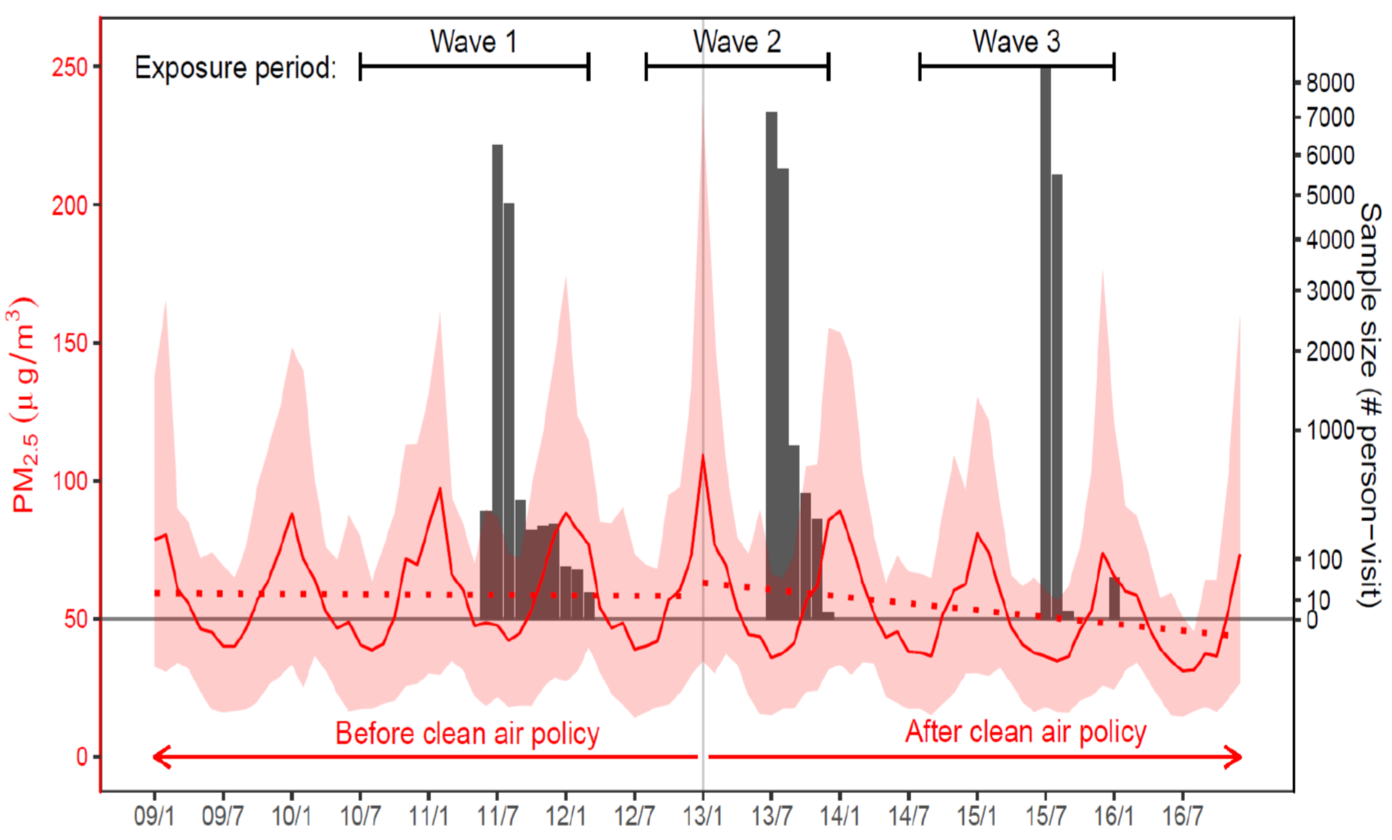
Xue, et al. Science China Earth Sciences, 2019.

Accountability Study in China:

epidemiological study based method

Clean Air Action and Multi-dimension Health Benefits Based on CHARLS in China

- **Study period：** 2011-2015
- **Study population：** The China Health and Retirement Longitudinal Study (CHARLS)
- **Health outcomes:** sub-clinical symptoms, including *lung functions*, *depressive symptoms and etc.*
- **Exposure：** $PM_{2.5}$ concentration (0.1° grid)
- **Method:** DID, mixed-effect models



Survey samples of CHARLS and $PM_{2.5}$ level during the clean air policy

$PM_{2.5}$ Reduction has improved Lung Function in Adults

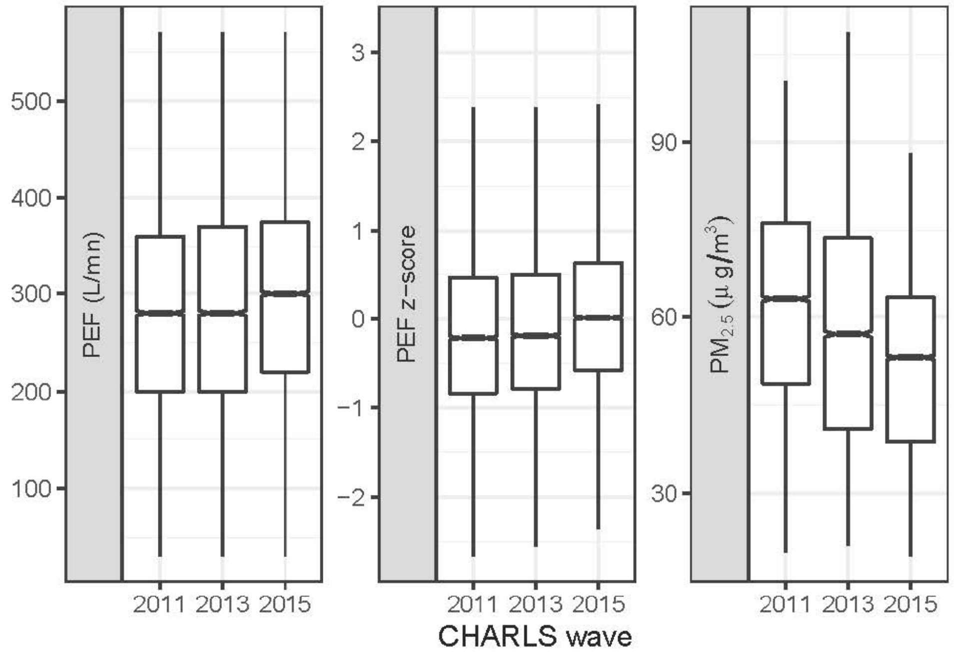


Table 3. Estimated associations between $PM_{2.5}$ and PEF.

