Efficacy of PRC's Clean Air Actions to Tackle $PM_{2.5}$ Pollution

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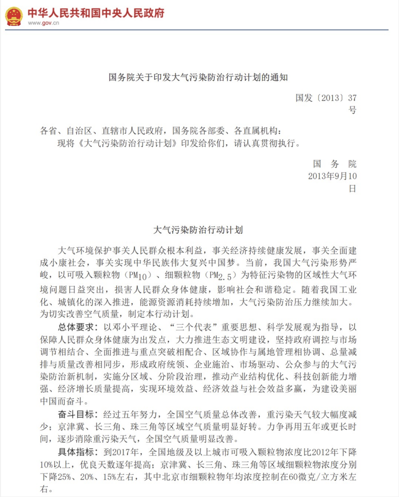
PRC has launched three phases of Clean Air Actions

2013-2017	2018-2020	2023-2025
Phase I	Phase II	Phase III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国务院关于印发大气污染防治行动计划的通知

国发〔2013〕37号

各省、自治区、直辖市人民政府，国务院各部委、各直属机构：
现将《大气污染防治行动计划》印发给你们，请认真贯彻执行。

国　务　院
2013年9月10日

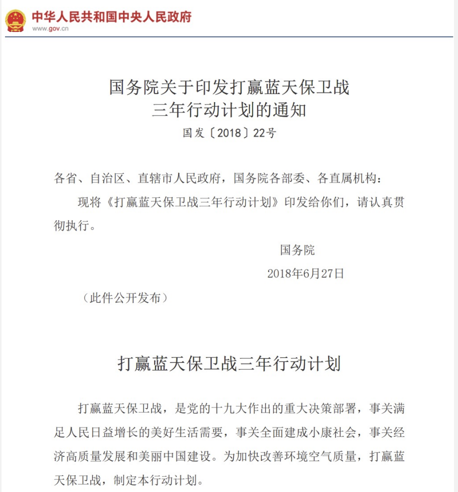
大气污染防治行动计划

大气环境保护事关人民群众根本利益，事关经济持续健康发展，事关全面建成小康社会，事关实现中华民族伟大复兴中国梦。当前，我国大气污染形势严峻，以可吸入颗粒物（PM_{10}）、细颗粒物（$PM_{2.5}$）为特征污染物的区域性大气环境问题日益突出，损害人民群众身体健康，影响社会和谐稳定。随着我国工业化、城镇化的深入推进，能源资源消耗持续增加，大气污染防治压力继续加大。为切实改善空气质量，制定本行动计划。

总体要求：以邓小平理论、“三个代表”重要思想、科学发展观为指导，以保障人民群众身体健康为出发点，大力推进生态文明建设，坚持政府调控与市场调节相结合、全面推进与重点突破相配合、区域协作与属地管理相协调、总量减排与质量改善相同步，形成政府统领、企业施治、市场驱动、公众参与的大气污染防治新机制，实施分区域、分阶段治理，推动产业结构优化、科技创新能力增强、经济增长质量提高，实现环境效益、经济效益与社会效益多赢，为建设美丽中国而奋斗。

奋斗目标：经过五年努力，全国空气质量总体改善，重污染天气较大幅度减少；京津冀、长三角、珠三角等区域空气质量明显好转。力争再用五年或更长时间，逐步消除重污染天气，全国空气质量明显改善。

具体指标：到2017年，全国地级及以上城市可吸入颗粒物浓度比2012年下降10%以上，优良天数逐年提高；京津冀、长三角、珠三角等区域细颗粒物浓度分别下降25%、20%、15%左右，其中北京市细颗粒物年均浓度控制在60微克/立方米左右。


中华人民共和国中央人民政府
www.gov.cn

国务院关于印发打赢蓝天保卫战三年行动计划的通知
国发〔2018〕22号

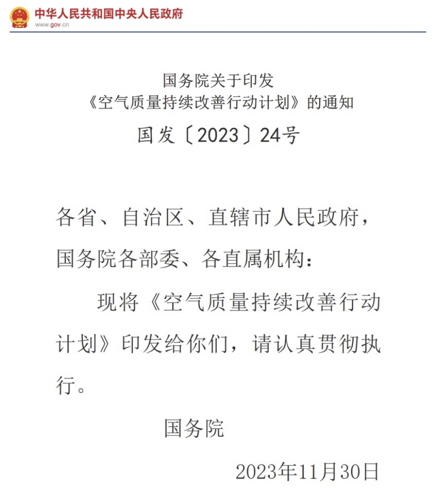
各省、自治区、直辖市人民政府，国务院各部委、各直属机构：
现将《打赢蓝天保卫战三年行动计划》印发给你们，请认真贯彻执行。

国务院
2018年6月27日

（此件公开发布）

打赢蓝天保卫战三年行动计划

打赢蓝天保卫战，是党的十九大作出的重大决策部署，事关满足人民日益增长的美好生活需要，事关全面建成小康社会，事关经济高质量发展和美丽中国建设。为加快改善环境空气质量，打赢蓝天保卫战，制定本行动计划。


中华人民共和国中央人民政府
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国务院关于印发
《空气质量持续改善行动计划》的通知
国发〔2023〕24号

