清华大学能源环境经济研究所
INSTITUTE of ENERGY, ENVIRONMENT and ECONOMY
TSINGHUA UNIVERSITY

Provincial economic and air quality-related health impacts of China’s potential partitioned carbon regulation

Presenter: Xinyi Liu
Tsinghua University

June 27, 2025
2025 GTAP Conference

Joint work with Hantang Peng, Mingwei Li, Da Zhang, Fengwei Wan, Junling Huang and Xiliang Zhang

Background: China's potential new carbon regulation

- **Historical carbon control mechanisms in China**
  - China has set provincial targets to reduce energy and CO_2 intensity since the 12th Five Year Plan (FYP, 2011–2015).
- **Recent policies**
  - China has announced a shift from "dual control" of total energy consumption and energy intensity to "dual control" of total carbon emissions and carbon intensity. (China State Council, 2024)
  - China's national emissions trading system (ETS) launched in 2021, which may cover power sector and eight energy-intensive sectors by 2030. (Zhang et al., 2021)

➢ Adopt a **partitioned carbon regulation** mechanism similar to the European Union (EU)'s approach?

	Agriculture	Construction	Transportation	···	Small Industries	Electricity	Steel	Cement	···	Aluminum
Beijing										
Tianjin										
Hebei										
⋮										
Xinjiang										

Non-ETS sectors, controlled by provincial targets

ETS-sectors

Background: ETS's impact on air quality

- **Spatial transfer of co-emitted air pollutants induced by implementation of an ETS**
  - In theroy, carbon markets may induce the transition of air pollutants and reduce the benefits. (Mendelsohn 1986, Tietenberg 1995; Farber 2012; Muller and Mendelsohn 2009; Henry et al 2011)
  - The EU ETS and California's ETS may exacerbate air pollution inequality. (Anderson et al 2018; Cushing et al 2018; Hernandez-Cortes and Meng 2023; Stuhlmacher et al 2019)

- **Serious air pollution problems and induced health burden in China**
  - China remains to be among the countries with the highest levels of $PM_{2.5}$ and ozone concentrations (Van Donkelaar et al 2021, Lyu et al 2023) . Premature deaths attributed to air pollution in China are estimated to be 1.2 million people in 2017. (Yin et al., 2020)
  - China has launched the "Beautiful China" initiative for achieving significant improvements in air quality in 2035. (Xinhua News Agency 2024)

Objective

Limitations in exsiting literature:

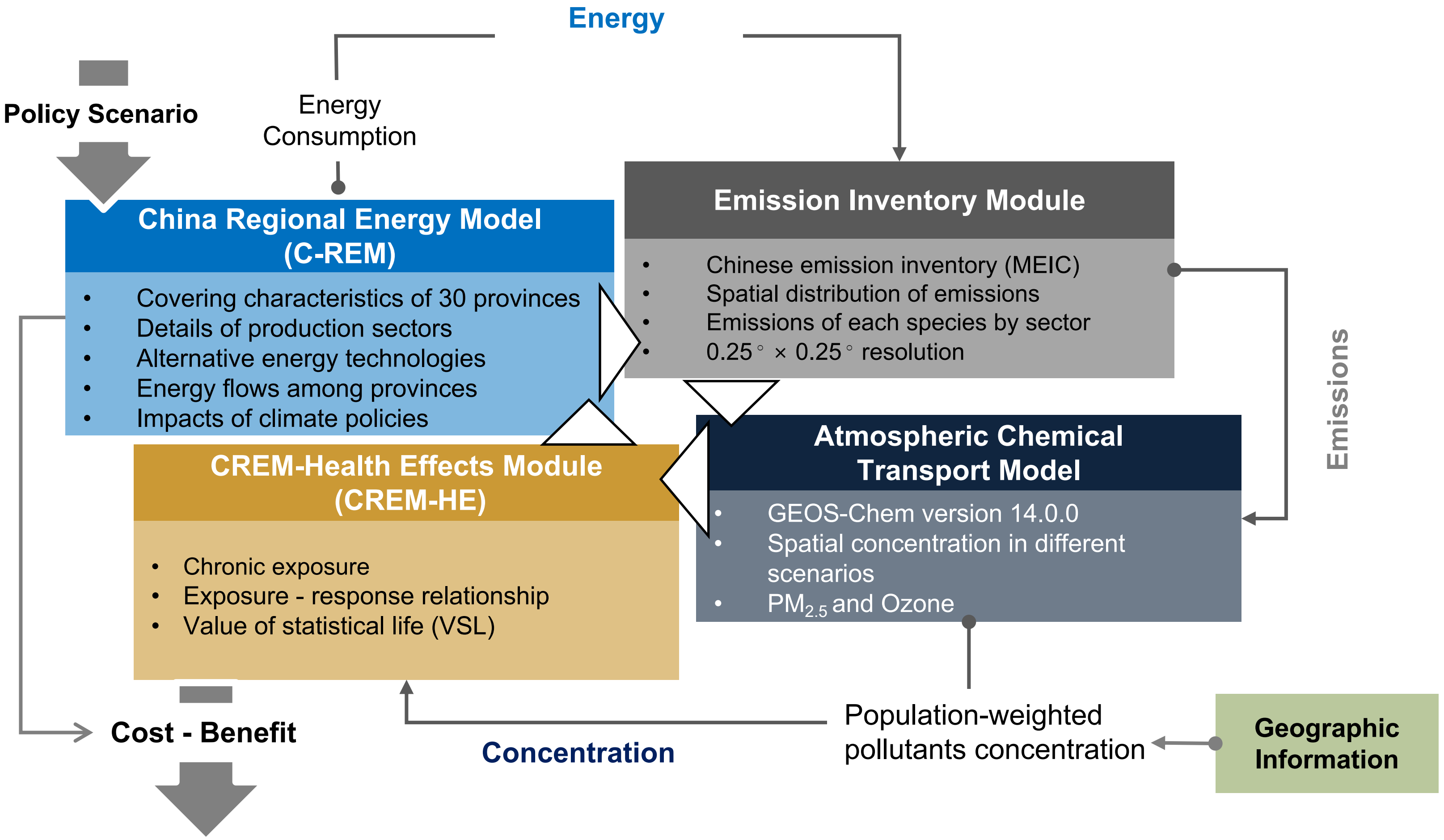
- Ignoring potential partitioned carbon regulation mechanism in the context of China (Zhang et al., 2013; Cui et al., 2014; Fan et al., 2016)
- Lacking the assessment of air pollutants transfer under ETS with atmospheric chemical transport models. (Zhang and Zhang 2020; He et al., 2022)