Outcome	Adjusted covariates*	Inclusion criteria#	Change (95% confidence intervals) per 10 μg/m³ reduction in $PM_{2.5}$	Subjects	Visits
PEF	Age only‡	All longitudinal samples	15.84 (14.18, 17.50)	13959	35055
	Set 1		15.74 (14.02, 17.45)		
	Set 2		14.41 (12.65, 16.17)		
	Set 1	Subset 1	15.54 (13.46, 17.62)	7137	21411
		Subset 2	14.05(12.33, 15.78)	13339	33168
		Subset 3	14.43(12.74, 16.12)	13147	32670
z-score	Age only‡	All longitudinal samples	0.13 (0.12, 0.14)	13959	35055
	Set 1		0.13 (0.11, 0.14)		
	Set 2		0.12 (0.10, 0.13)		

*Set 1: Ambient temperature, age, urban/rural residence, education, marriage, smoking and drinking. Set 2: Set 1 + indoor temperature maintenance, cooking energy type, building type, rent payment, household tidiness, and in-house telephone.

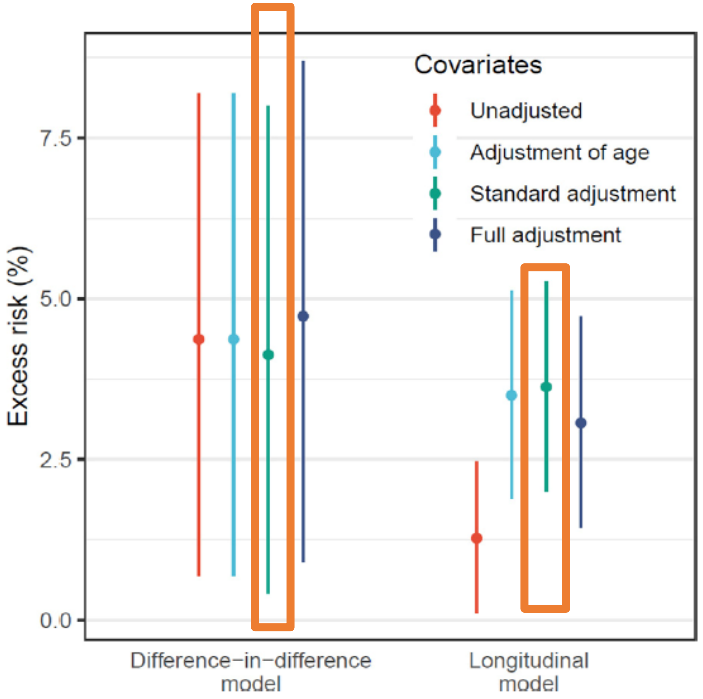
Subset 1: Subjects participated in all three waves of CHARLS. Subset 2: subjects who attended at least two waves and had a PEF measurement of high quality. From all PEF records, we excluded measurements if the participants (1) did not apply full effort to the test; (2) sat or lay down during the test; (3) were unable to complete the test due to health issues; or (4) tried but failed to complete the test. Subset 3: excluding truncated measurements (values = 30 or 890 L/min) from subset 2.

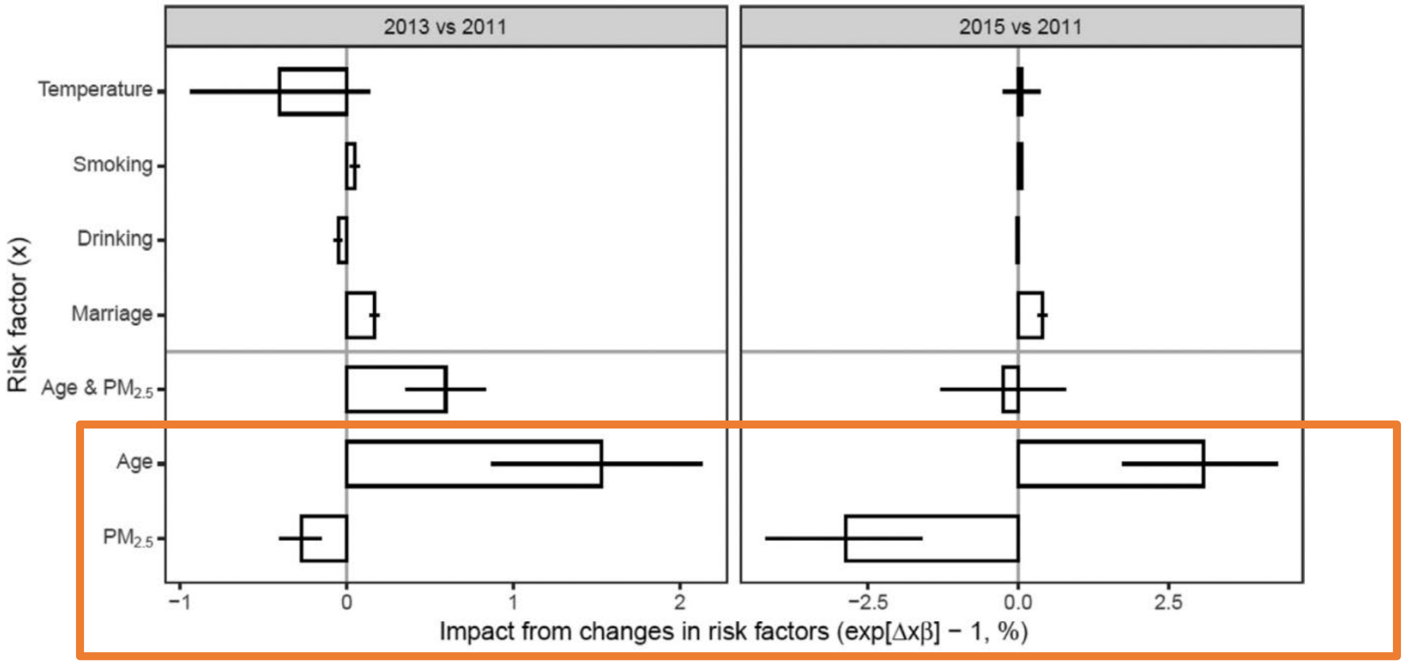
‡ The effects of age were controlled for using the spline (for PEF) or z-score approach.

- Based on mixed-effect model, Compared with the reference in 2011, after the policy was implemented, the mean PEF was elevated by 9.19 (6.79–11.59) L/min and 36.64 (33.53–39.75) L/min in 2013 and 2015, respectively.
- According to the regression results, each 10-μg/m³ reduction of $PM_{2.5}$ was associated with a 14.95 (12.62–17.28) L/min improvement of PEF.

Xue, et al. Annals of the American Thoracic Society. 2020.

Clean Air Action has improved depressive symptoms





- ❑ Based on DID model, a 10-μg/m^3 reduction of $PM_{2.5}$ concentration was associated with a 4.14% (95% CI: 0.41–8.00%) decrement in the depressive score.
- ❑ Improved air quality during 2011–2015 offset the negative impact from 5-years' aging.

Xue, et al. The Lancet Regional Health - Western Pacific , 2021.

Study limitations

- Study design:

Spatial controls are rarely involved.

- Outcome:

Lack of studies focusing on mortality as a health outcome.