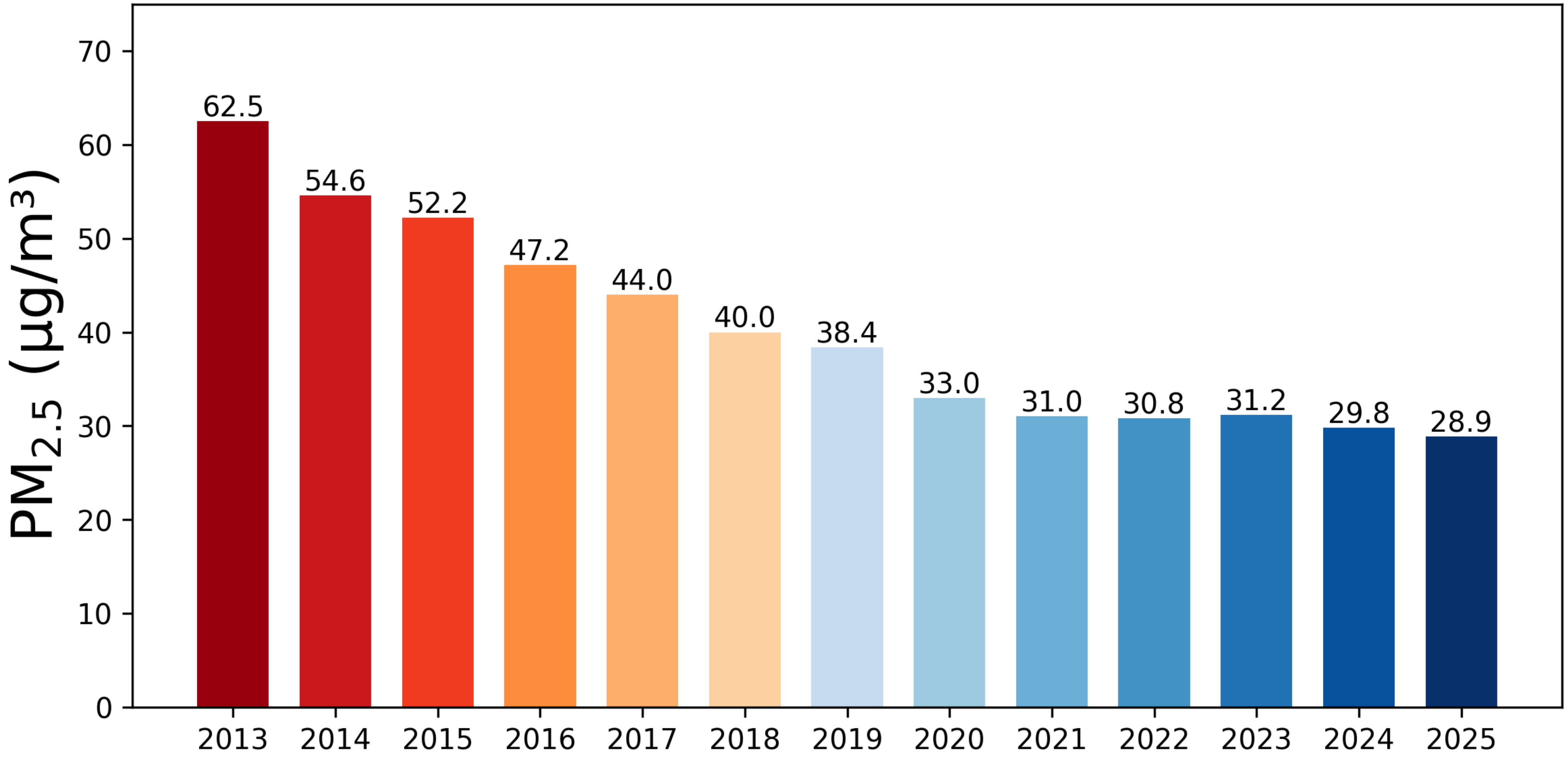
各省、自治区、直辖市人民政府，国务院各部委、各直属机构：
现将《空气质量持续改善行动计划》印发给你们，请认真贯彻执行。

国务院
2023年11月30日

Since 2013, PRC has successively launched three actions to address severe air pollution and reduce $PM_{2.5}$ levels, promoting air quality improvement through a phased and progressively strengthened policy framework.

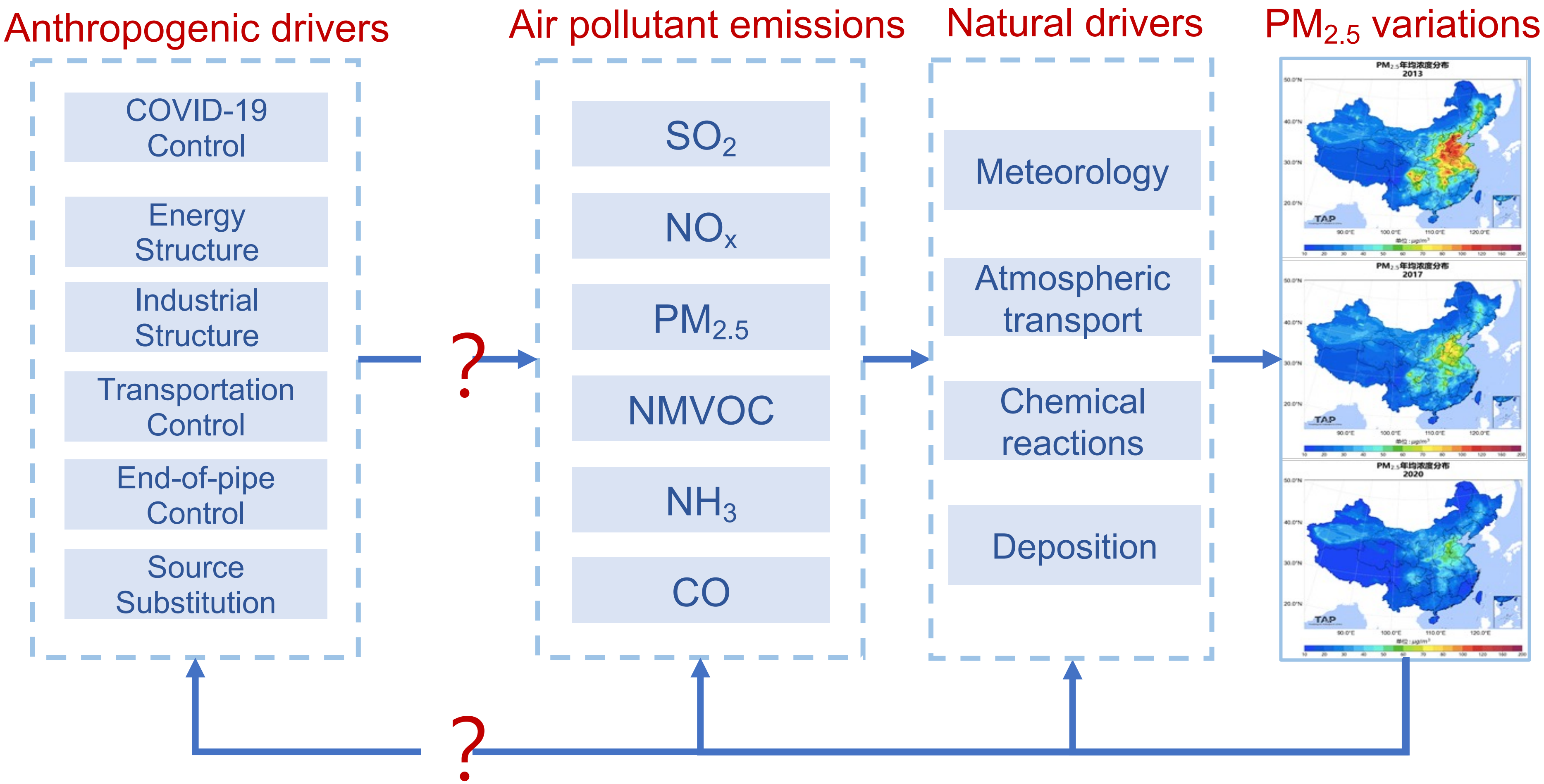
$PM_{2.5}$ air quality in PRC improved significantly