What are the economic and air quality impacts of China's carbon policy under three different carbon control mechanisms with the same total national CO_2 emissions constraint in 2035?

- Estimate the economic benefits of different carbon control mechanisms
- Estimate the air quality and health impacts of the spatial transfer of co-emitted air pollutants
- Conduct cost-benefit analysis of different carbon control mechanisms

Integrated assessment framework

- Capture the relationship between energy consumption, pollutant emissions, air quality, and human health
- Simulate the health losses or gains to populations in different regions of China resulting from climate policies



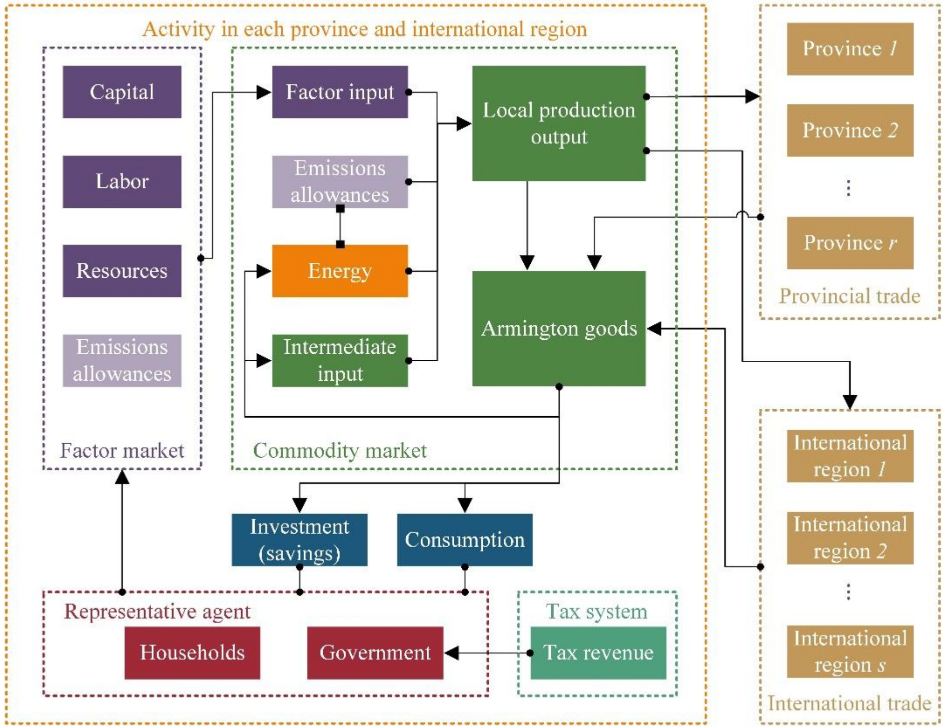
Modeling framework

Source: modified from Zhang *et al.* (2017)

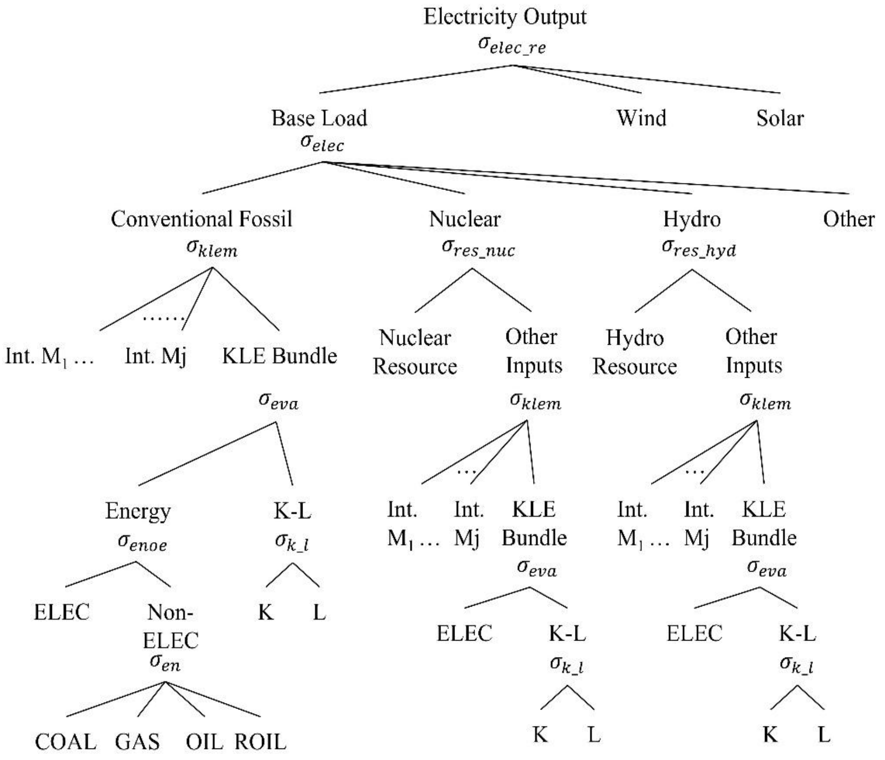
C-REM : China Regional Energy Model (Version 4)

