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Health Impacts of Carbon Neutrality in China under Different Technological Solutions

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Part 01

Introduction

Part 01 Background

China's Carbon Neutrality Goal requires systematic socio-economic transformation and application of key emission reduction technologies.

Extensive research on pathways to achieve carbon neutrality.

- Pathways towards Carbon Neutrality (Zhang X et al. (2020), He et al. (2021), Li et al. (2022), Liu et al. (2022), IEA (2020), Duan H et al. (2021), and more.)

Focused Research on Specific Technologies

- **Biomass Resources:** e.g., Huang et al. (2020), Kang et al. (2020), Nie et al. (2022), Xing, X. et al. (2021), Wang, R. et al. (2021). **Biomass energy potential in 2060 ranges 4~13EJ.**
- **Non-fossil Energy Generation:** e.g., Chen et al. (2021), Liu L et al. (2022), Zhuo et al. (2022), Zhai et al. (2023), Wang Y. et al. (2023). **Wind and Solar energy potential in 2060 ranges 9-15 PWh**
- **CCUS (Carbon Capture, Utilization, and Storage):** e.g., Tang et al. (2021), Fan et al. (2023), and others. **CCUS potential ranges 0~2.5 Gt/year.**

Li, L., Zhang, Y., Zhou, T., Wang, K., Wang, C., Wang, T., ... & Lü, G. (2022). Mitigation of China's carbon neutrality to global warming. *Nature Communications*, *13*(1), 5315.
Liu, Z., Deng, Z., He, G., Wang, H., Zhang, X., Lin, J., ... & Liang, X. (2022). Challenges and opportunities for carbon neutrality in China. *Nature Reviews Earth & Environment*, *3*(2), 141-155.
Zhang X., Huang X., Zhang D., Geng Y., Tian L., Fan Y., Chen W. (2022). Research on the Pathway and Policies for China's Energy and Economy Transformation toward Carbon Neutrality. [in Chinese] *Management World*, 38(01),35-66.
Zhang, S., & Chen, W. (2022). Assessing the energy transition in China towards carbon neutrality with a probabilistic framework. *Nature communications*, *13*(1), 87.

Part 01 Background

Studies vary significantly due to different evaluation methods and assumptions about technology costs. → multiple technological pathways to achieve carbon neutrality.

Different Mitigation Technologies have Different Implications on Human Health

- **Environmental Air Quality:** Carbon neutrality improves air quality (Tang et al., 2022; Cheng et al., 2021/2023; Ma et al., 2023; Shi et al., 2021; Xu et al., 2022; Zhang & Chen, 2022.) ; impacts vary by technology (Zhang, S. et al., 2021).
- **Climate:** Different pathways can lead to different temperature rises due to aerosols' cooling effects (Akhtar et al., 2013; Xu et al., 2022; Wang et al.,2023).

Need for deep understanding of systemic differences, magnitude of differences, and decision-making factors between technological solutions.

Wang, P. et al. Aerosols overtake greenhouse gases causing a warmer climate and more weather extremes toward carbon neutrality. Nat. Commun. 14, 7257 (2023).
Xu, B. et al. Impacts of regional emission reduction and global climate change on air quality and temperature to attain carbon neutrality in China. Atmospheric Res. 279, 106384 (2022).
Zhang, S. et al. Incorporating health co-benefits into technology pathways to achieve China's 2060 carbon neutrality goal: a modelling study. Lancet Planet. Health 5, e808–e817 (2021).

Part 01 Our study

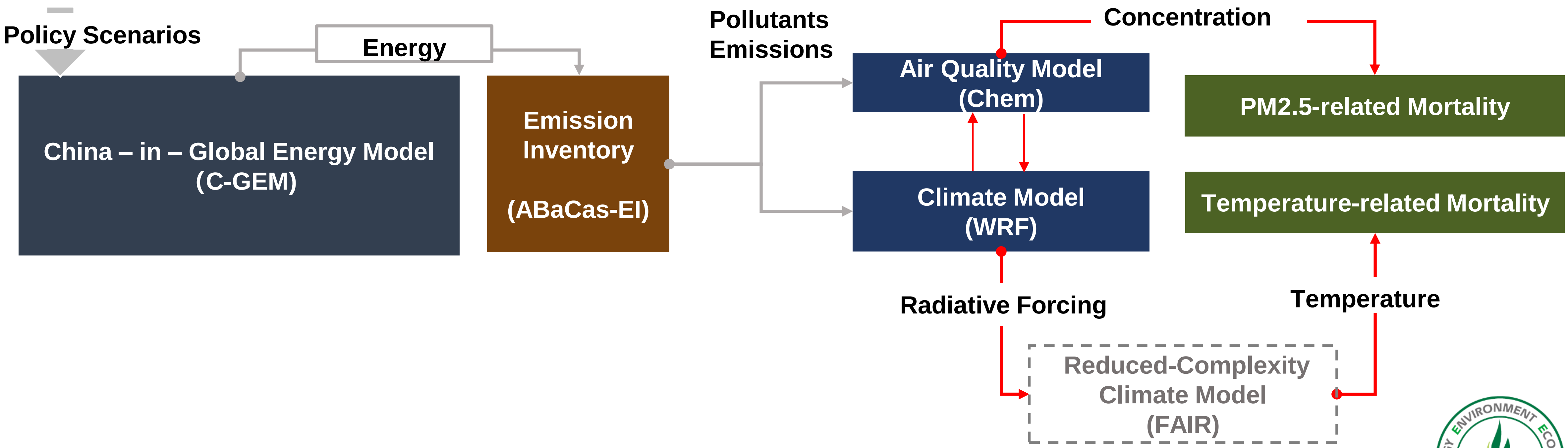
What are the air pollutant-related health impact of carbon neutrality in China?

