Synergies and co-benefits of a clean energy transition in China

Princeton School of Public and International Affairs

Denise L. Mauzerall
Professor
Princeton University

Civil and Environmental Engineering

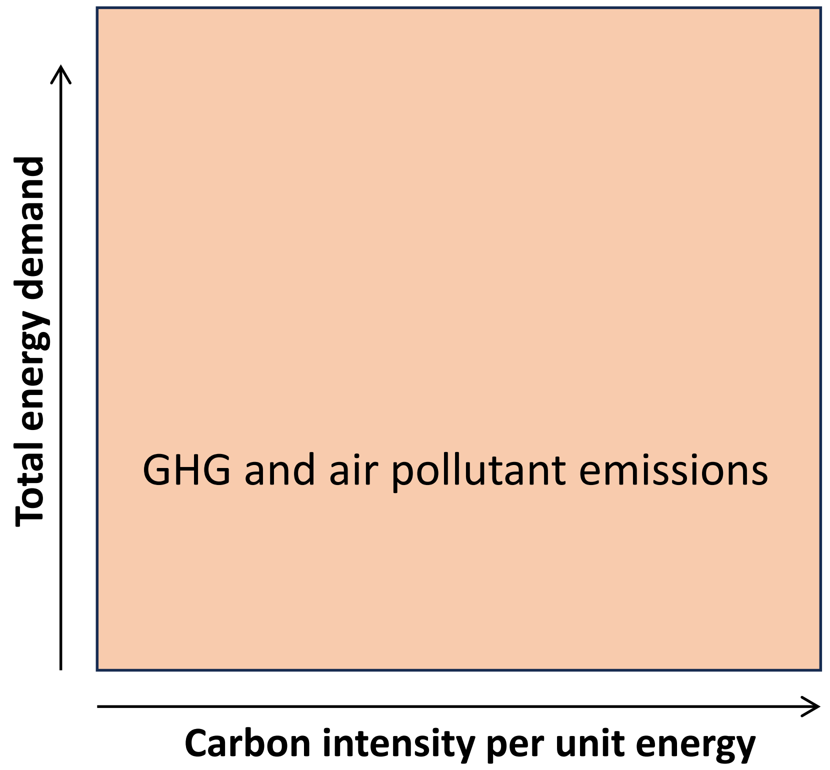
Nature Conference – Air Pollution and Climate Change
Beijing, China
May 23, 2024

Objectives

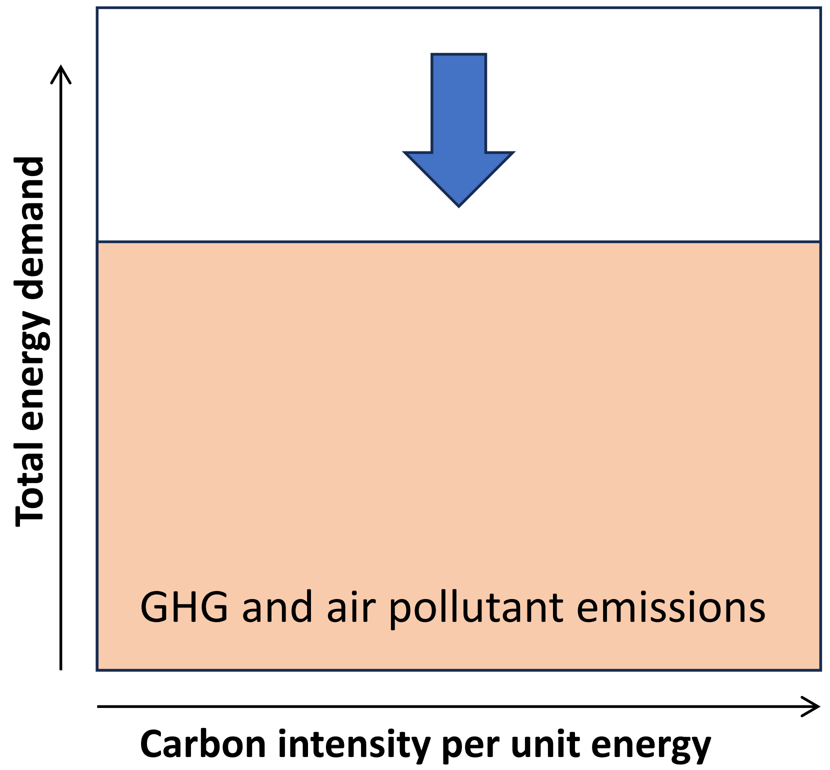
Evaluate Opportunities, Synergies and co-Benefits of Decarbonization in the **Residential, Industry, Power, Transport** and **Agricultural** sectors to reduce:

- Greenhouse Gas Emissions ($CO_{2(eq)}$)
- Air Pollutant Emissions and Resulting Concentrations;
- Premature Mortalities Due to Air Pollution.
- Costs of mitigation