A multi-region, multi-sector, recursive dynamic CGE model

- A global CGE model resolves China's economy and energy system **at the provincial level**
- Updated with GTAP11 and 2017 provincial I-O data
- 20 production sectors and 2 consumption sectors
- Include renewable electricity production and carbon capture and storage technologies



Modeling framework of C-REM



The nested CES function for electricity production

Source: Peng H, Qu C, Karplus VJ, et al. The C-REM 4.0 model: A CGE model for provincial analysis of China's carbon neutrality target. *Energy and Climate Management*, 2024, https://doi.org/10.26599/ECM.2024.9400006

Other modules

- Emission inventory: Chinese emission inventory (MEIC)
- Atmospheric chemistry transport model: GEOS-Chem version 14.0.0
- Evaluation of premature deaths：
  - $PM_{2.5}$: MRBRT (meta-regression–Bayesian regularized trimmed) concentration-response function (CRF) (Global Burden of Disease Collaborative Network, 2021)
  - Ozone: log-linear CRF (Murray et al. 2020)
  - Consider the uncertainty of concentration-response fuctions
- Deaths valuation:
  - Adopt the age-adjusted value of Value of Statistical Life (VSL), according to expected lifetime and welfare distribution (Yin et al. 2021)
  - Consider the uncertainty of the values of VSL

Scenario design

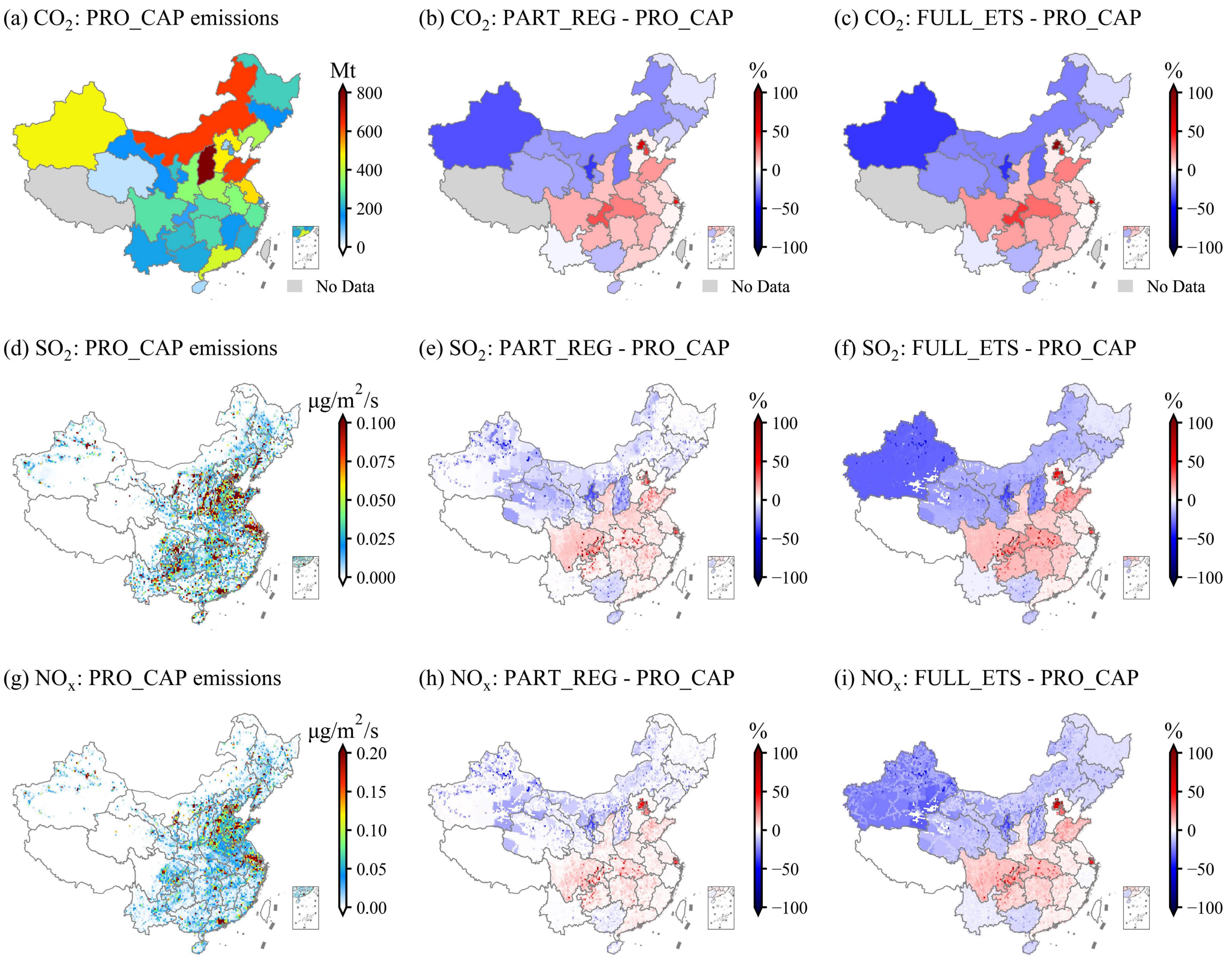
Scenario name	Total CO_2 emissions	ETS coverage	Initial ETS allowance allocation	ETS emissions cap	Provincial control targets
PRO_CAP (provincial control)	**8.9 Gt** (implied by carbon neutrality scenario in Zhang et al (2022))	None	None	None	Set provincial targets for total emissions according to five groups of carbon intensity reduction rates
PART_REG (paritioned carbon regulation)		Power and eight industry sectors	Equal to the resulting sectoral emissions in PRO_CAP	**5.9 Gt** (equal to the resulting total emissions of power and eight industry sectors in PRO_CAP)	Set provincial targets for non-ETS emissions equal to the sum of the non-ETS emissions in PRO_CAP
FULL_ETS (full ETS coverage)		All sectors	Equal to the resulting sectoral emissions in PRO_CAP	**8.9 Gt**	None