In what ways do the health impacts of various CO_2 mitigation technological solutions differ in the context of carbon neutrality in China?

Part 02

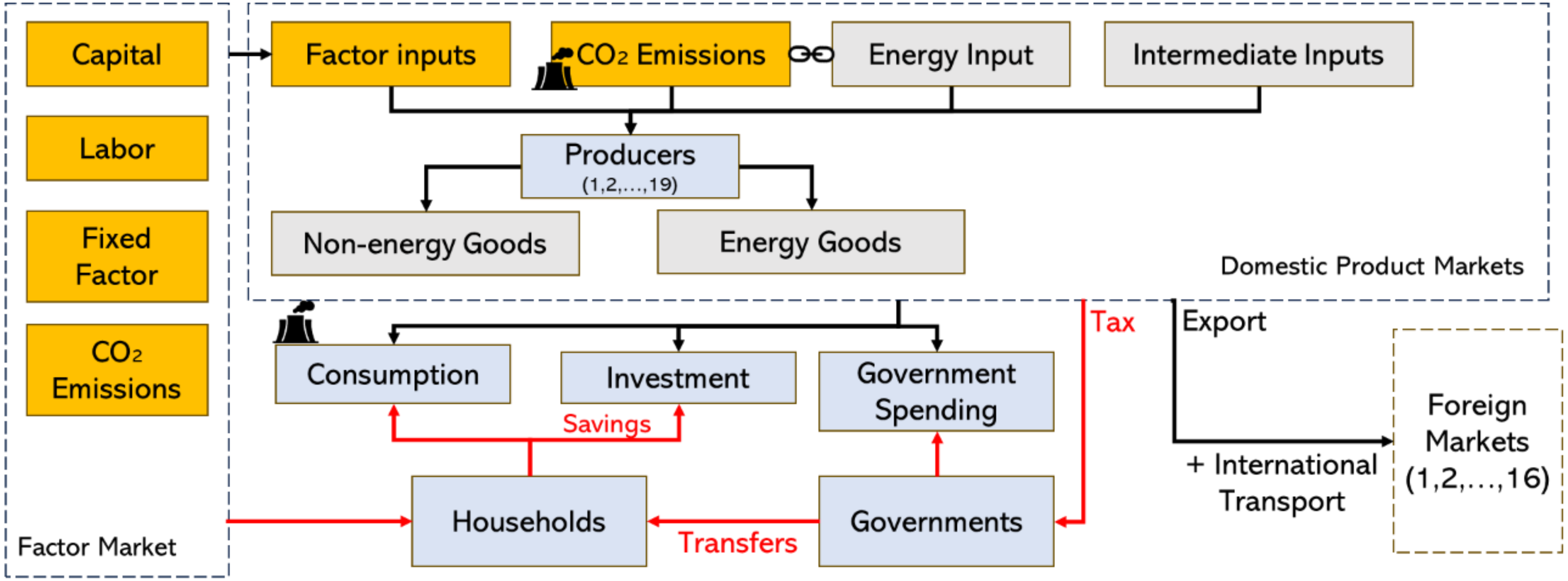
Modeling Framework

Part 02　Model Framework



Part 02 China-in-Global Energy Model, C-GEM

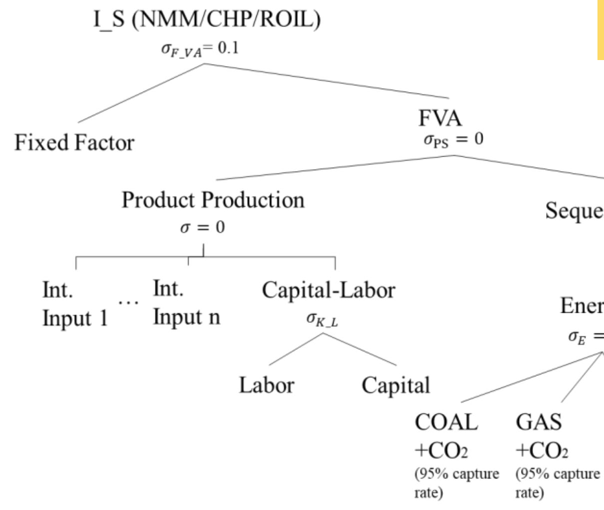
- A global CGE model, with 17 Regions, 22 sectors.
- China's parameters are calibrated based on localized and most recent economic and energy data for China.
  - Integrates China's input-output table and energy balance table with the GTAP database.



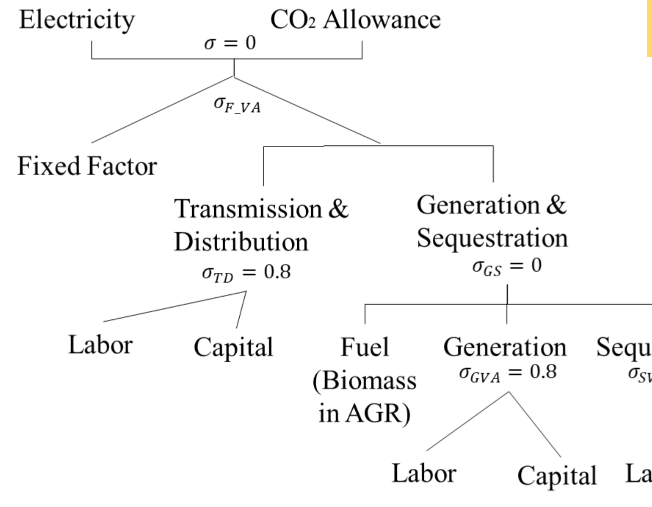
Part 02 China-in-Global Energy Model, C-GEM

- Incorporates important zero-emissions and negative-emissions technologies
  - Wind and solar energy, nuclear energy
  - Electric vehicles
  - Carbon Capture and Storage (CCS) utilization in electricity and industrial sectors
  - Bio-energy With Carbon Capture and Storage (BECCS)
  - Direct Air Capture with Carbon Storage (DACCS)