National population weighted mean $PM_{2.5}$ concentrations



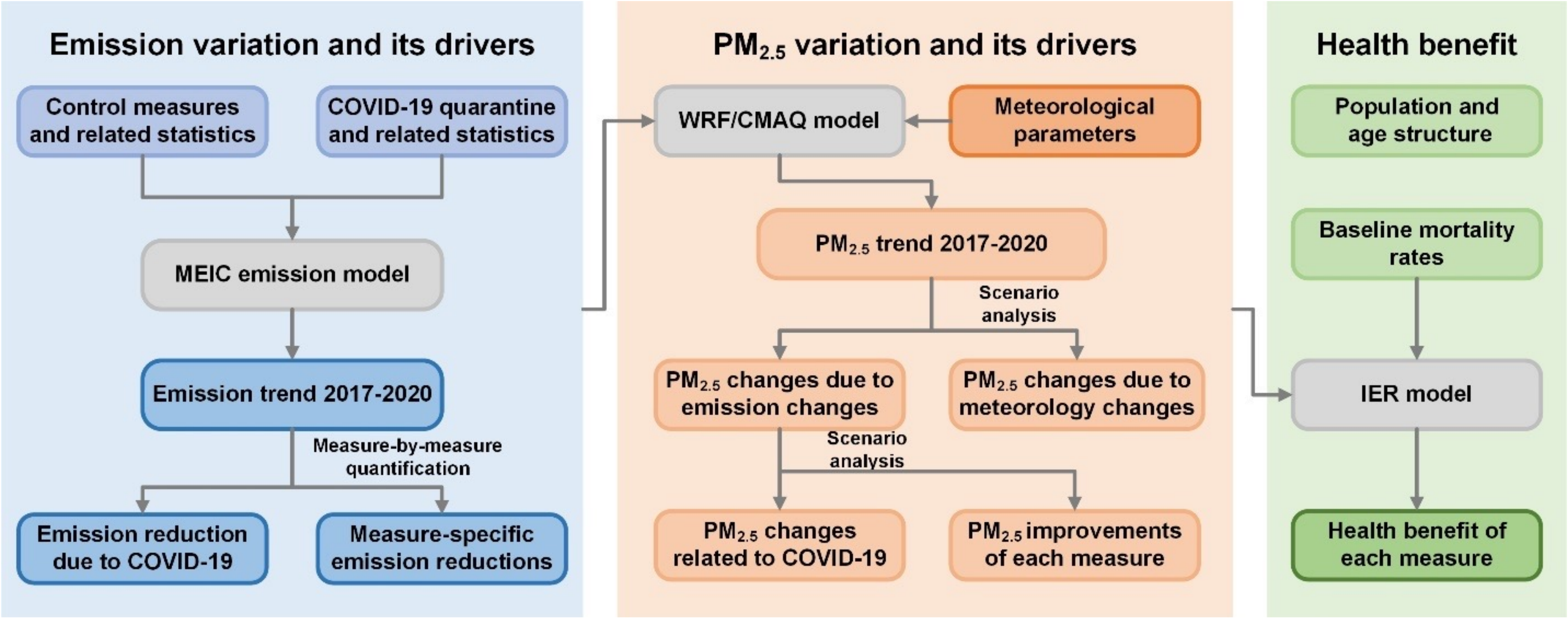
Source: http://tapdata.org/

$PM_{2.5}$ variations are influenced by complex natural and anthropogenic drivers



How can we scientifically quantify their contributions to $PM_{2.5}$ reduction?

Methodology framework to estimate the drivers underlying $PM_{2.5}$ improvements

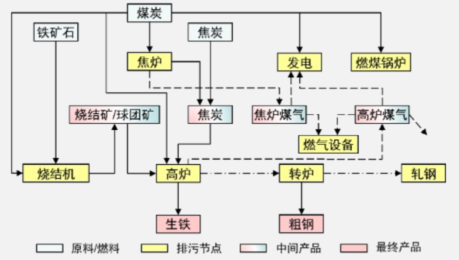


Development of MEIC emission model

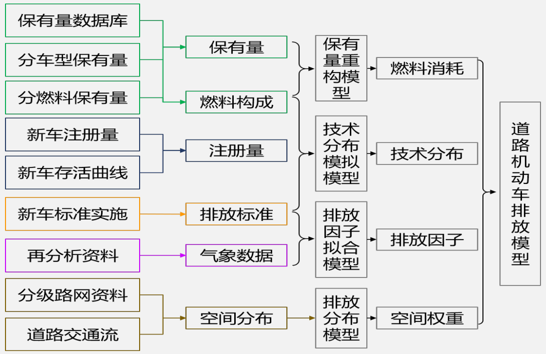
Unit-level industrial model

$$Emis_{s,y,m} = U \times P \times \left(\frac{H_0}{H_y}\right) \times T_y \times f_{m,y} \times EF_{s,k,y} \times \prod_n (1 - \eta_{n,s} \times \tau_{n,m,y})$$