Results: Impact on emissions

CO_2

SO_2

NO_x



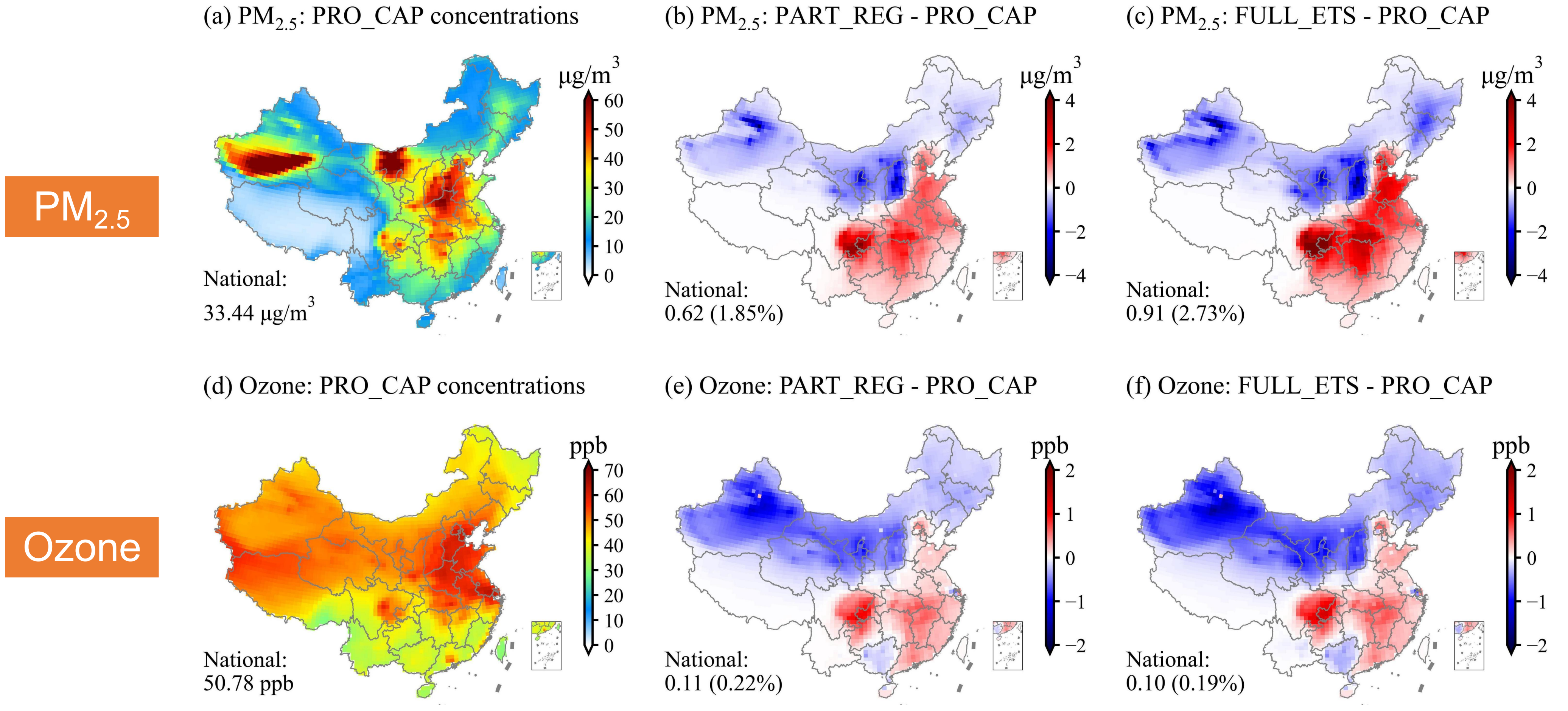
Changes in the CO_2, SO_2, and NO_x concentrations

- A north-to-south transfer of CO_2 emissions in PART_REG and FULL_ETS.
  - Lower marginal abatement cost in northeast provinces
  - Less stringent reduction targets in northeast provinces in PRO_CAP
- The spatial distribution of the percentage changes in SO_2 and NOx is similar to that in CO_2 emissions, due to the co-emitted nature of these species.