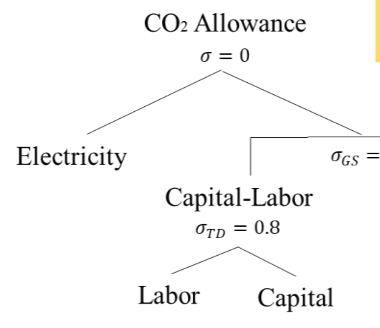
Industrial CCS



BECCS



DACCS



Part 03

Scenarios

Part 03 Scenarios

- Carbon neutrality target represented by a national ETS, with inclusion of all emitters and negative-emission technologies

Scenarios	Central Scenario (CS)	High Renewable (HR)	High Biomass (HB)
Description	• Balanced between the development of different technologies.	• Higher potential of the wind, solar, hydro and nuclear energy, and easier electricity utilization. • Lower potential of CCS.	• Higher potential of BECCS and Biomass. • Lower potential of wind, solar, nuclear energy.
Characteristics			
Total CO_2 Captured by biomass burning per year ($GtCO_2$/year)	0.5	0.2	0.8
Total CO_2 Captured by DAC per year ($GtCO_2$/year)	0.4	0.1	0.2
Total CO_2 Captured per year ($GtCO_2$/year)	2.2	0.3	2.3
Share of Non-fossil energy in primary energy consumption (%)	80	97	80
Wind and Solar Generations (PWh)	12	15	11
Share of electricity, heat and hydrogen in final energy consumption (%)	82	95	78