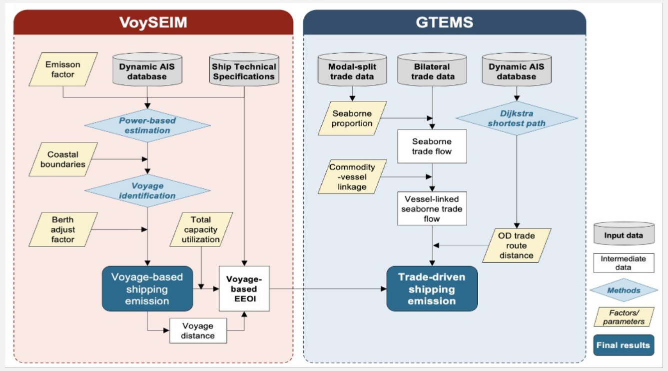
$$A_{m,i,j} = A_{m,k,j} \times \frac{\lambda_m \frac{C_i * T_i}{e_i}}{\sum \frac{\lambda_m C_{k,j} * T_{k,j}}{e_{k,j}}}$$



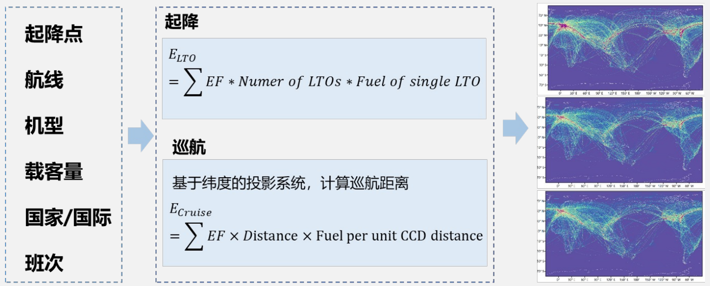
On-road fleet turn-over model



Voyage-based shipping model



Route-based aviation model



- Develop a non-aggregated model system for the high-resolution estimation of mass emission sources in order to improve the spatio-temporal resolution of emission inventory.

Systematically examine the implementation status of different measures

		Phase I	Phase II
Strengthen industrial emission standards	Enforce ultra-low emission retrofits in power sector	770 GW	170 GW
	Enforce ultra-low emission retrofits in iron and steel	-	620 millon ton
	Tighten emission limit for cement industry	Emission limit in GB 4915-2013	Special emission limit in GB 4915-2013
Phase out small and polluting factories	"Small and polluting" enterprises were phased out or rectified	62,000 enterprises	360,000 enterprises
Phase out outdated industrial capacities	Phase out outdated coal-fired power generation	25 GW	20 GW
	Phase out outdated iron and steel capacity	200 million ton	120 million ton
	Phase out outdated cement capacity	250 million ton	140 million ton
	Phase out outdated flat glass capacity	110 million weight box	50 million weight box
Upgrades on industrial boilers	Promote new emission standard	GB 13271-2014	Ultra-low emission limit for large boilers in key regions
	Phase out small boilers	200 thousand	110 thousand

Systematically examine the implementation status of different measures

		Phase I	Phase II
Promote clean fuels in the residential sector	Upgraded to clean stoves Applied washed clean coal Coal substituted by natural gas and electricity	lower sulfur and ash 6 million households	- - 23 million households
Control of mobile source emissions	Tighten emission standard for light duty vehicles Tighten emission standard for heavy duty vehicles Eliminate old and yellow label vehicles Promote new energy vehicles "Highway to Railway": Railway cargo volume "Highway to Waterway": Waterway cargo volume	China 5 China 5 20 million increased by 1.5 million decreased by 7% increased by 19%	China 6a China 5 6 million increased by 3.4 million increased by 23% increased by 14%
Management of VOC emissions	Release VOC emission control standard Release VOC content limit standard Promote the use of water-based paints	- - 35% water-based paints in 2017	GB 37823-2019, GB 37824-2019, GB 37822-2019 GB 18581-2020, GB 18582-2020, GB 33372-2020, GB 38508-2020 48% water-based paints in 2020
Management of agricultural source	Croplands applied with soil testing and formula fertilization technology Reduce national fertilizer consumption	- decreased by 1%	13.3 milliton ha decreased by 10%

Multi-driver decomposition method for air pollution changes

$PM_{2.5}$ variations and mortality risk → **Meteorological variations** / **Emission changes** →

Policy drivers

- Standards strengthening
- Clean coal replacement
- Coal-fired boiler control
- Small enterprises phaseout
- Outdated capacity phaseout
- Mobile source control
- Power plants retrofit
- Dust control

Chemical transport model

↑

Brute-force scenario matrix

2013 EMIS	2013 MET
2017 EMIS	2017 MET

↑

Emission inventory model

Emission changes | **Emission change drivers** → **Concentration & health drivers**