Results: Impact on air quality

Under PART_REG and FULL_ETS scenarios:

- $PM_{2.5}$ decreases in northern China and increases in central and southern China.
- Changes in ozone concentration show a similar pattern.



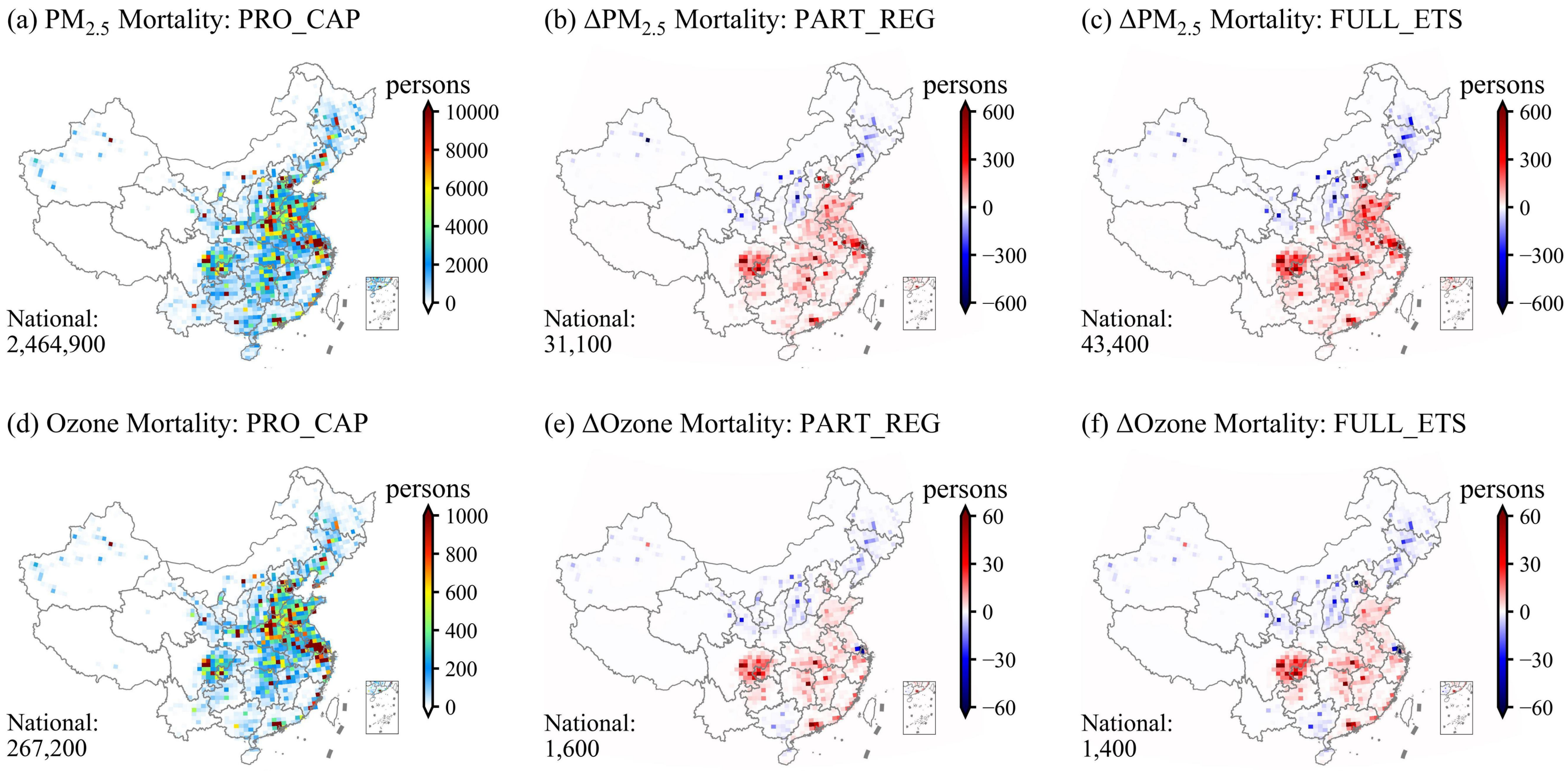
Changes in the $PM_{2.5}$ and ozone concentrations

Results: Impact on premature deaths

- **Provincial distribution**: Premature deaths due to air pollution increase in central and southern China and decrease in northern China under PART_REG and FULL_ETS.
- **National level**: National premature deaths increase by ~32,700 under PART_REG, and ~44,800 under FULL_ETS.