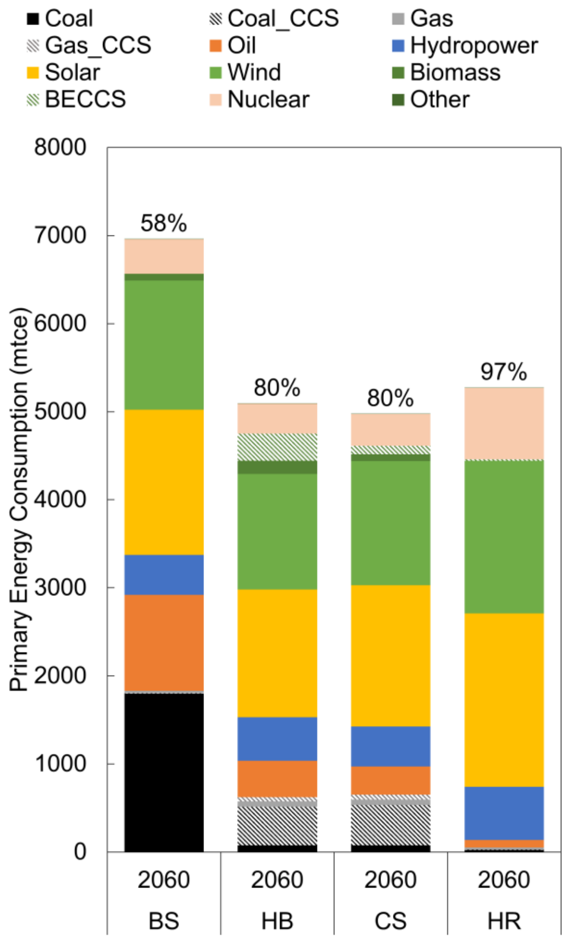
Scenario Design Method

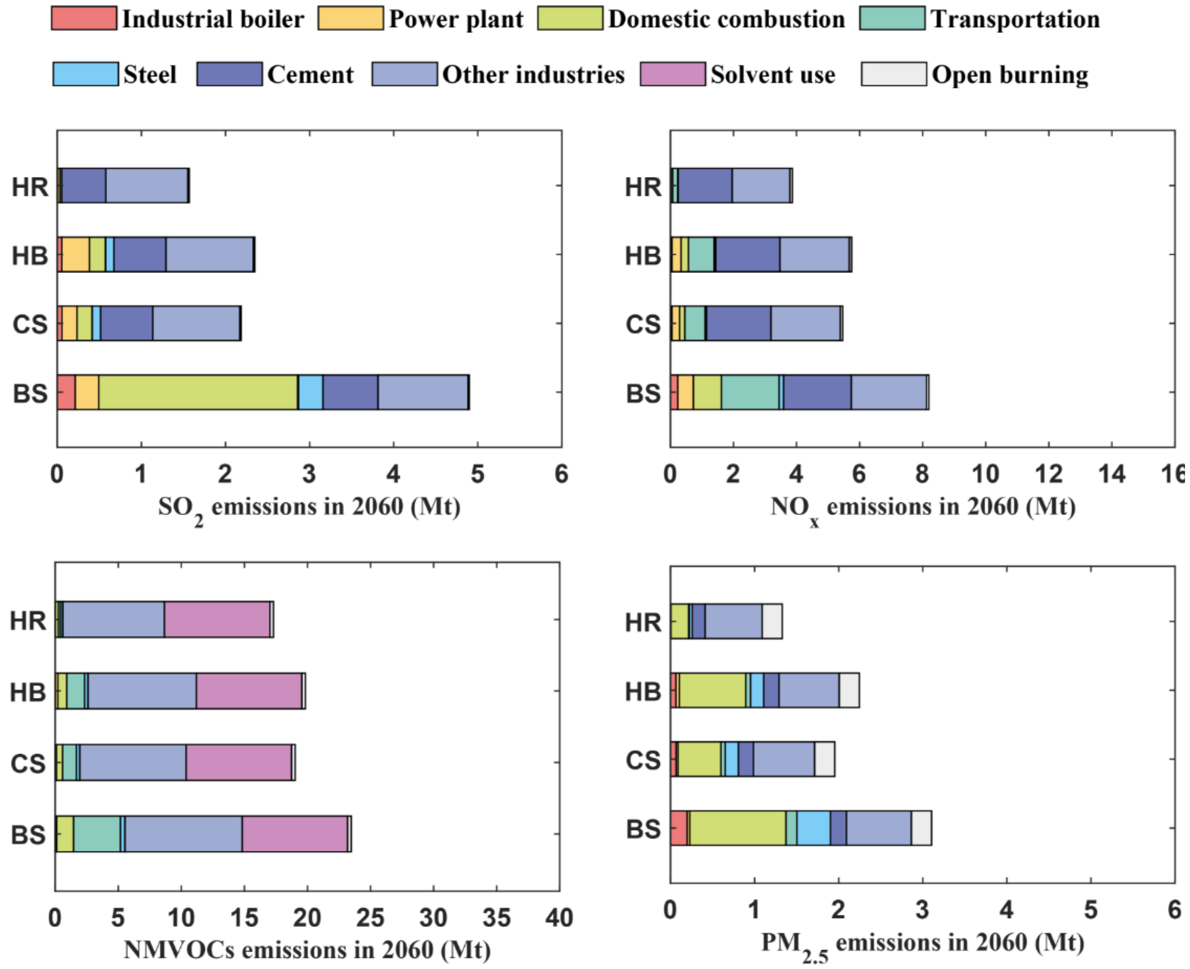
- Conducted numerous simulations varying technology parameters to identify three **possible representative** scenarios.
  - Principle: **Technically feasible, policy-compatible**, and **cost-comparable,** with the **largest possible differences**.
- Baseline scenario: 4%/year reduction rate of CO_2/GDP; No CCS technology becomes available.