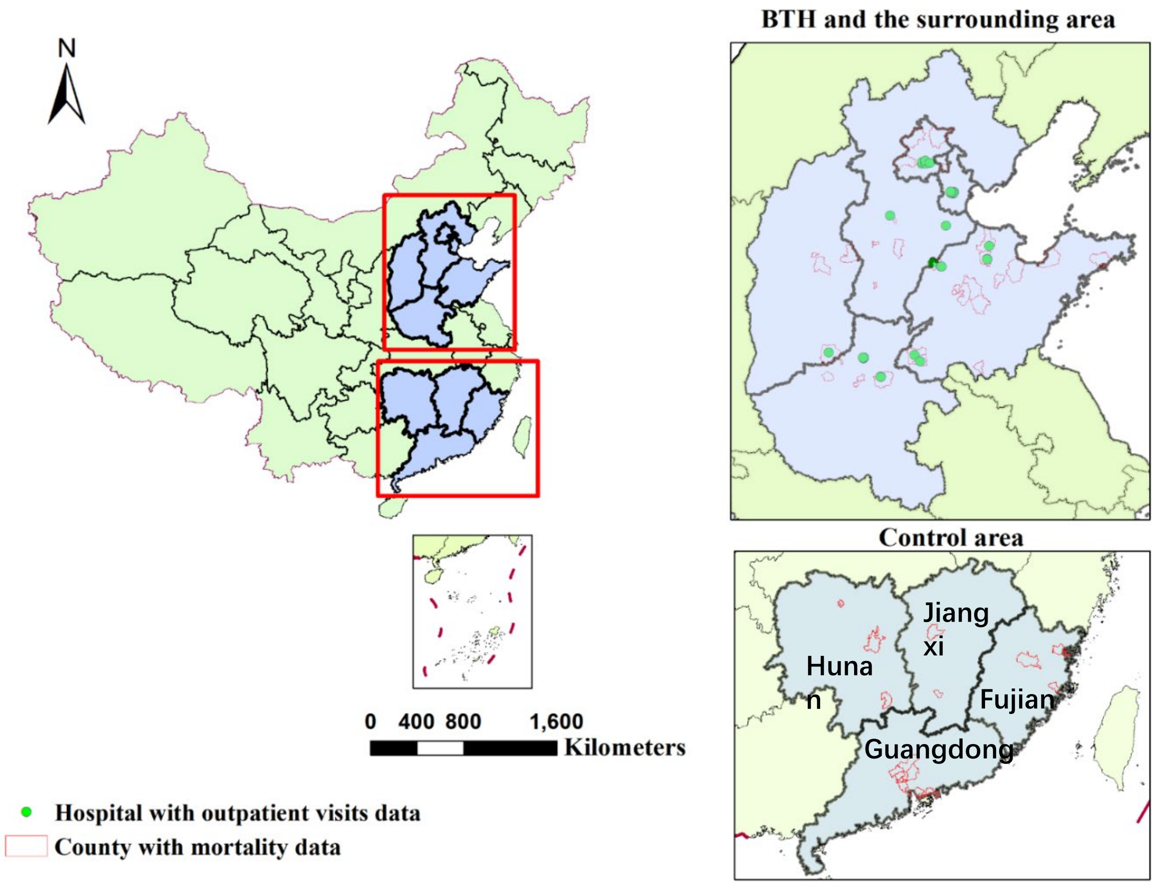
- Study results:

Contributors for the decline in air pollution related effects could not be fully explained.

Accountability Study in Beijing-Tianjin-Hebei Region(BTH)

Study design

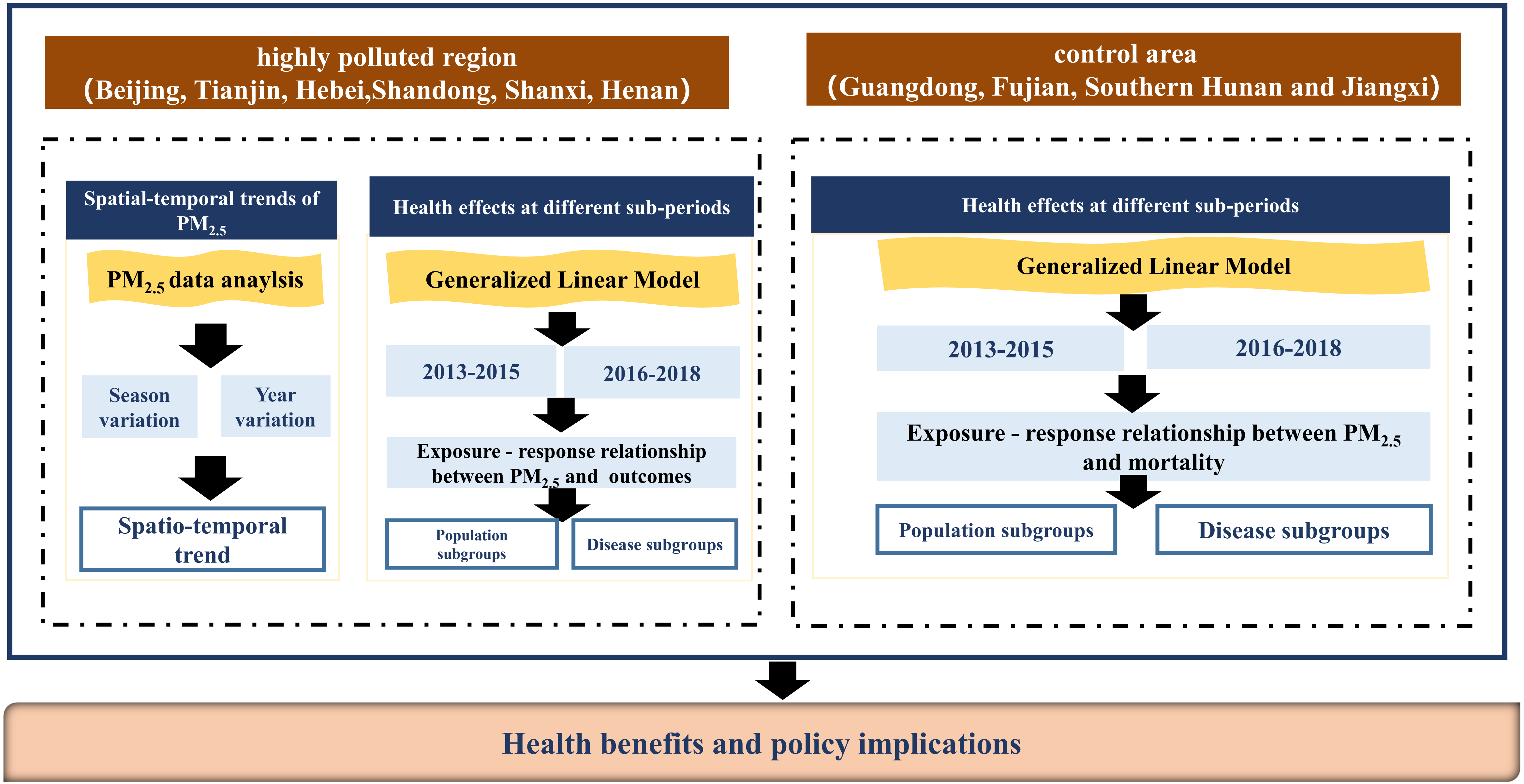
Based on multi-center datasets, a two-stage time-series analysis was used to quantify the temporal and spatial changes of the acute health impact of $PM_{2.5}$ after the implementation of the China National Action Plan on Air Pollution Prevention and Control in the BTH region.