Policy measure decomposition

$$\Delta Emis = f(\Delta A, \Delta X, \Delta EF, \Delta\eta)$$

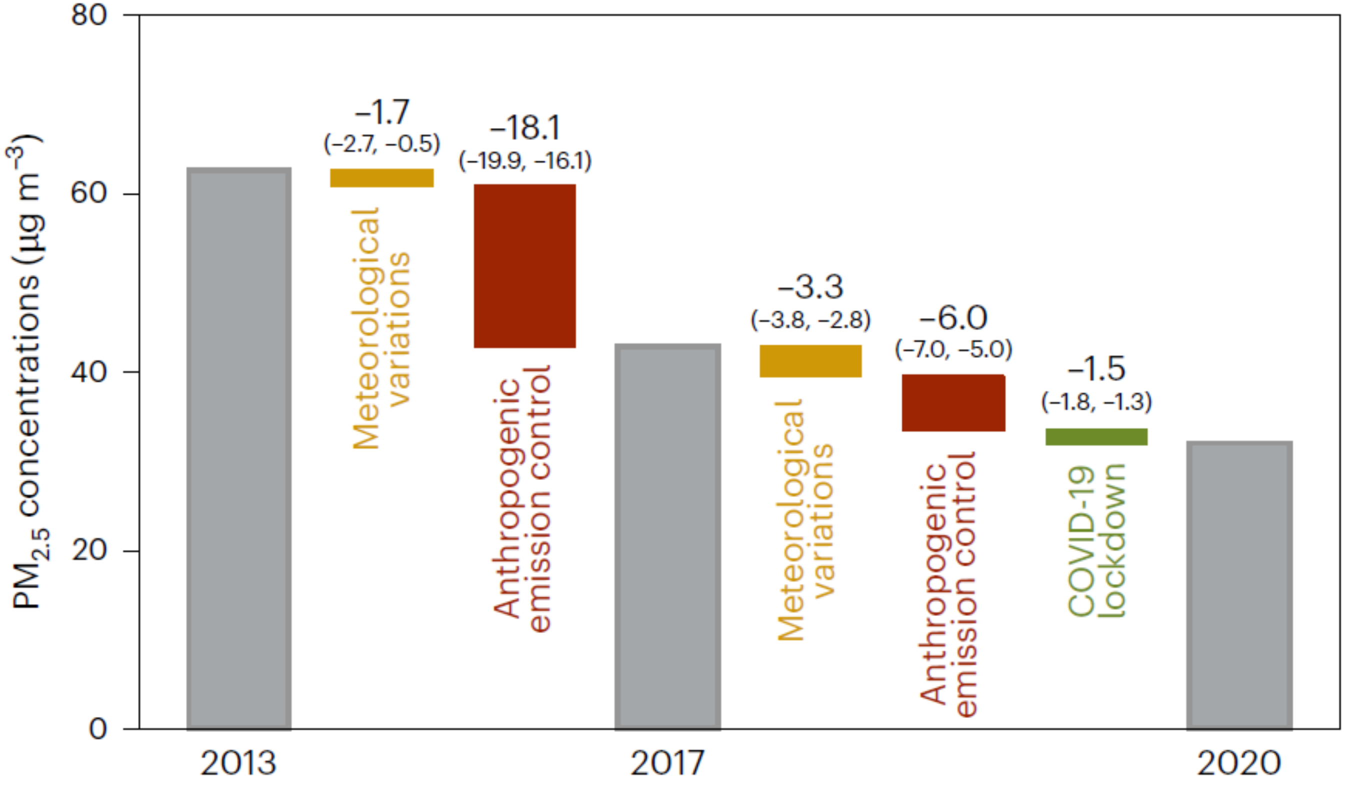
Policy Driver Matrix

$$\begin{pmatrix} M_1 \\ M_2 \\ M_3 \\ M_4 \\ M_5 \\ M_6 \\ M_7 \\ M_8 \end{pmatrix} \Rightarrow \begin{pmatrix} A & \Delta X & EF & \Delta\eta \\ \Delta A & \Delta X & EF & \Delta\eta \\ \Delta A & X & EF & \eta \\ A & \Delta X & EF & \Delta\eta \\ \Delta A & X & EF & \eta \\ \Delta A & \Delta X & EF & \Delta\eta \\ A & \Delta X & EF & \Delta\eta \\ \Delta A & \Delta X & EF & \Delta\eta \end{pmatrix}$$

BF scenario matrix simulation

	Emissions	Meteorology
Base	2013 2017	2013 2017
S1	S1	2017
S2	S2	2017
S3	S3	2017
…	…	2017
Sn	Sn	2017

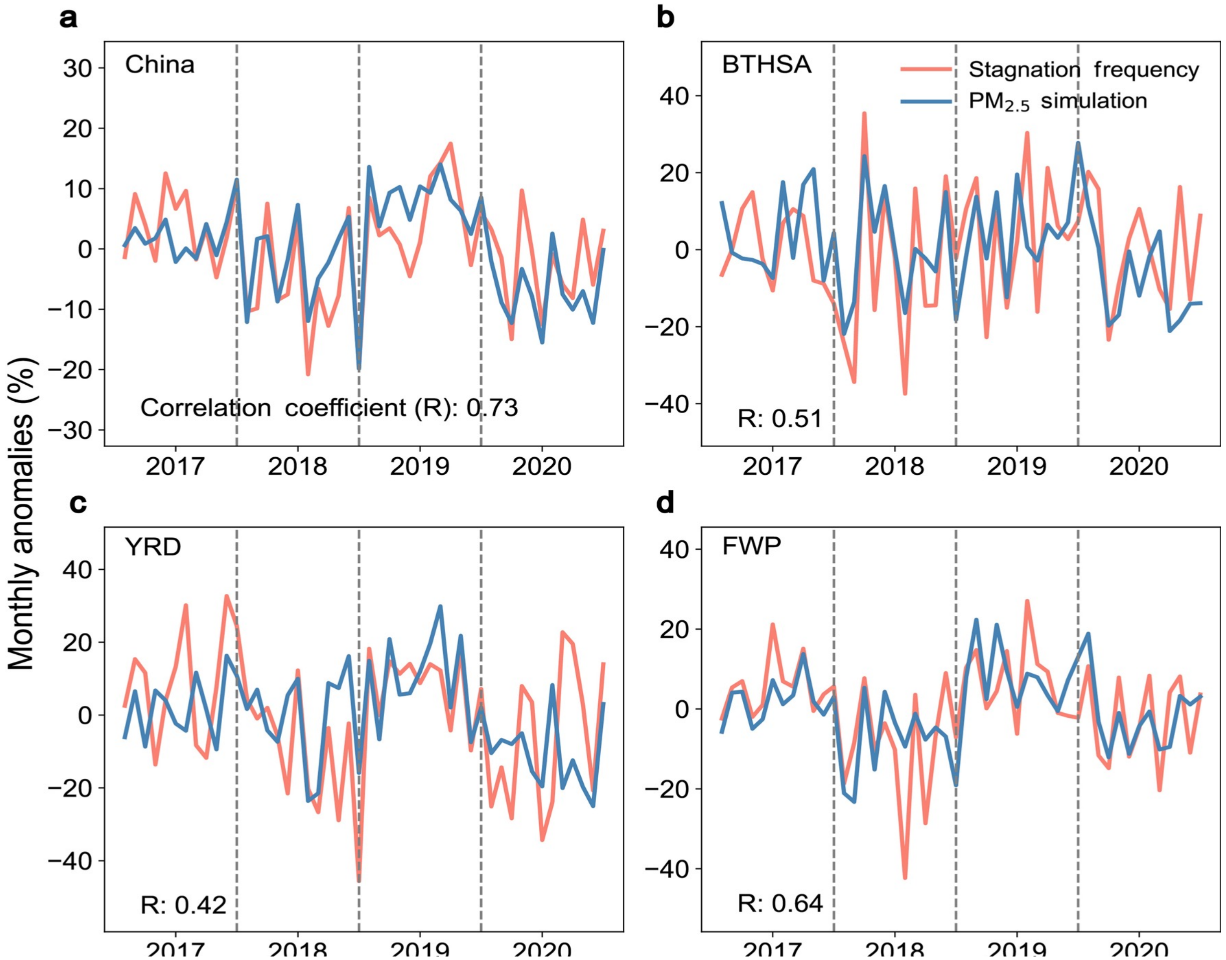
Drivers of $PM_{2.5}$ variations in PRC, 2013–2020