Two approaches to decarbonizing the economy

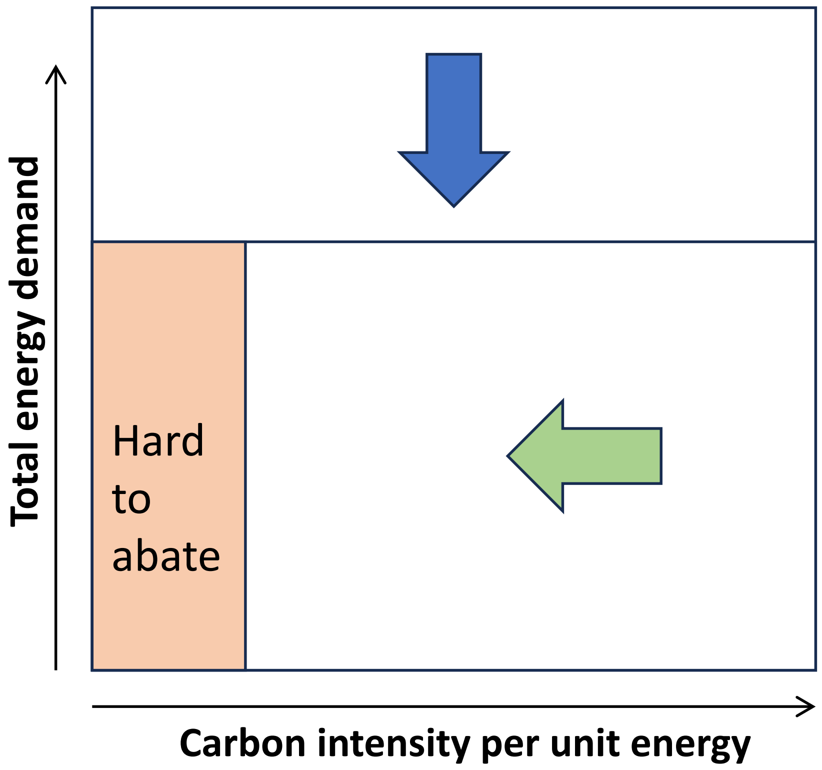


Demand-side approach to decarbonizing the economy



Demand-side approach:
Improve energy efficiency to reduce total energy demand

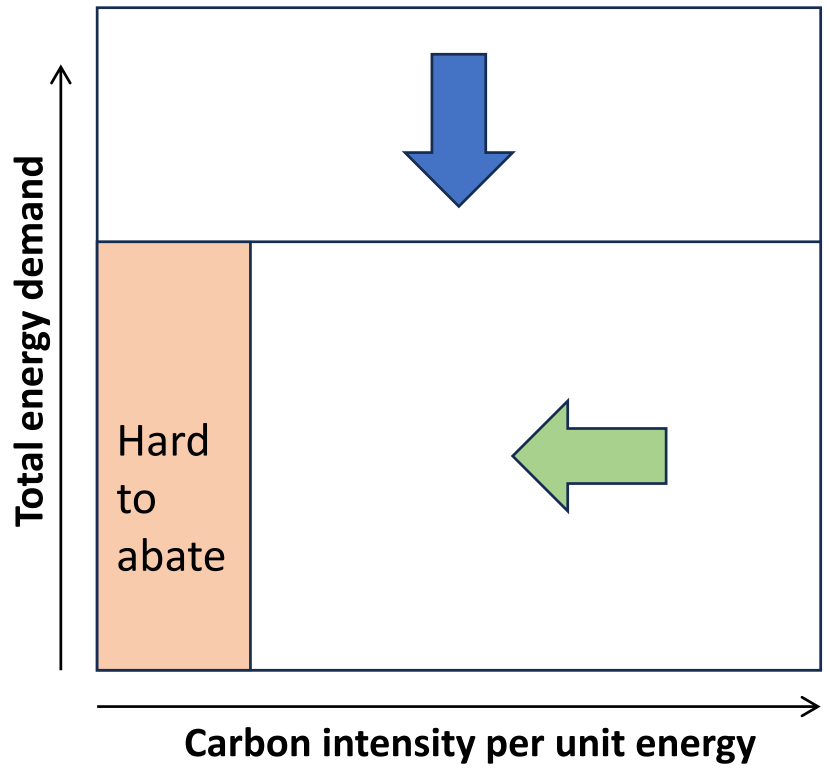
Supply-side approach to decarbonizing the economy



Demand-side approach:
Improve energy efficiency to reduce total energy demand

Supply-side approach:
Decarbonize the remaining energy required for the process.

Two approaches to decarbonizing the economy



Demand-side approach:
Improve energy efficiency to reduce total energy demand

Supply-side approach:
Decarbonize the remaining energy required for the process.

Goals:

1. Identify opportunities to reduce energy demand;
2. Identify opportunities to decarbonize energy supply;
3. Examine process synergies to decarbonize the remaining hard-to-abate sectors.

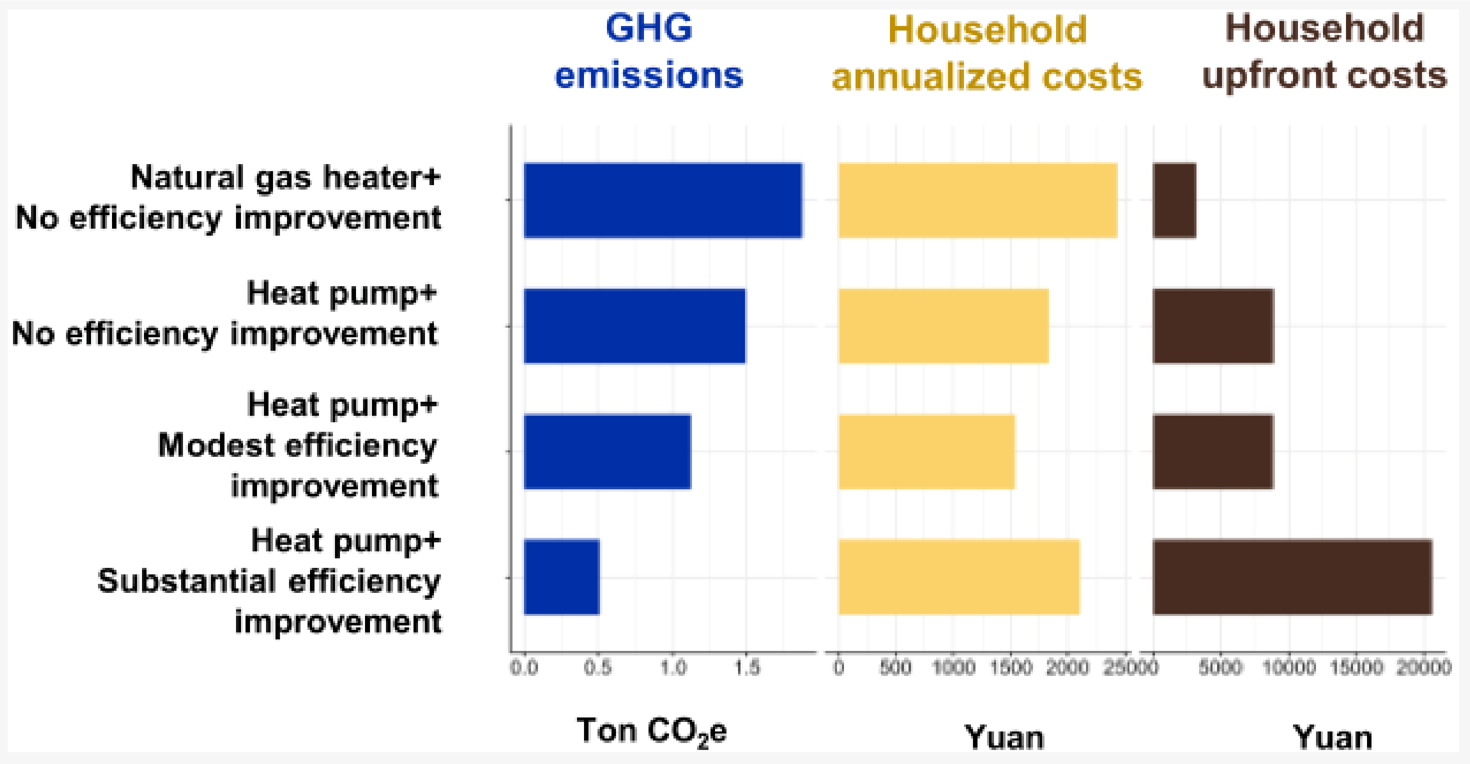
Demand Side: Benefits of Improving Building Envelope Efficiency