- **Time differences**： divide the entire study period into two subperiods, **2013 to 2015** and **2016 to 2018**, to estimate $PM_{2.5}$-related health effects separately and to observe whether the effects of the two subperiods have changed.

- **Region differences**： **heavily polluted region** is BTH and the surrounding area; **control area** include Guangdong, Fujian, Southern Hunan, and Southern Jiangxi, which have experienced relatively low $PM_{2.5}$ concentrations

Study design



Health Outcome and exposure

Daily health outcome data, 2013 to 2018

- non-accidental mortality (A00-R99)
- circulatory disease mortality (I00-I99)
- respiratory disease mortality (J00-J99)

Mortality data
Study region: BTH and control regions
Data source: DSP system of China CDC

Daily outpatient visit data
Study region: the BTH and Beijing
Data source: 30 hospitals' information system

Hospital admissions data
Study region: Beijing
Data source: Beijing Municipal Health Commission Information Center

Daily exposure data, 2013 to 2018

- Air pollution
- Meteorological data

Daily average $PM_{2.5}$ and O_3
Study region: counties within the BTH
Data sources: the National Environmental Monitoring System

Daily mean temperature and relative humidity
Study region: counties within the BTH
Data sources: the Chinese Meteorological Data Sharing Service System

Statistical Analysis

Divide the entire study period into 2013 to 2015 and 2016 to 2018, to estimate $PM_{2.5}$-related effects separately and to observe whether the effects of the two periods have changed.

- **Two step analysis:**

  multi-county time-series analysis + random-effect meta-analysis

$$LogE(Y)=Intercept+\beta X_t+ns(time,df)+ns(temperature,df)+ns(humidity,df)+day\ of\ week+public\ holidays$$

E(Y) —Expected number of deaths/outpatients/inpatients on day t;

X_t —$PM_{2.5}$ component concentration on day t;

ns —The natural spline function controls the time trend, temperature and humidity variables;

day of week —Day of the week effect;

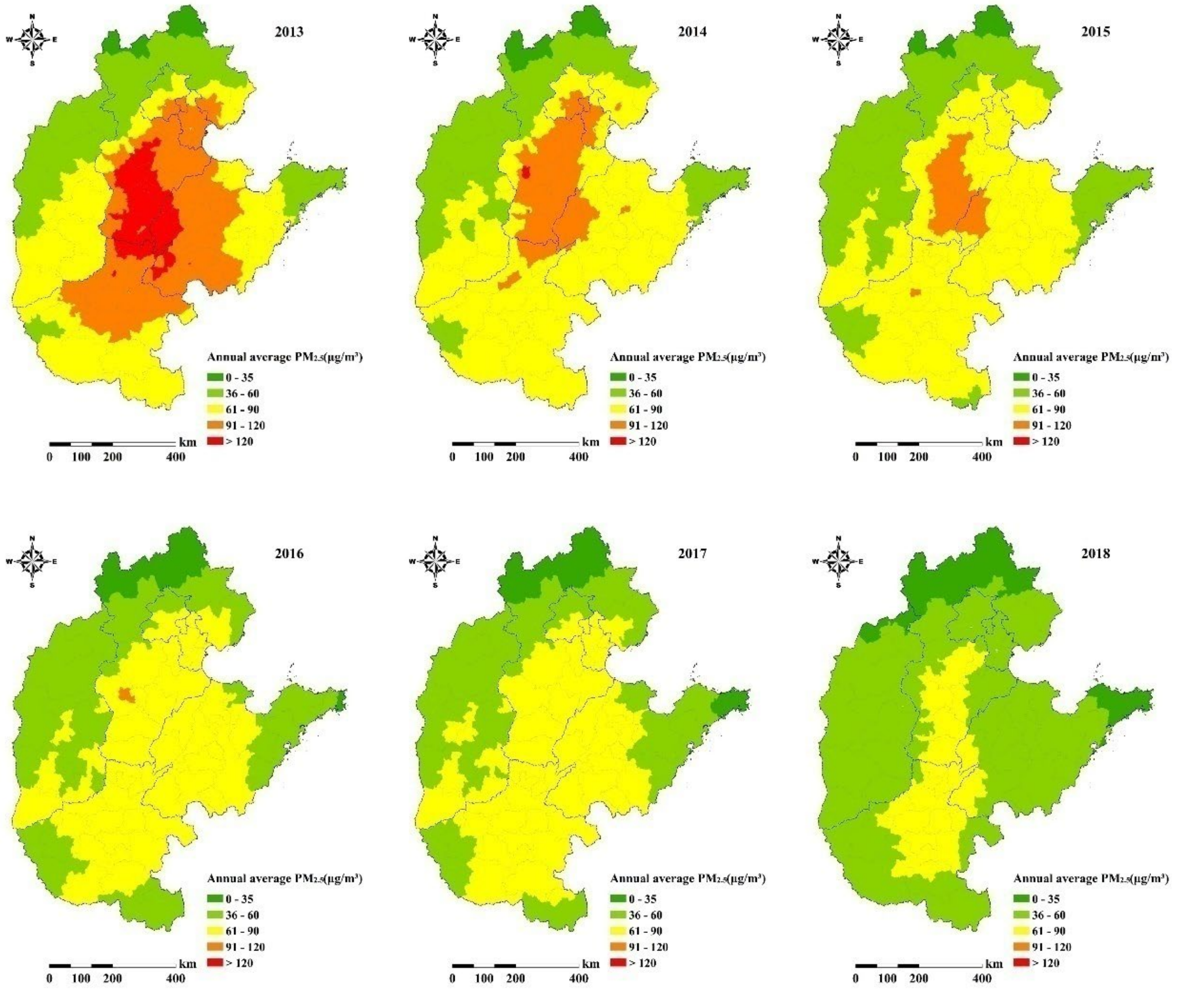
public holidays —the effect of public holidays;

Intercept —intercept.