Part 04

Results

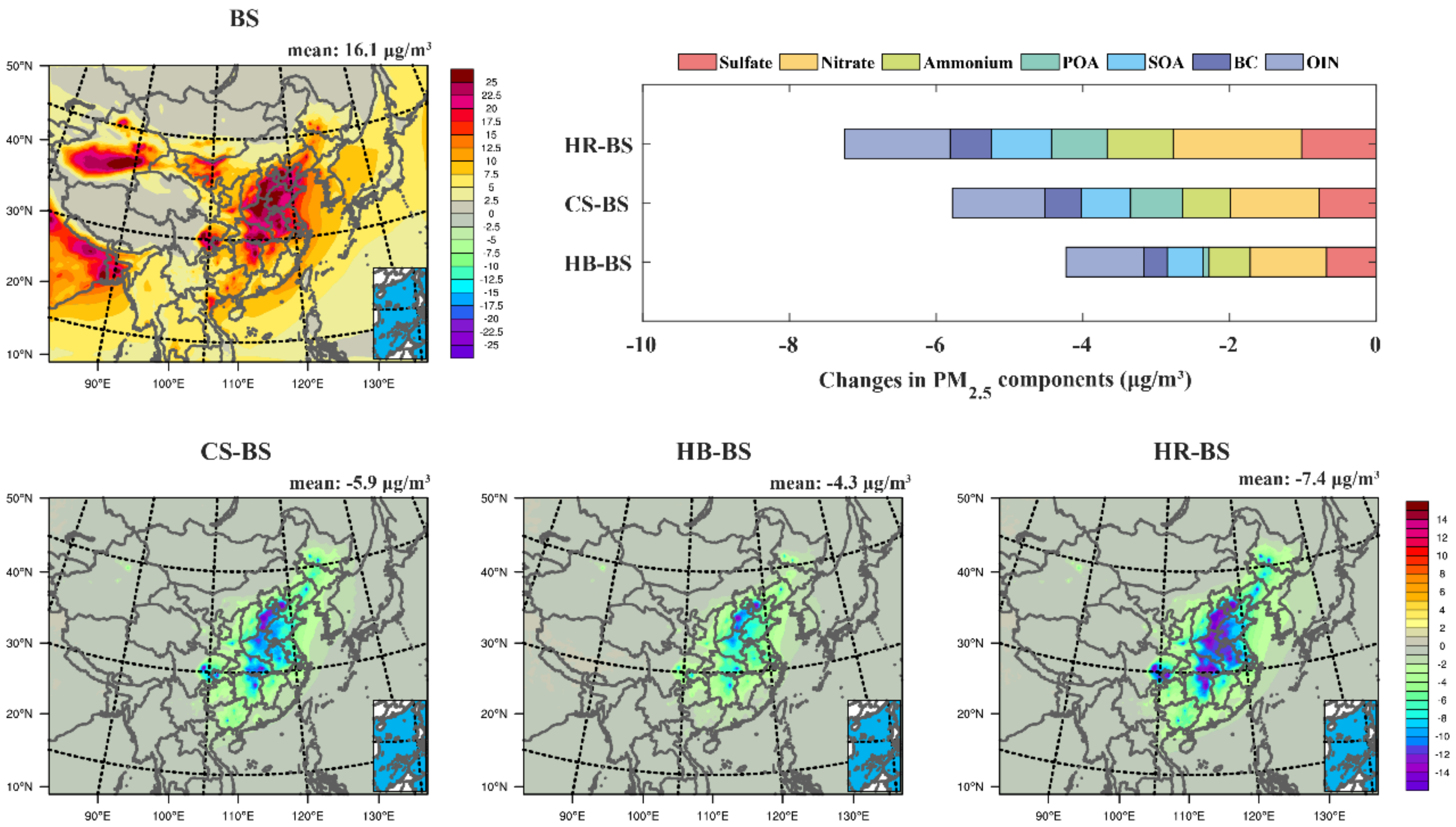
Part 04 Results Energy Structure & Emissions