$PM_{2.5}$ -induced mortality

Ozone-induced mortality



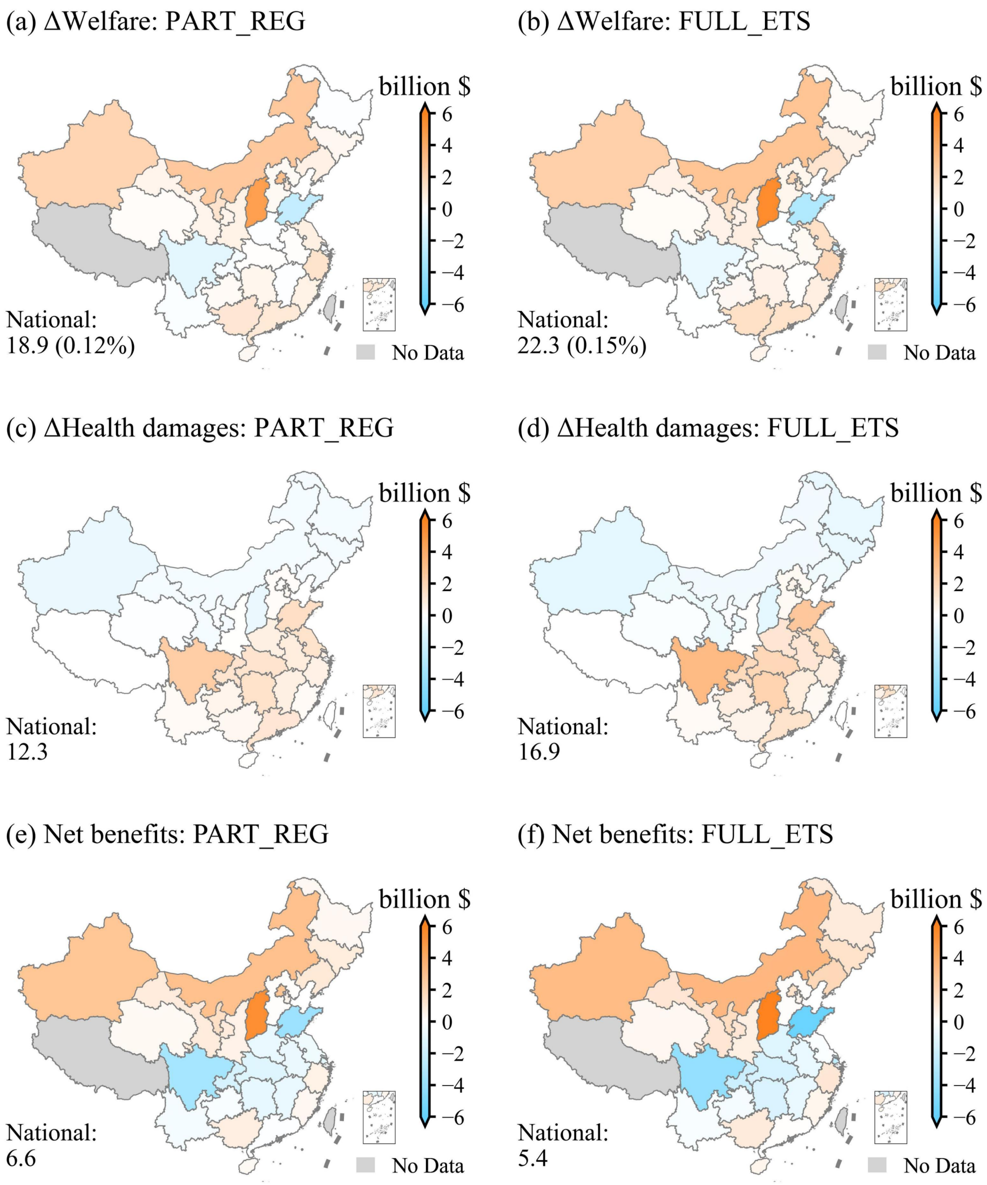
Changes in $PM_{2.5}$ -induced and ozone-induced mortality