- **Test of the differences in the effect estimates between the two periods**

$$Z=\frac{\beta_{2013-2015}-\beta_{2016-2018}}{\sqrt{se(\beta_{2013-2015})^2+se(\beta_{2016-2018})^2}}$$

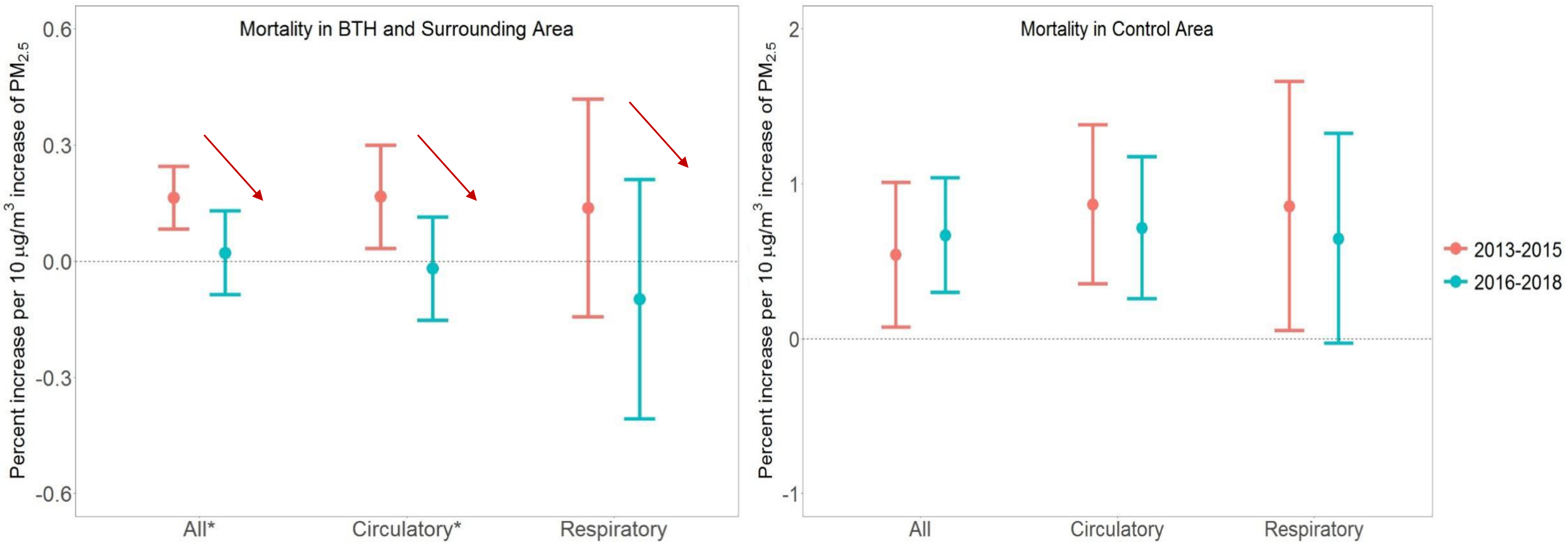
Preliminary results: Change in regional $PM_{2.5}$ concentration



Annual $PM_{2.5}$ concentration in BTH region, 2013-2018

- **The annual $PM_{2.5}$ concentrations in BTH and the surrounding area from 2013 to 2018 indicate a decreasing trend by year.**
- **The mean daily $PM_{2.5}$ level was reduced by 20 μg/m^3 in the period of 2016 to 2018, which was likely related to coal emissions control.**
- **The southern area of Hebei Province indicated large reduction of $PM_{2.5}$ concentration.**

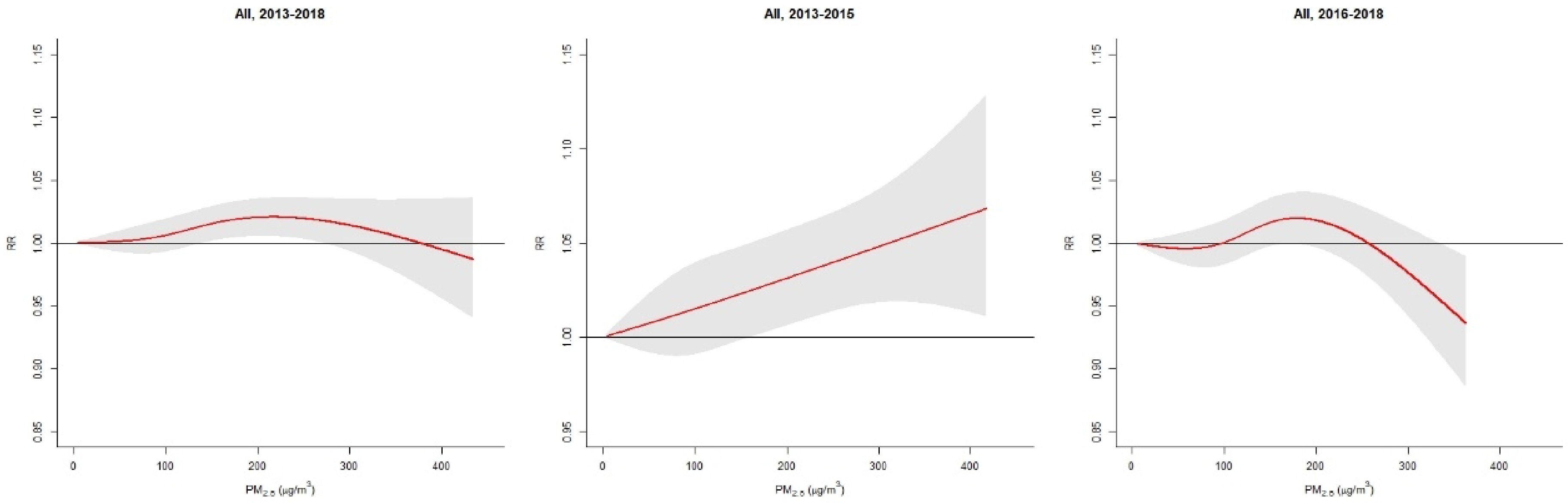
Preliminary results: Change in $PM_{2.5}$ related all-cause mortality risk



- In Beijing-Tianjin-Hebei and the surrounding area, a 10 μg/m^3 increase in $PM_{2.5}$ concentrations was associated with a 0.16% (95% CI: 0.08%, 0.24%) and 0.02% (95% CI: -0.09%, 0.13%) increase in mortality from 2013 to 2015 and from 2016 to 2018, respectively.