Environmental Science & Technology
pubs.acs.org/est

2022

Improving Building Envelope Efficiency Lowers Costs and Emissions from Rural Residential Heating in China

Shangwei Liu, Hongxun Liu, and Denise L. Mauzerall*



Building retrofits:

- Improving building envelope efficiency prior to heat pump installation reduces size and resulting costs of new heaters;
- Operating costs and hence backsliding to coal also decrease.

Financing:

- Replacing current fuel subsidies with building envelope subsidies is a win-win-win for rural households, local government and the environment

New building construction:

- Whole home insulation coupled with heat pumps avoids carbon lock-in.

Supply Side: Diversifying Heat Sources in China's Urban District Heating Systems Will Reduce Carbon Lock-in

Liu, S, Y Guo, F Wagner, H Liu, R Cui, DL Mauzerall

nature energy

In press 2024

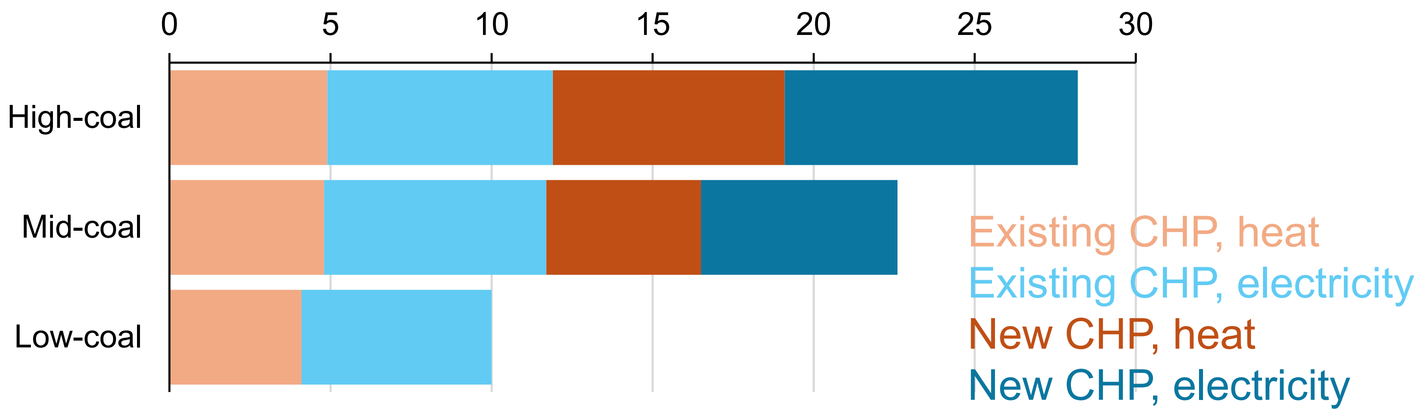
China's reliance on coal power plants for urban district heating risks carbon lock-in as the power plants are needed for heat and thus can't be shut down and replaced with renewable energy.