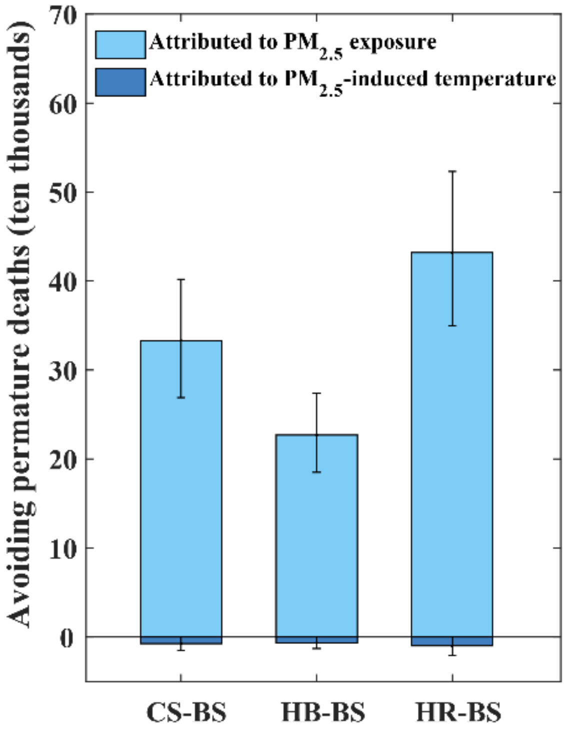
* Percentage represents the proportion of non-fossil energy in primary energy consumption

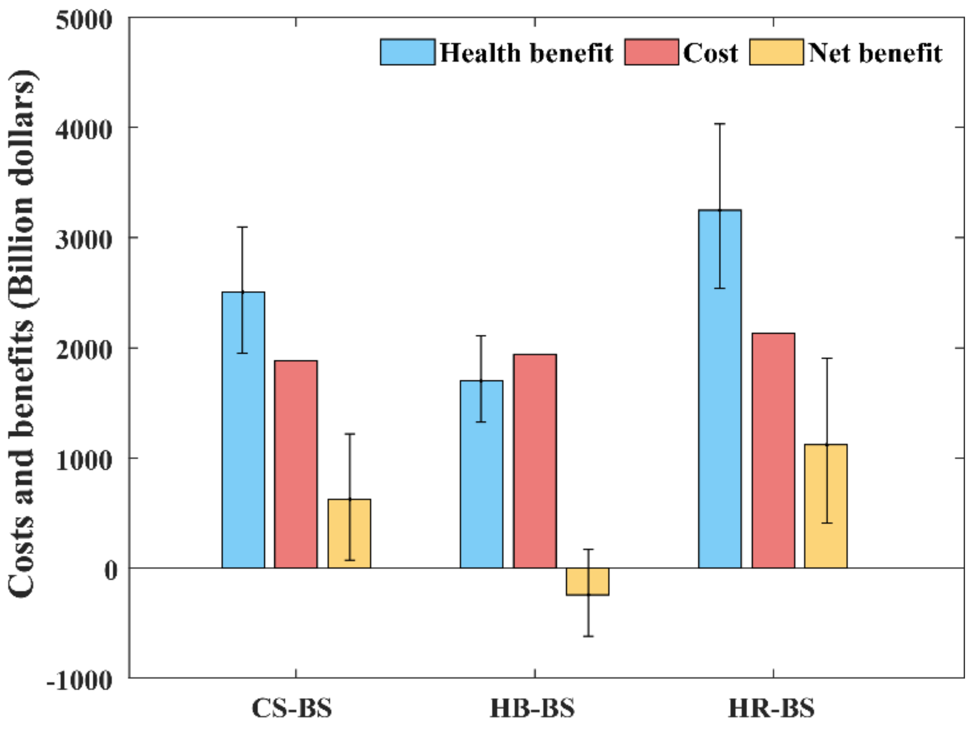
Part 04 Results Air Quality



- ➢ Population-weighted $PM_{2.5}$ concentrations in 2060 decrease by 4.3 (27%), 5.9 (37%), and 7.4 μg/m³ (46%) compared to the baseline scenario.
- ➢ Increased technology development shifting to clean renewable energy leads to **significant** improvements in air quality.
- ➢ Rural areas benefit more from transitioning to renewable energy due to reduced emissions of air pollutants.