Preliminary results: Change in $PM_{2.5}$ related all-cause mortality risk

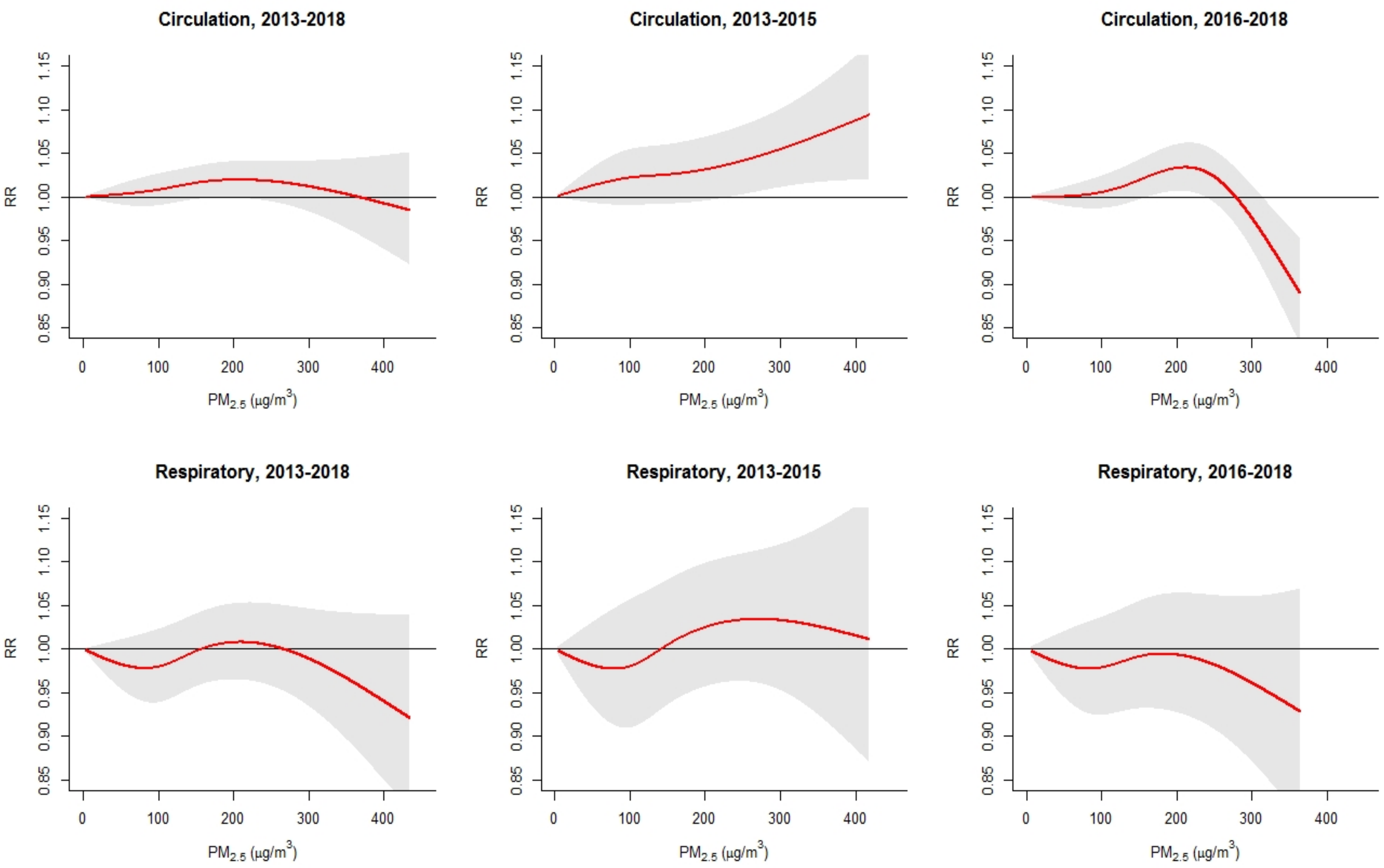
Exposure - response curve of $PM_{2.5}$ and mortality at different periods in Beijing-Tianjin-Hebei and surrounding areas



- **The exposure-response curves of the $PM_{2.5}$ concentration and daily all-cause mortality in BTH and the surrounding area for the entire study period, 2013 to 2018, showed a monotonic increase in the excess relative rate until approximately 250μg/m³, after which the excess relative rate monotonically decreased.**
- **The exposure-response curves for 2013-2016 showed a monotonically linear increase whereas the exposure-response curves for 2016-2018 had an inverted J shape, with nearly no significant effect.**

Preliminary results: Change in $PM_{2.5}$ related cause-specific mortality risk

Exposure-response curve of $PM_{2.5}$ (Lag 0-1 days) and circulatory and respiratory diseases mortality in Beijing-Tianjin-Hebei and surrounding areas at different periods



- **Similar results were observed for cardiovascular mortality, but linear increases were not observed for respiratory mortality for 2013-2015.**

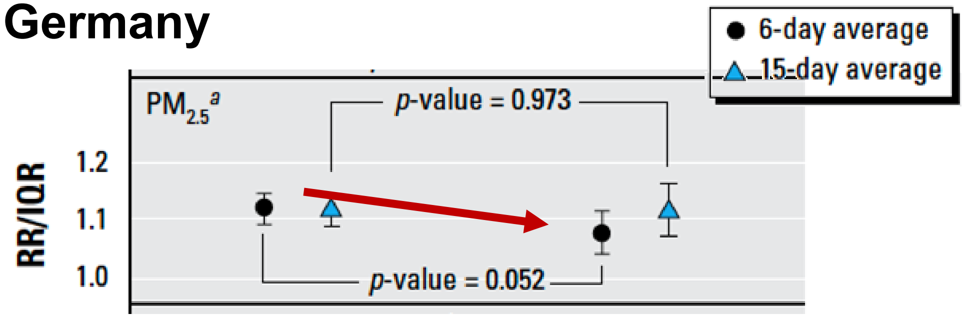
Discussion: Comparison between health benefits in China and developed countries

USA

TABLE 2. Estimates and 95% posterior intervals for the national and regional (eastern United States and western United States) percentage increase in all-cause, cardiorespiratory, and other-cause mortality associated with a 10-μg/m^3 increase in PM_{10}* at lag 1 for the periods 1987–1994, 1995–2000, and 1987–2000

	1987–1994	95% PI	1995–2000	95% PI	1987–2000	95% PI
All cause						
East	0.29	0.12, 0.46	0.13	−0.19, 0.44	0.25	0.11, 0.39
West	0.12	−0.07, 0.30	0.18	−0.07, 0.44	0.12	−0.02, 0.26
National	0.21	0.10, 0.32	0.18	0.00, 0.35	0.19	0.10, 0.28
Cardiorespiratory						
East	0.39	0.16, 0.63	0.30	−0.13, 0.73	0.34	0.15, 0.54
West	0.17	−0.07, 0.40	0.13	−0.23, 0.50	0.14	−0.05, 0.33
National	0.28	0.14, 0.43	0.21	−0.03, 0.44	0.24	0.13, 0.36
Other						
East	0.21	−0.03, 0.44	0.00	−0.49, 0.50	0.15	−0.09, 0.39
West	0.09	−0.21, 0.38	0.23	−0.15, 0.62	0.11	−0.10, 0.33
National	0.15	−0.02, 0.32	0.17	−0.07, 0.41	0.15	0.00, 0.29