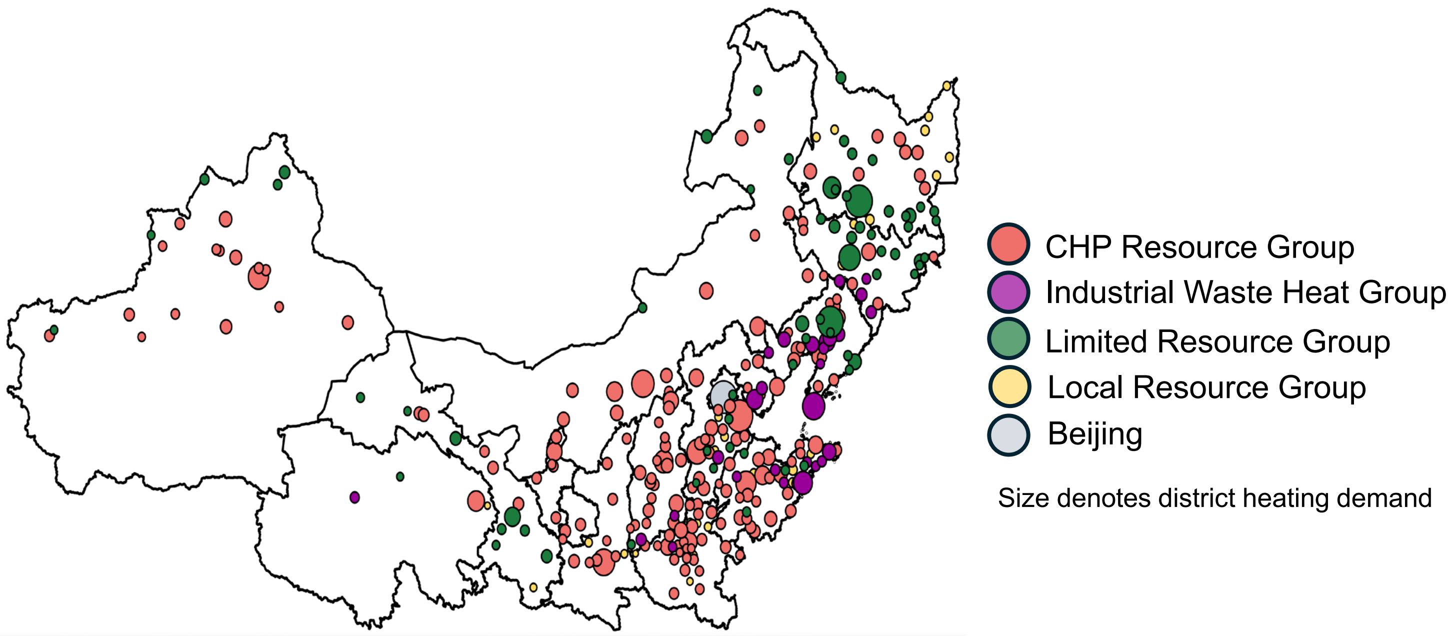
We examine the cost and emission implications of various possible near-term (2020-2030) district heating investment scenarios:

- **High-coal:** primarily existing and many new coal combined heat and power (CHP)
- **Mid-coal**: existing and new coal CHP + industrial waste heat (steel, nuclear)
- **Low-coal:** no new coal CHP + industrial waste heat + air/ground-source heat pumps

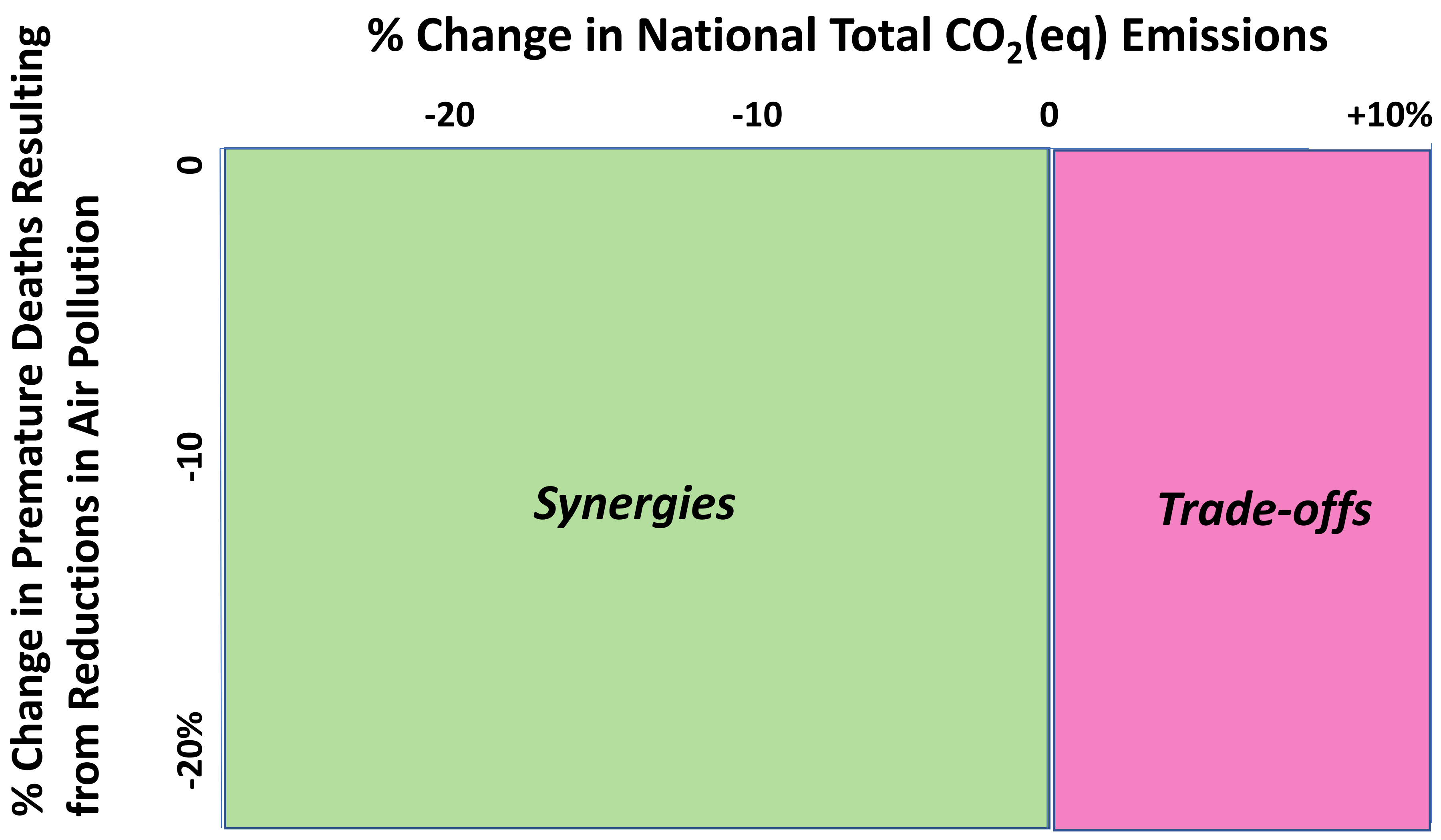
We propose a city-level strategy to implement government policy proposals to electrify district heating and deploy low-carbon heating technologies.