Results: Cost-benefit analysis

Welfare

Health damage

Net benefit



Changes in the welfare, health damage, and net benefit

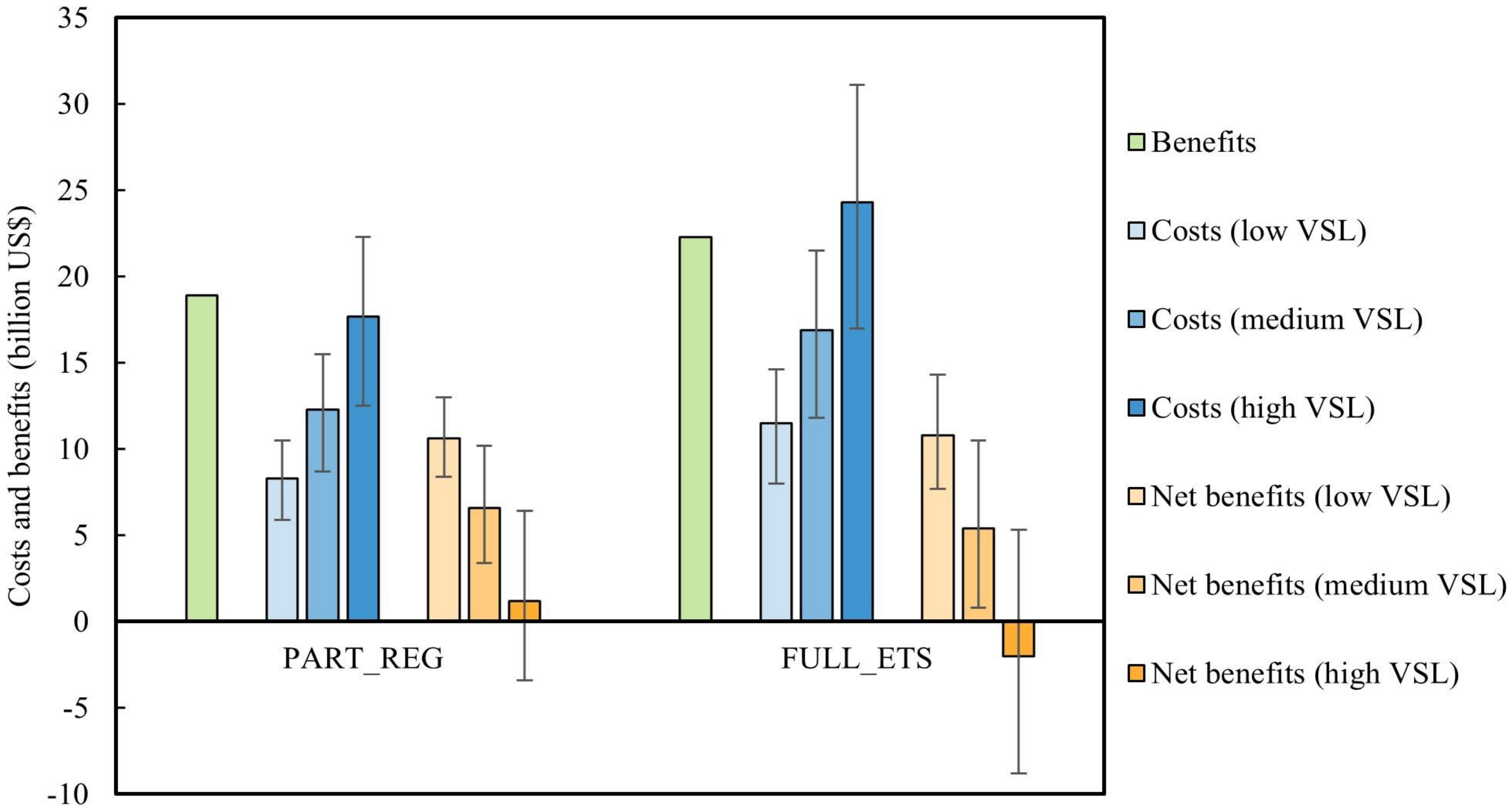
National change	PART_REG (billion USD)	FULL_ETS (billion USD)
Welfare	18.9	22.3
Health damage	12.3	16.9
Net benefit	6.6	5.4

Results of cost-benefit analysis

- The national welfare increases from carbon emission trading.
- The national health damage increases, but only offsets part of the increased welfare.
- Regional pattern:
  - Net positive impact: northern and southeastern coastal provinces
  - Net negative impact: some central and eastern provinces

Results: Uncertainties in CRF and VSL selection

- PART_REG scenario consistently demonstrates positive net benefits except under extreme cases.
- FULL_ETS scenario may result in negative net benefits when adopting the high VSL value.



Uncentainty analysis

	2035 VSL (million US$)	Base value reference
Low	0.95	Hoffmann et al. (2017)
Medium	1.40	Cao et al. (2023)
High	2.02	OECD (2012)

VSL values

Summary

- Employ an integrated modeling framework to compare the **economic impacts and health outcomes associated with $PM_{2.5}$ and ozone**
- Compare three carbon control mechanisms with the same target for national total carbon emissions in 2035
  - The **partitioned carbon regulation mechanism** achieves 85% of the welfare improvement observed under an ideal mechanism with comprehensive ETS coverage.
  - The ETS induces **a transfer of CO_2 and co-emitted air pollutant emissions from northern to southern China** compared to the provincial control mechanism
  - When accounting for health impact transfers, **the ETS remains cost-effective at the national scale** compared to provincial control mechanisms, particularly under the partitioned control mechanism.
  - The northern and southeastern coastal provinces experience net positive benefits, while the central provinces face net negative impacts.
- **Policy implication**: The partitioned carbon regulation mechanism is a valuable option for China, while additional policies may be needed to ensure a more equitable distribution of impacts.

Thank you!

Xinyi Liu
xyliu24@mails.tsinghua.edu.cn

Jun 27, 2025

Scenario design（Appendix）

Group division of China's provinces for CO_2 intensity target setting

Group	Provinces
1	Beijing, Tianjin, Hebei, Shanghai, Jiangsu, Zhejiang, Shandong, Guangdong
2	Fujian, Jiangxi, Henan, Hubei, Chongqing, Sichuan, Shaanxi
3	Shanxi, Liaoning, Jilin, Anhui, Hunan, Guizhou, Yunnan
4	Inner Mongolia, Heilongjiang, Guangxi, Gansu
5	Hainan, Qinghai, Ningxia, Xinjiang

The CO_2 emission intensity reduction target during each period for each group in the PRO_CAP scenario.