- During 2013–2017, emission reductions were the dominant driver of $PM_{2.5}$ declines.
- During 2017–2020, favorable meteorology, COVID-19 lockdowns (in 2020), and emission reduction measures contributed 30%, 14%, and 56%, respectively, to $PM_{2.5}$ improvement.

Zhang et al., PNAS, 2019; Geng et al., Nature Geoscience, 2024

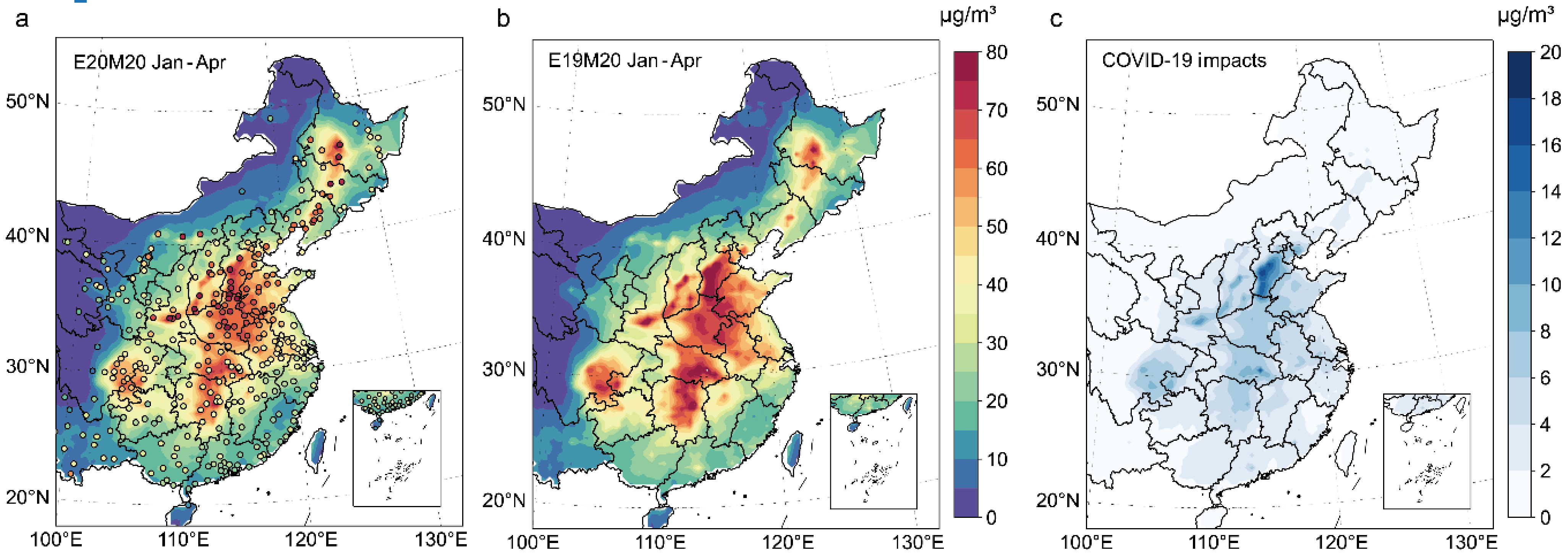
Impacts of meteorology variations



- Variations in meteorology contributed 3.3 μg/m³ to the $PM_{2.5}$ decline.
- Compared with 2017, 2020 experienced higher wind speeds, more precipitation, and fewer stagnant-air days.
- Higher wind speeds in winter 2020 were driven by the "Warm Arctic–cold Eurasia" pattern, which enhanced cold-air outbreaks and strong winds.
- Increased precipitation was linked to the strong 2019 Indian Ocean Dipole, which led to sustained Indian Ocean warming and anomalously heavy rainfall in PRC during summer 2020.