Committed CO_2 emissions from existing and new CHP plants during the heating season, 2020-2060, Gt





Synergies and Trade-offs between Reducing Air Pollutant and GHG Emissions

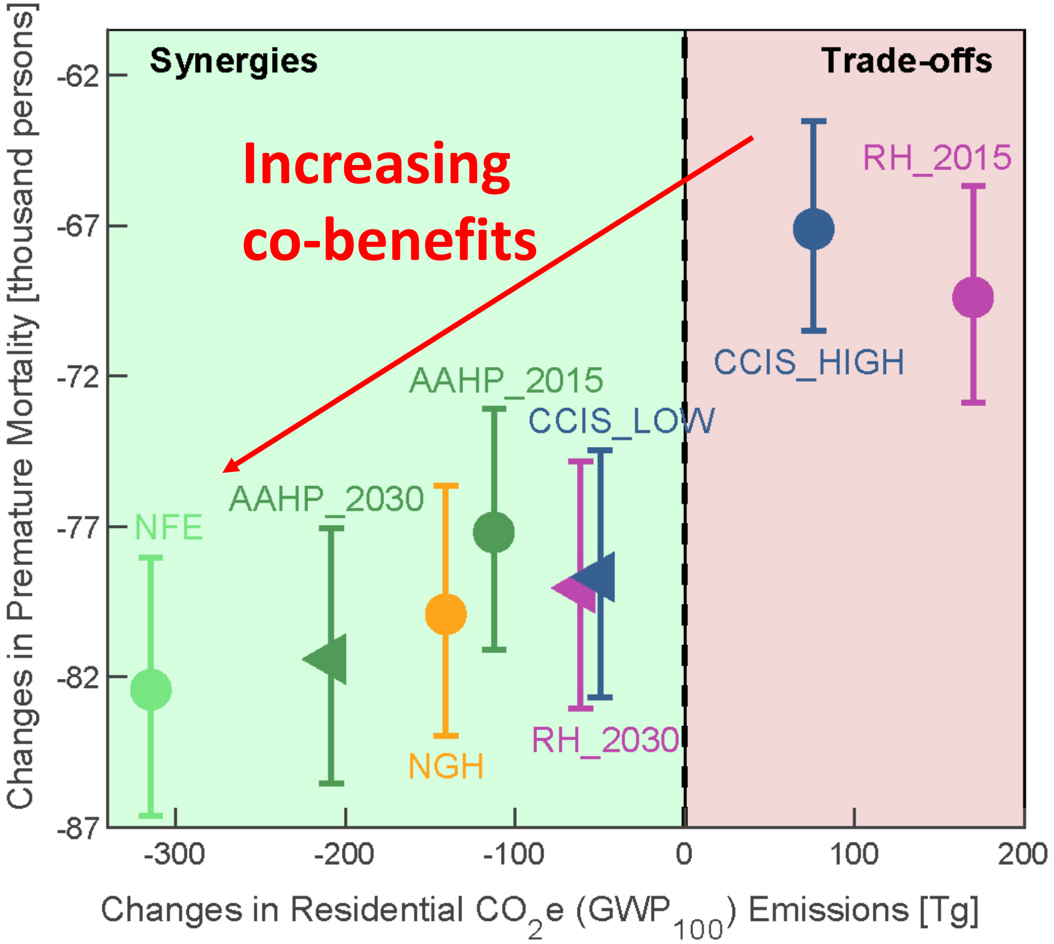


Supply Side: Synergies and Trade-offs in Rural Clean Heating Options

M Zhou, H Liu, L Peng, Y Qin, D Chen, L Zhang, DL Mauzerall

nature sustainability
2021

Health (air-quality) and Climate Impacts of clean heating options compared to 2015 base case



Legends:

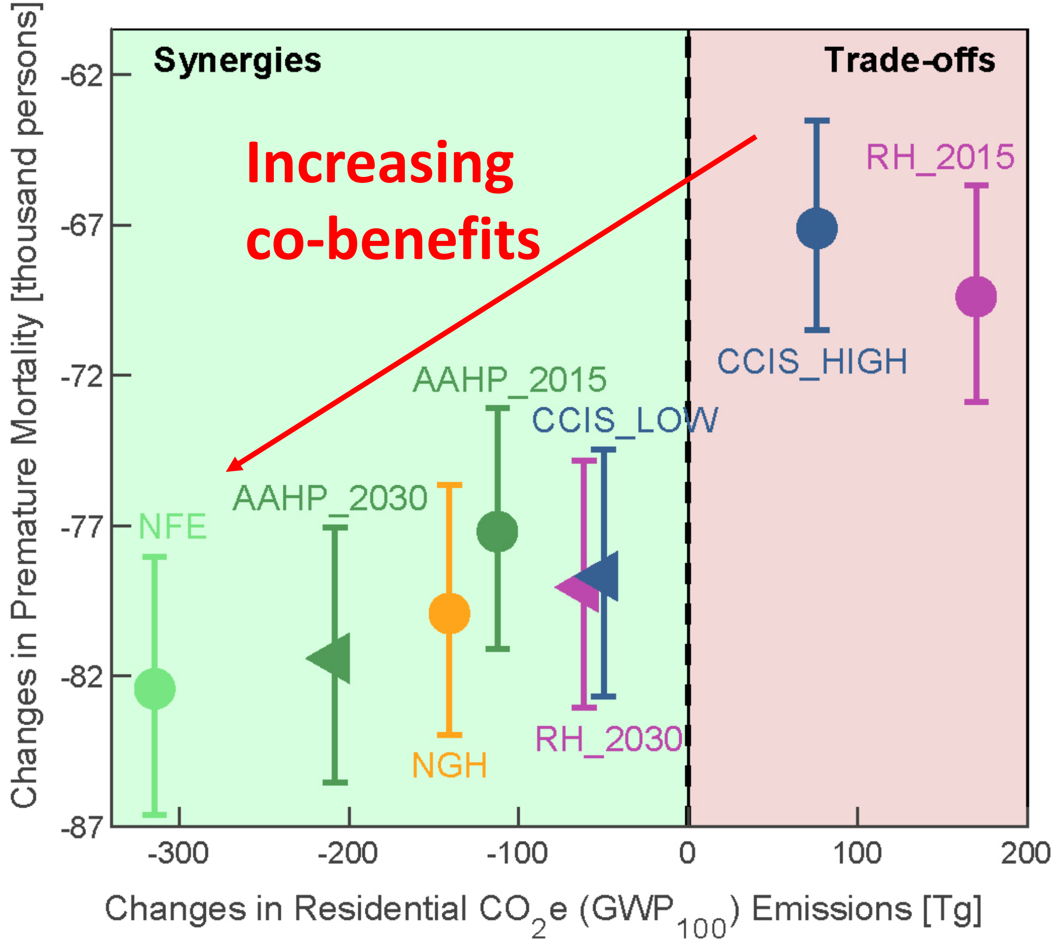
- Clean coal improved stoves (CCIS)
- Gas heaters (NGH)
- Resistance heaters (RH)
- Heat pumps (AAHP)
- Heat pumps w/ non-fossil electricity (NFE)