Part 04 Results Health Impacts

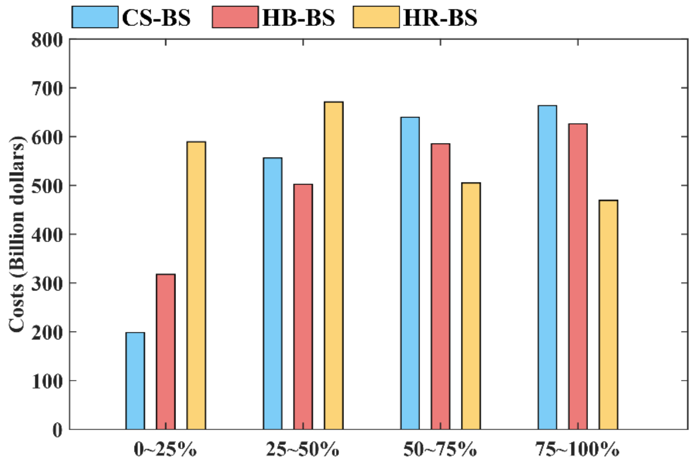


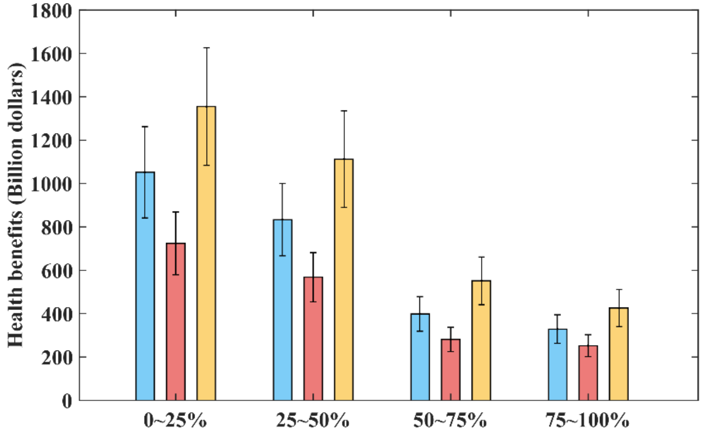


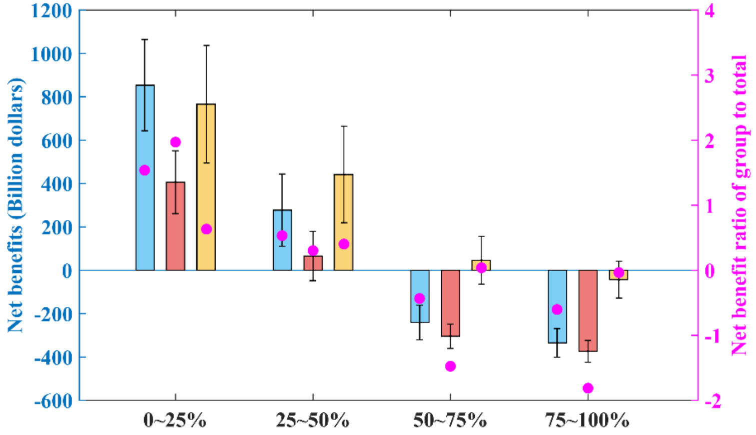
- Avoidance of 230 [190-280], 340 [270-400], and 440 [350-530] thousand premature deaths in 2060.
- The increase in GMAT in HR results in 10,052 premature deaths (confidence interval 588-20,693), 1/40 of the $PM_{2.5}$ pollution-attributable avoiding premature deaths.
- Generated net gains of -0.2 (-0.6 to 0.1), 0.6 (0.03 to 1.2) and 1.1 (0.3 to 1.8) trillion dollars.-> **Technology choice does matter!**

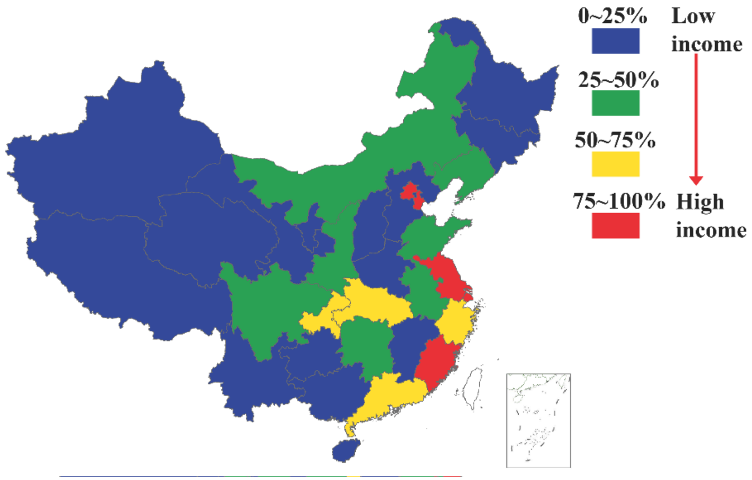
Cromar, K. R. et al. (2022). Global health impacts for economic models of climate change: a systematic review and meta-analysis. Ann. Am. Thorac. Soc. 19, 1203–1212
Rennert, Kevin, et al. "Comprehensive evidence implies a higher social cost of CO2." *Nature* 610.7933 (2022): 687-692.
BenMAP-CE： Environmental Protection Agency. (2022). BenMAP-CE
Chen, Y., Guo, F., Wang, J., Cai, W., Wang, C., & Wang, K. (2020). Provincial and gridded population projection for China under shared socioeconomic pathways from 2010 to 2100. *Scientific Data*, *7*(1), 83.