Group	Period		
	2021-2025	2026-2030	2031-2035
1	22.0%	24.5%	30.5%
2	21.0%	23.5%	29.5%
3	20.0%	22.5%	28.5%
4	18.0%	20.5%	26.5%
5	14.0%	16.5%	22.5%

References

Aldy J E and Viscusi W K 2008 Adjusting the Value of a Statistical Life for Age and Cohort Effects *Rev. Econ. Stat.* **90** 573–81 DOI: 10.1162/rest.90.3.573

Cao C, Song X, Cai W, Li Y, Cong J, Yu X, Gao M and Wang C 2023 Estimating the value of a statistical life in China: A contingent valuation study in six representative cities *Chinese J. Popul. Resour. Environ.* **21** 269–78 DOI: 10.1016/j.cjpre.2023.11.009

Chang S, Yang X, Zheng H, Wang S and Zhang X 2020 Air quality and health co-benefits of China's national emission trading system *Appl. Energy* **261** 114226 DOI: 10.1016/j.apenergy.2019.114226

China State Council 2024 Inform on the issuing of the Work Plan for Accelerating the Construction of a Dual Control System for Carbon Emissions Online: https://www.gov.cn/zhengce/content/202408/content_6966079.htm

Cui L B, Fan Y, Zhu L and Bi Q H 2014 How will the emissions trading scheme save cost for achieving China's 2020 carbon intensity reduction target? *Appl. Energy* **136** 1043–52 DOI: 10.1016/j.apenergy.2014.05.021

Van Donkelaar A et al 2021 Monthly Global Estimates of Fine Particulate Matter and Their Uncertainty *Environ. Sci. Technol.* **55** 15287–300 DOI: 10.1021/acs.est.1c05309

European Commission 2020 *Communication COM/2020/562: Stepping up Europe's 2030 climate ambition Investing in a climate-neutral future for the benefit of our people* Online: https://knowledge4policy.ec.europa.eu/publication/communication-com2020562-stepping-europe's-2030-climate-ambition-investing-climate_en

Fan Y, Wu J, Xia Y and Liu J Y 2016 How will a nationwide carbon market affect regional economies and efficiency of CO2 emission reduction in China? *China Econ. Rev.* **38** 151–66 DOI: 10.1016/j.chieco.2015.12.011

Farber D A 2012 Pollution markets and social equity: Analyzing the fairness of cap and trade *Ecol. Law Q.* **39** 1–56

HE G, PAN Y and XIE Y 2022 *Market vs. Planning: Emission Abatement under Incomplete Information and with Local Externalities* Online: https://www.econ.cuhk.edu.hk/econ/images/content/news_event/seminars/2022-23_1st/HeGuojun.pdf

Hoffmann S, Krupnick A and Qin P 2017 Building a Set of Internationally Comparable Value of Statistical Life Studies: Estimates of Chinese Willingness to Pay to Reduce Mortality Risk *J. Benefit-Cost Anal.* **8** 251–89 DOI: 10.1017/bca.2017.16

References

Li M, Zhang D, Li C T, Mulvaney K M, Selin N E and Karplus V J 2018 Air quality co-benefits of carbon pricing in China *Nat. Clim. Chang.* **8** 398–403 DOI: 10.1038/s41558-018-0139-4

Lyu X et al 2023 A synergistic ozone-climate control to address emerging ozone pollution challenges *One Earth* **6** 964–77 DOI: 10.1016/j.oneear.2023.07.004

Mendelsohn R 1986 Regulating heterogeneous emissions *J. Environ. Econ. Manage.* **13** 301–12 DOI: 10.1016/0095-0696(86)90001-X

Muller N Z and Mendelsohn R 2009 Efficient Pollution Regulation: Getting the Prices Right *Am. Econ. Rev.* **99** 1714–39 DOI: 10.1257/aer.99.5.1714

Murray, Christopher JL, et al. 2020 Global burden of 87 risk factors in 204 countries and territories, 1990–2019: a systematic analysis for the Global Burden of Disease Study 2019. The lancet 396.10258 (2020): 1223-1249.

OECD 2012 *Mortality Risk Valuation in Environment, Health and Transport Policies* Online: http://dx.doi.org/10.1787/9789264130807-en

Tietenberg T 1995 Tradeable permits for pollution control when emission location matters: What have we learned? *Environ. Resour. Econ.* **5** 95–113 DOI: 10.1007/BF00693018

Yin H et al 2021 Population ageing and deaths attributable to ambient PM2·5 pollution: a global analysis of economic cost *Lancet Planet. Heal.* **5** e356–67 DOI: 10.1016/S2542-5196(21)00131-5

Zhang D, Springmann M and Karplus V J 2016 Equity and emissions trading in China *Clim. Change* **134** 131–46 DOI: 10.1007/s10584-015-1516-x

Zhang H and Zhang B 2020 The unintended impact of carbon trading of China's power sector *Energy Policy* **147** 111876 DOI: 10.1016/j.enpol.2020.111876

Zhang X, Huang X, Zhang D, Geng Y, Tian L, Fan Y and Chen W 2022 Research on the pathway and policies for China's energy and economy transformation toward carbon neutrality *Manage. World* **38** 35–66 DOI: 10.19744/j.cnki.11-1235/f.2022.0005

Zhang X, Ou X, Yang X, Qi T, Nam K-M, Zhang D and Zhang X 2017 Socioeconomic burden of air pollution in China: Province-level analysis based on energy economic model *Energy Econ.* **68** 478–89 DOI: 10.1016/j.eneco.2017.10.013

Zhang X, Zhang D and Yu R 2021 Theory and practice of China's national carbon emissions trading system *J. Manag. World* **37** 80–95 DOI: 10.19744/j.cnki.11-1235/f.2021.0108