Supply Side: Synergies and Trade-offs in Rural Clean Heating Options

nature sustainability

M Zhou,… DL Mauzerall, 2021

Health (air-quality) and Climate Impacts



Legends:

◀ ● Clean coal improved stoves (CCIS)

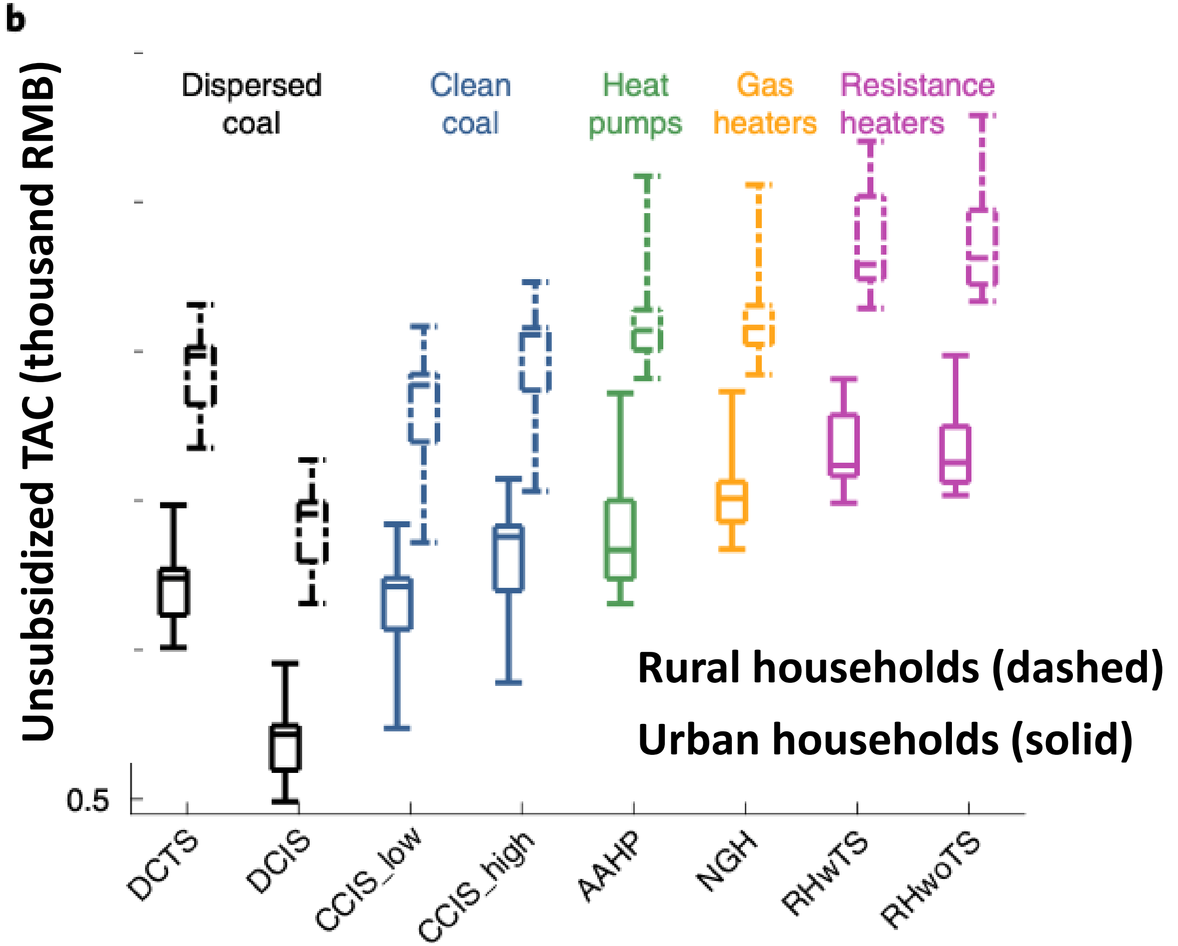
● Gas heaters (NGH)

◀ ● Resistance heaters (RH)

◀ ● Heat pumps (AAHP)

● Heat pumps w/ non-fossil electricity (NFE)