Geng et al., Nature Geoscience, 2024

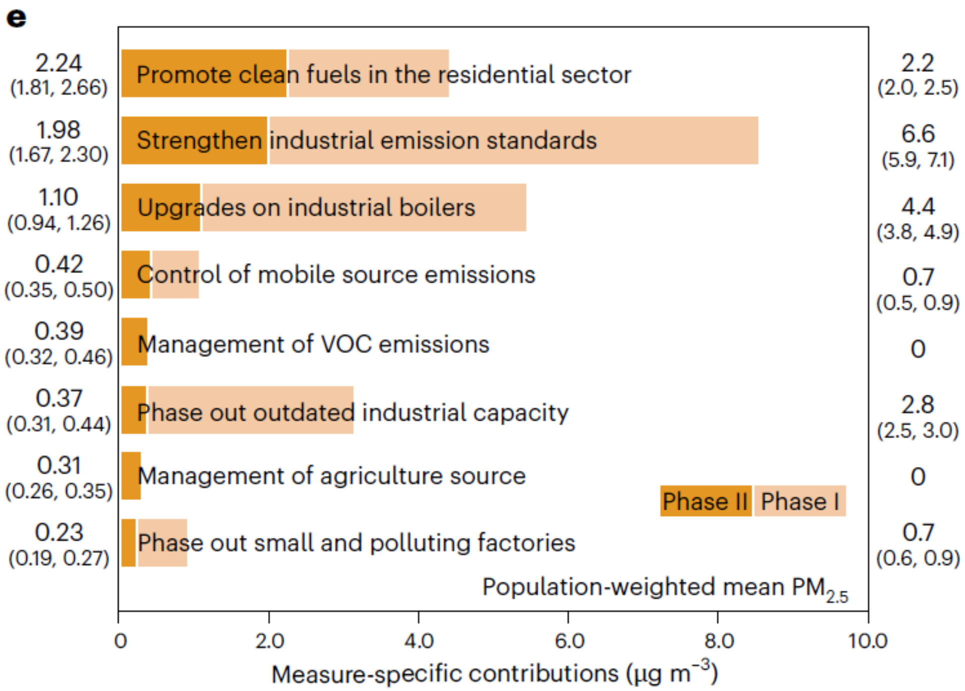
Impacts of COVID-19 lockdown measures



- The study attributed the emission reductions during the first four months of 2020, relative to the same period in 2019, to the impacts of COVID-19 control measures.
- These reductions lowered the annual mean $PM_{2.5}$ exposure by 1.5 μg/m³, accounting for about 14% of the total decline during 2017–2020.

Geng et al., Nature Geoscience, 2024

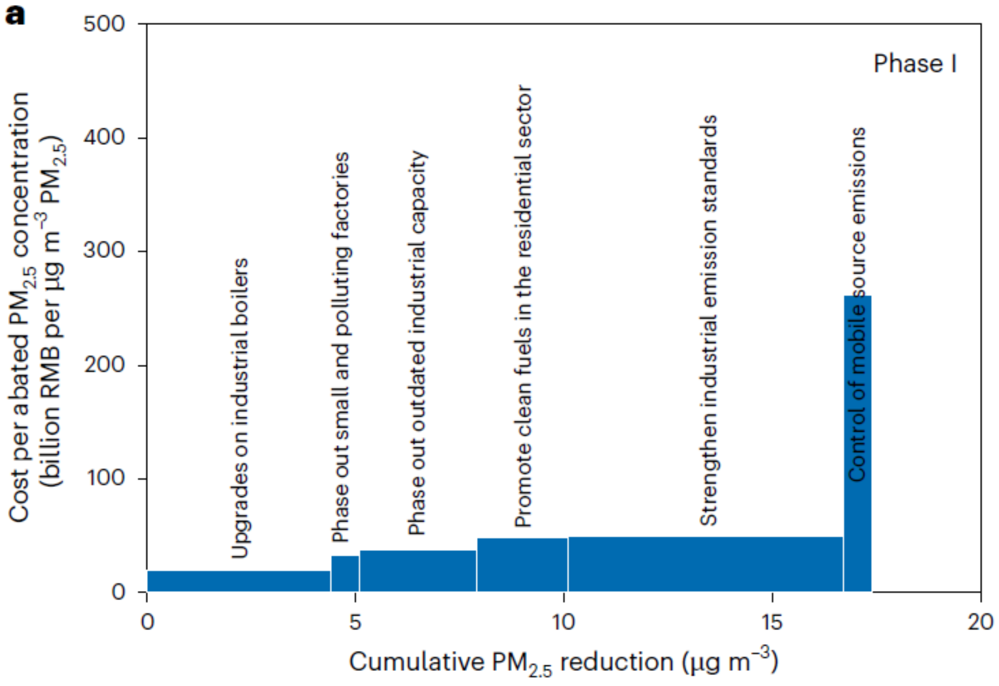
Impacts of emission reduction measures

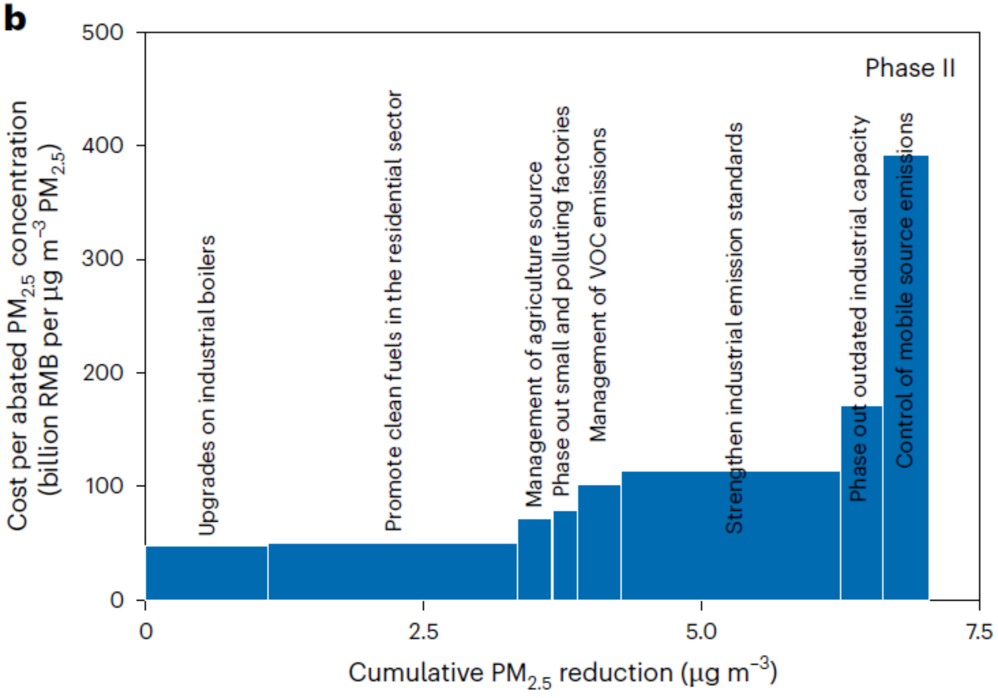


- During Phase II, the contributions of strengthening industrial emission standards, upgrades on industrial boilers, phasing out outdated industrial capacity, and phasing out small and polluting factories to $PM_{2.5}$ improvement were markedly lower than during Phase I.
- During Phase II，Promoting clean fuels in the residential sector, control of mobile source emissions, management of NMVOC emissions, and management of agriculture sources achieved $PM_{2.5}$ reductions comparable to or greater than those during Phase I.