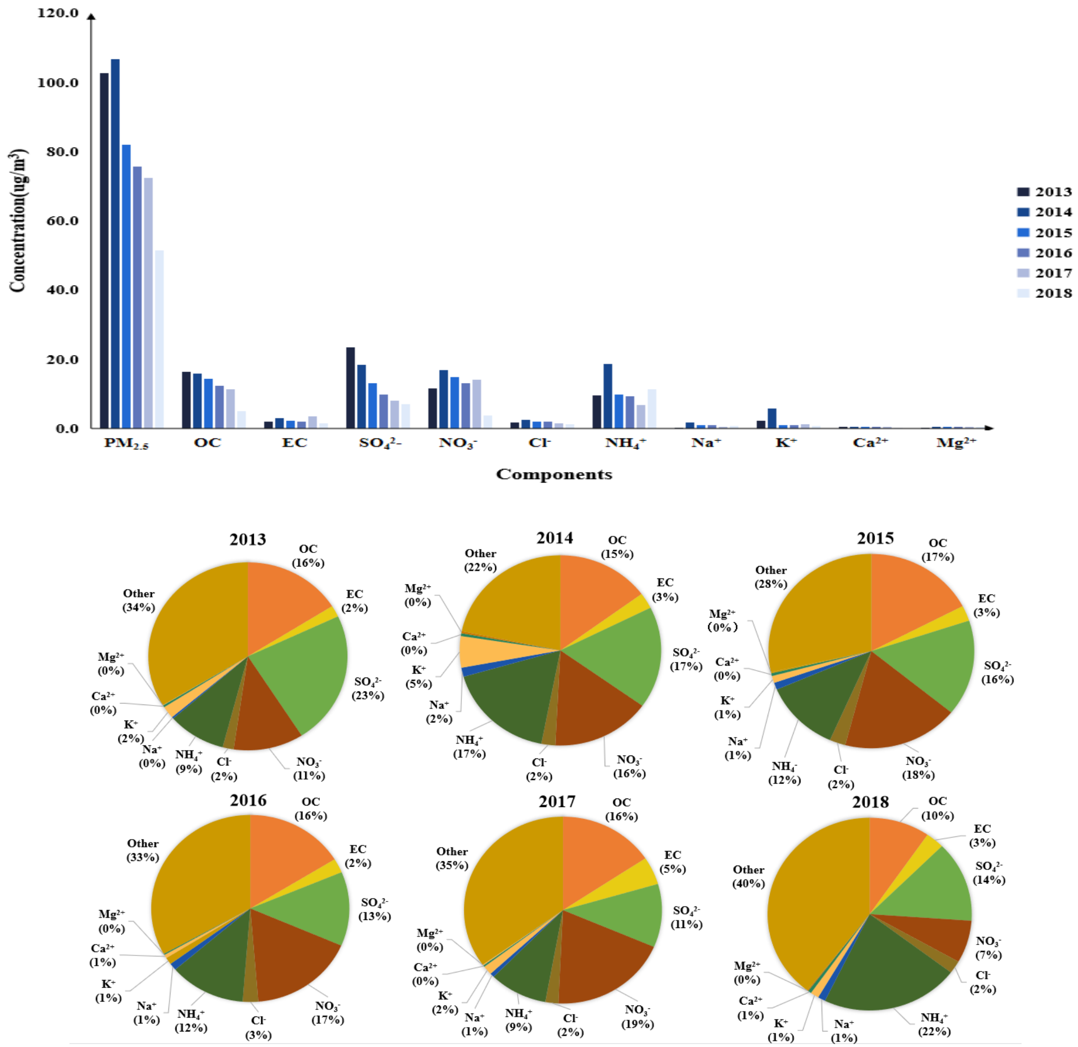
Germany



- The effects of $PM_{2.5}$ were significantly decreased for the total and circulatory mortalities in China.
- In USA, the effects of PM_{10} on all cause and cardiovascular mortality declined during 1987–2000
- In Germany, the effects of short-term $PM_{2.5}$ exposure on all cause mortality indicated a weak decline.

Discussion: Potential contributors for the health benefits in China

- The changes in components or sources
- Use of air purifiers and residential energy substitution
- The air pollution control measures implemented recently targeting coal emissions control



Concentrations and proportions of $PM_{2.5}$ components in Beijing

Prospects

Accountability studies on long-term health benefits of air pollution regulations in China, 2008-2019

HEI

RFA 18-1: Assessing Improved Air Quality and Health From National, Regional, and Local Air Quality Actions

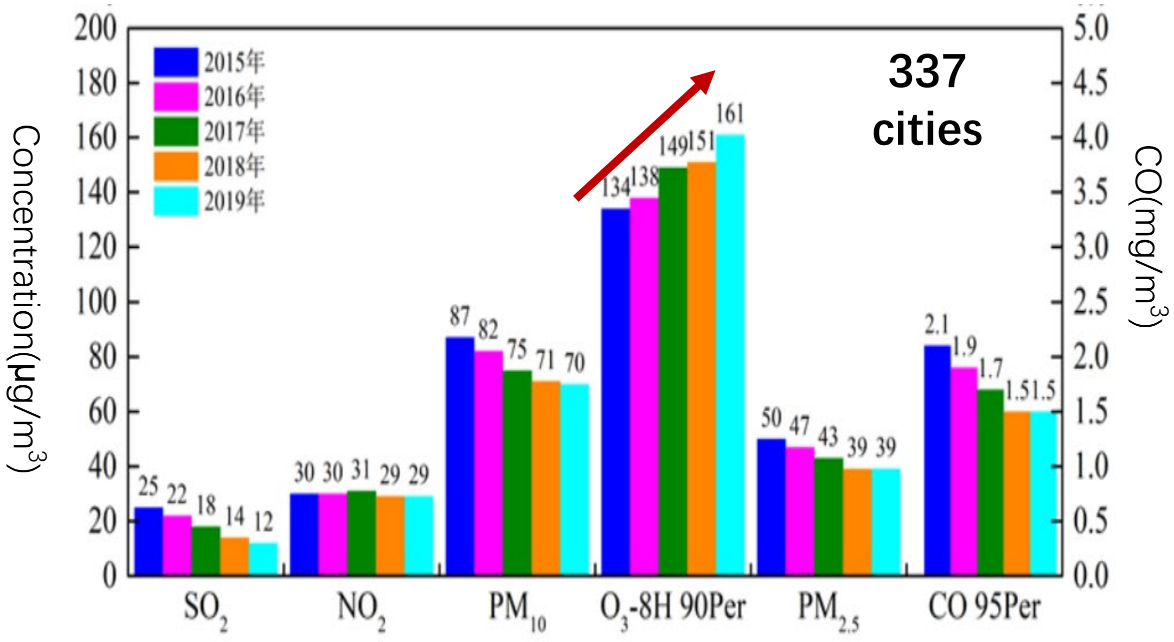
PI: Patrick L Kinney,

Boston University

The ongoing study will evaluate the major national regulatory policies that were implemented in China from 2008–2018. The investigators will focus on regulations in particular regions that target specific sources, such as coal combustion, and how they have reduced ambient concentrations of fine particles (and their components).