Household Costs



Increasing costs

TAC=Annualized Capital Cost + Annual Operating Cost

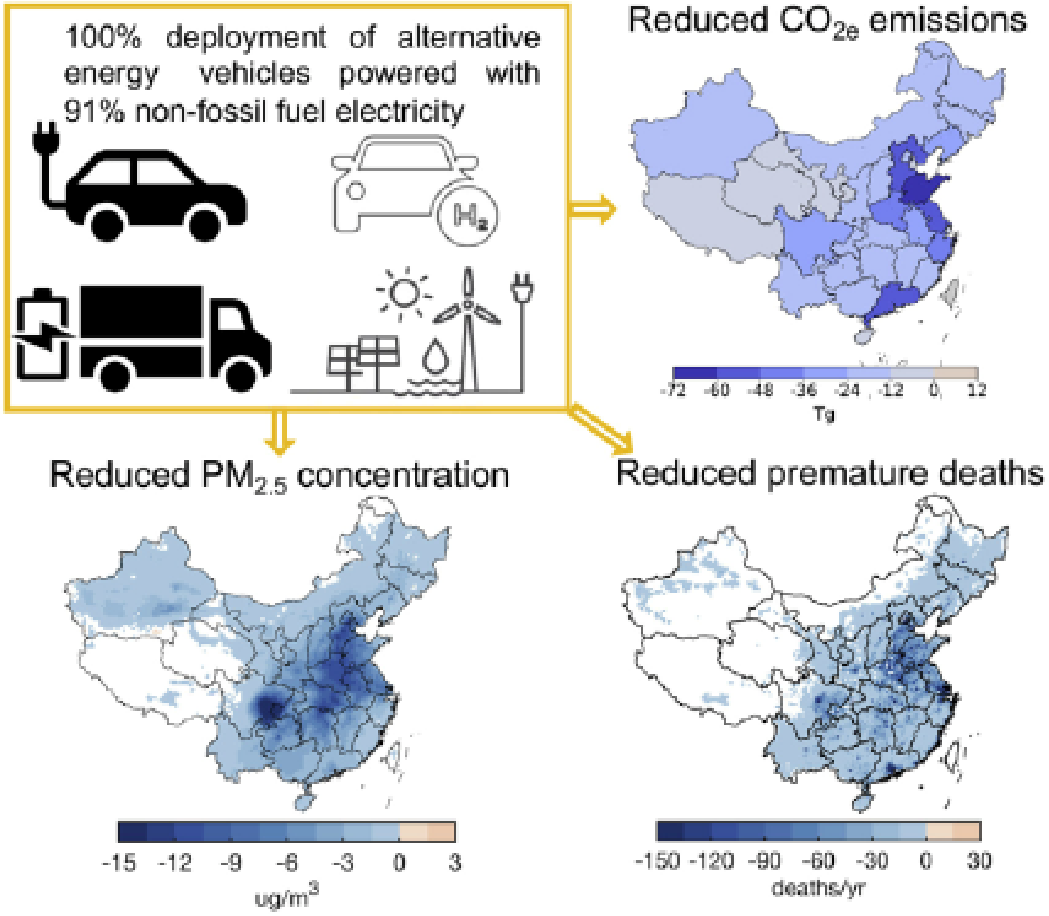
Alternative energy vehicle deployment delivers climate, air quality and health co-benefits when coupled with decarbonizing power generation in China

One Earth
2021

L Peng, F Liu, M Zhou, M Li, Q Zhang, and DL Mauzerall*

Supply Side – Vehicle and Power Sectors

- Rapid deployment of AEVs using high coal power grid will increase air pollutant (SO_2 and $PM_{2.5}$) and CO_{2e} emissions.
- Rapid decarbonization of the grid is critical to benefit from increased penetration of AEVs.
- AEV deployment will result in reduction in all air pollutants and CO_{2e} emissions when the penetration of renewable power is above 40% (low renewable energy scenario).



Deaths/yr/27km^2 grid box

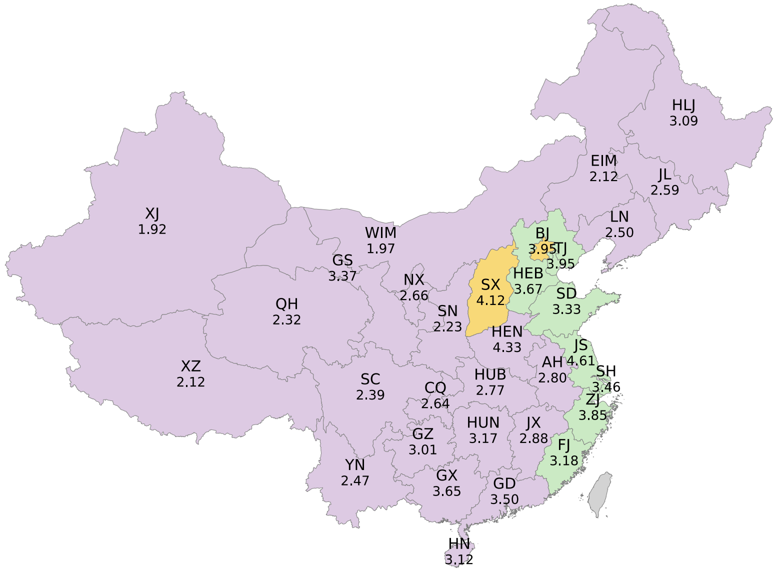
Subsidizing Grid-Based Electrolytic Hydrogen Will Increase GHG Emissions in Coal Dominated Power Systems