Part 04 Results Distributional Impacts





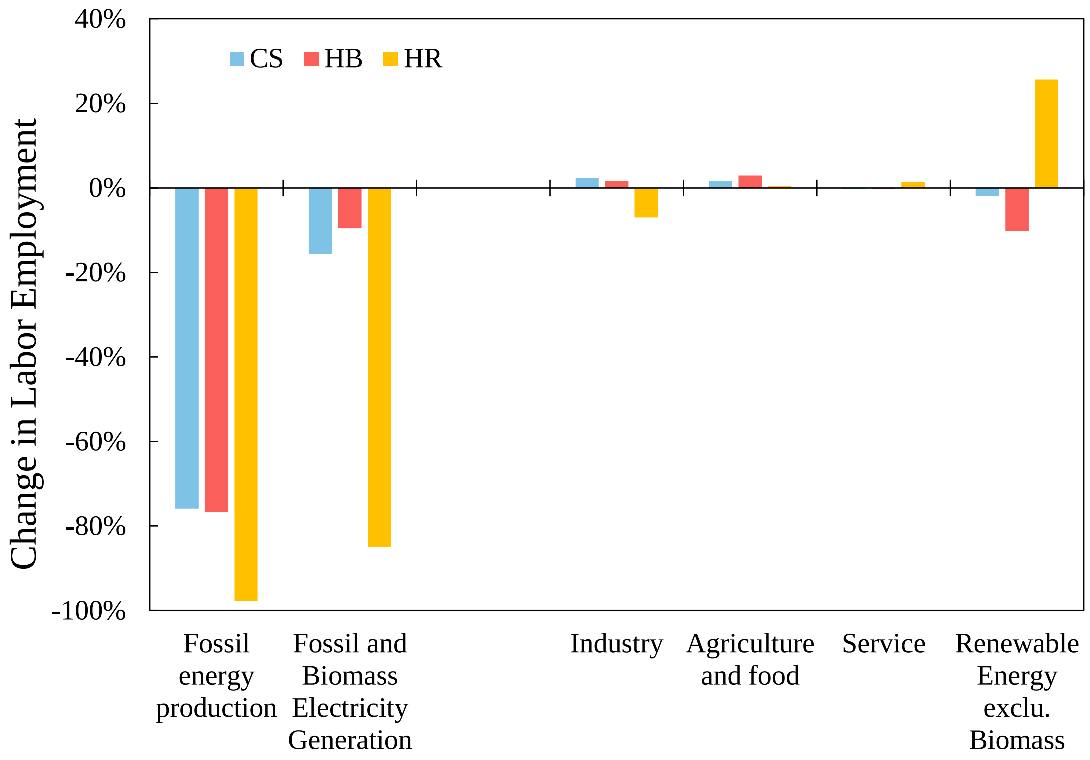




- ➢ A greater portion of the net co-benefits of carbon neutrality are allocated to relatively poor provinces.
- ➢ This phenomenon beneficial to the poor will be amplified in the CS and HR scenarios.
- DACCS and BECCS generates a significant amount of rent from emissions allowance in 2060 (~1% national GDP).
- These provinces in the lowest income group, such as Xinjiang and Yunnan, happen to be more suitable for negative emissions technologies DACCS and BECCS (Xing et al., 2021).

Xing, X., Wang, R., Bauer, N., Ciais, P., Cao, J., Chen, J., ... & Xu, S. (2021). Spatially explicit analysis identifies significant potential for bioenergy with carbon capture and storage in China. Nature communications, 12(1), 3159.

Part 04 Results Distributional Impacts



Carbon Capture and Storage can also contribute to the preservation of employment opportunities within the fossil energy sectors.

Part 04 Conclusions

- A decarbonization pathway associated with high utilization of clean renewable energy is estimated to reduce $PM_{2.5}$ concentration by the most, 7.4 μg m^{-3} (47%), and achieve the maximum health benefit of 3,326 billion dollars (CI: 2627~3961 billion dollars).

- Only half and three-quarters of $PM_{2.5}$ improvement and health benefits can be achieved by the pathways associated with high utilization of biomass energy or carbon capture and storage, respectively.

- Under certain conditions, the implementation of DACCS and BECCS could benefit economically disadvantaged regions in China and preserve employment opportunities within the fossil energy sectors.
  - Requires further investigation for a comprehensive understanding.

- Our study focuses on the benefit side of carbon neutrality:
  - Requires further investigation on designing policies to achieve the certain technology scenario.

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