Geng et al., Nature Geoscience, 2024

The marginal abatement cost curve during the Clean Air Actions

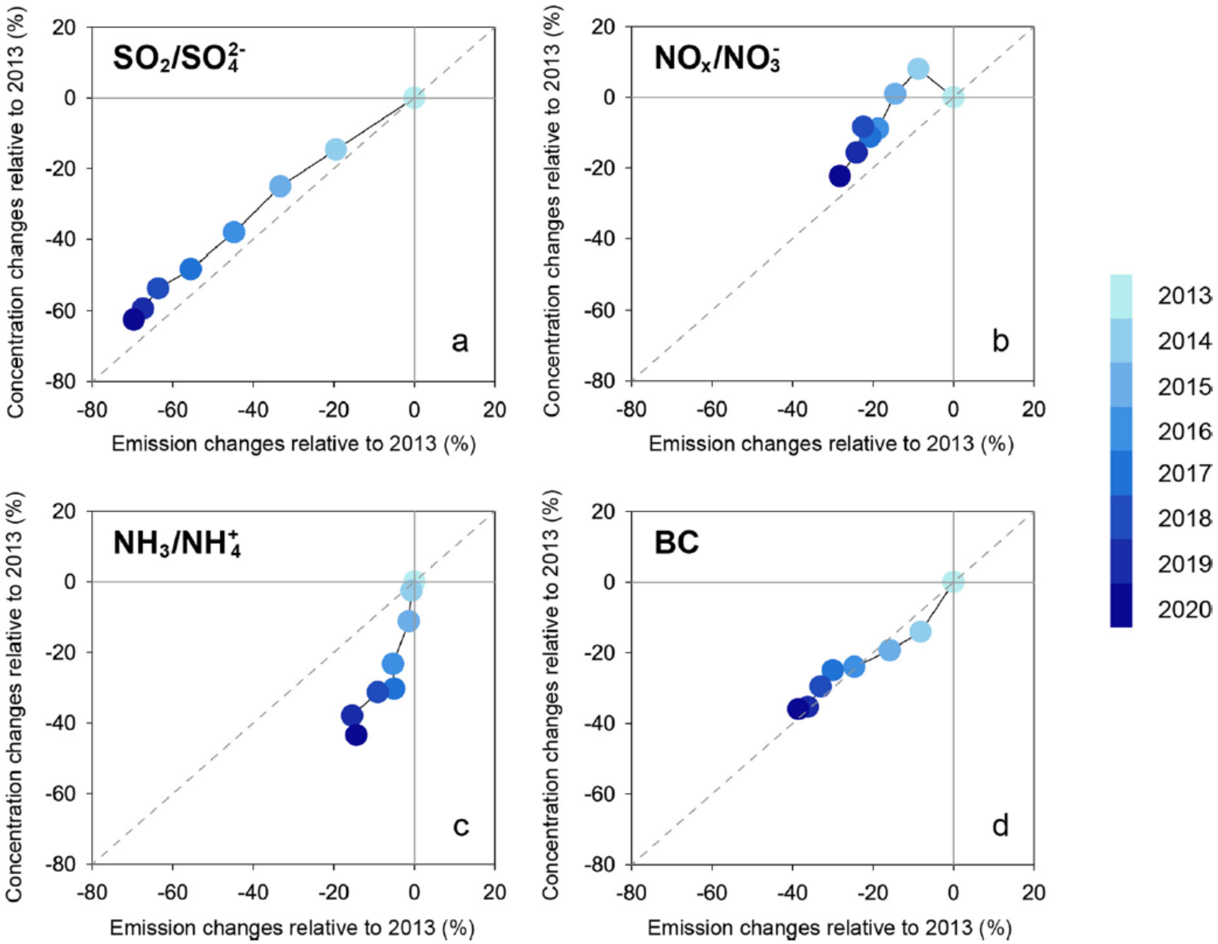




- During Phase II, the unit cost of reducing national $PM_{2.5}$ exposure by 1 μg/m³ was about RMB 100 billion, roughly twice that during Phase I.
- Upgrades on industrial boilers and promoting clean fuels in the residential sector were relatively cost-effective, whereas mobile source emission controls were less cost-effective.

Geng et al., Nature Geoscience, 2024

Cost-effectiveness is influenced by the nonlinear emission–concentration response relationship



- Upgrades on industrial boilers and promoting clean fuels in the residential sector primarily reduced primary $PM_{2.5}$ (e.g., BC and OC) and SO_2 emissions, with near-linear responses yielding higher cost effectiveness.
- Control of mobile source emissions primarily reduced NO_x and NMVOC emissions, with lower cost-effectiveness affected by nonlinear responses.

Geng et al., Nature Geoscience, 2024

Conclusions and policy implications

- After excluding the impacts of meteorology variations and COVID-19 lockdowns, emission reduction measures reduced annual $PM_{2.5}$ exposure by 4.5 μg/m^3 in Phase I and 2.3 μg/m^3 in Phase II, indicating a marked narrowing of effectiveness during Phase II.
- During Phase II, strengthened structural adjustment and VOC and NH_3 controls effectively reduced emissions, while the effectiveness of end-of-pipe measures weakened.
- During 2018–2020, the unit cost of reducing $PM_{2.5}$ was roughly twice that of 2013–2017, indicating increasing mitigation difficulty.
- Future efforts should further unlock the emission reduction potential of structural adjustment and implement strengthened, balanced measures for coordinated multi-pollutant control.

BAQ 2026
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CLEAN AIR ASIA | ADB | CLIMATE & CLEAN AIR COALITION TO REDUCE SHORT-LIVED CLIMATE POLLUTANTS | ESCAP Economic and Social Commission for Asia and the Pacific | UN environment programme

Thank you for listening!