Accountability study on O_3 and VOCs control actions

During 2013–2019, ambient ozone concentration and VOCs experienced an upward trend



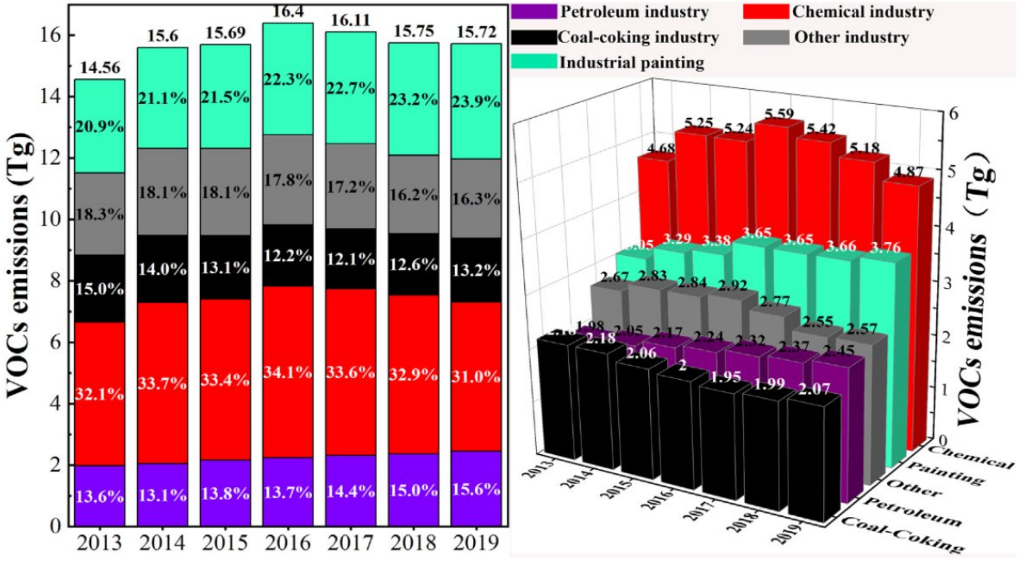
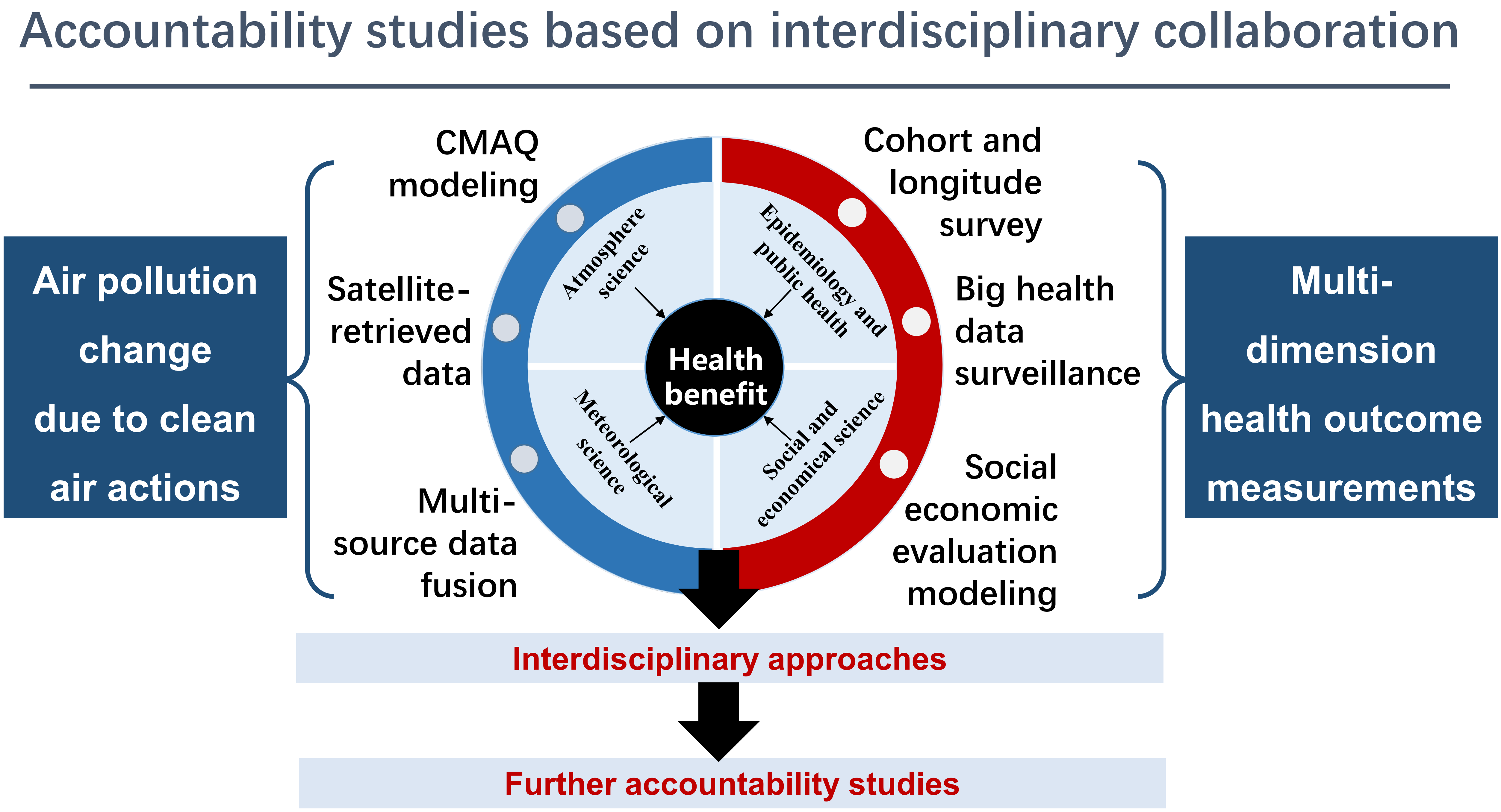


Fig. 2. Temporal changes of VOCs emissions from industrial sources in China during 2013–2019.

- ❑ **During the 14th five-year plan, further action plans are implemented, including the Elimination of heavily Polluted Weather, the Prevention and Control of Ozone Pollution, and the Pollution Control of Diesel Trucks**
- ❑ **Further accountability studies on ozone and VOCs control actions are expected.**

(Blue Book on Prevention and Control of Atmospheric Ozone Pollution in China 2020； Simayi et al. 2022)



Accountability studies based on interdisciplinary collaboration
Air pollution change due to clean air actions
CMAQ modeling
Satellite-retrieved data
Multi-source data fusion
Atmosphere science
Meteorological science
Epidemiology and public health
Social and economical science
Health benefit
Cohort and longitude survey
Big health data surveillance
Social economic evaluation modeling
Multi-dimension health outcome measurements
Interdisciplinary approaches
Further accountability studies

Thank you!

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