L Peng, Y Guo, S Liu, G He, DL Mauzerall

Environmental Science & Technology

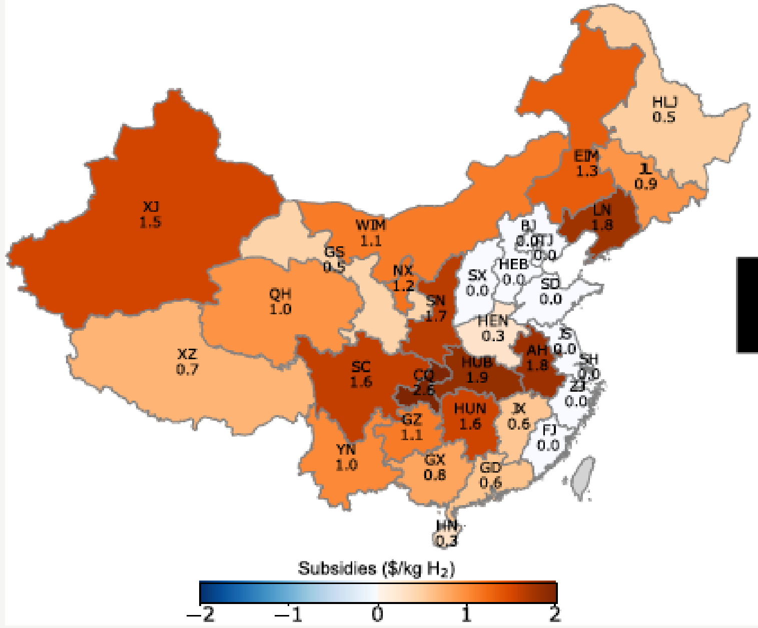
2024

The lowest electrolytic $LCOH_2$ by source and province in 2025 (2021USD/kgH2)

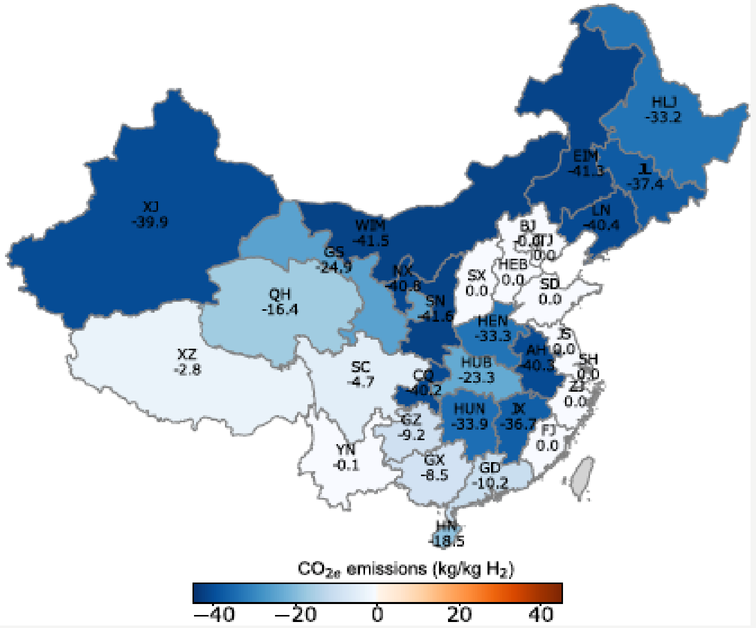


Solar-based H_2 Wind-based H_2 Grid-based H_2

Subsidy increase required to cost-competitively produce renewable-based rather than grid-based hydrogen in 2025



Corresponding decrease in CO_{2e} emissions from producing renewable-based rather than grid-based hydrogen in 2025



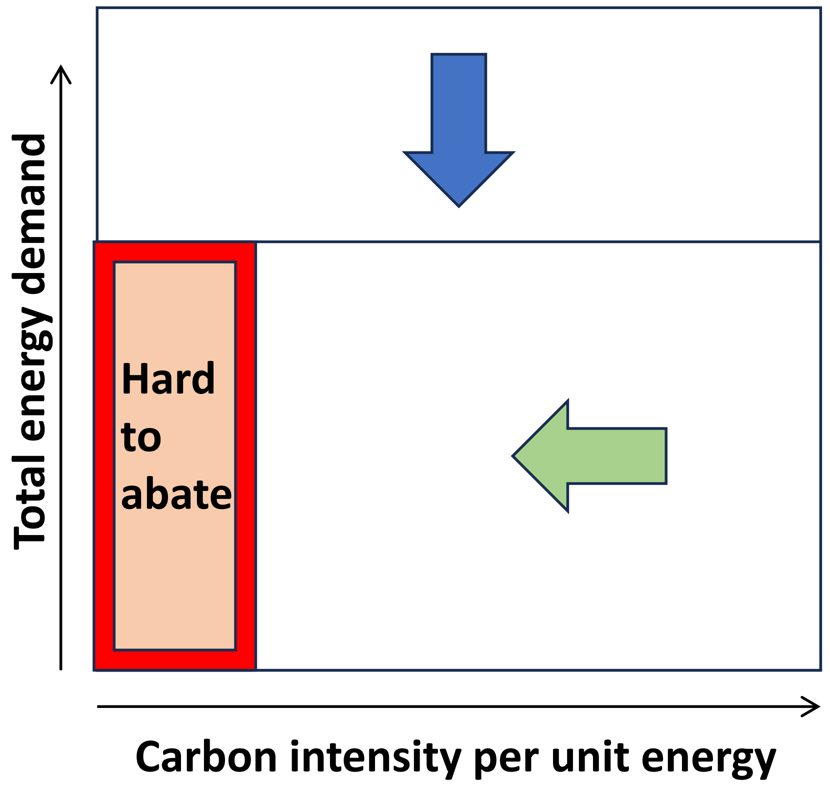
Subsidizing Grid-Based Electrolytic Hydrogen Will Increase GHG Emissions in Coal Dominated Power Systems

L Peng, Y Guo, S Liu, G He, DL Mauzerall

Environmental Science & Technology
2024

- Subsidies on grid based H_2 increase CO_{2e} emissions even compared with coal-based H_2 because grid electricity still heavily relies on coal.
- Economic support for non-fossil electrolytic hydrogen is critical to avoid an increase in CO_{2e} emissions as H_2 production rises.
- Large decreases in CO_{2e} result from producing renewable- rather than grid-based H_2 in 2025.

Synergies between sectors can help reduce hard-to-abate emissions



Demand-side approach:
Improve energy efficiency to reduce total energy demand

Supply-side approach:
Decarbonize the remaining energy required for the process.

Goals:

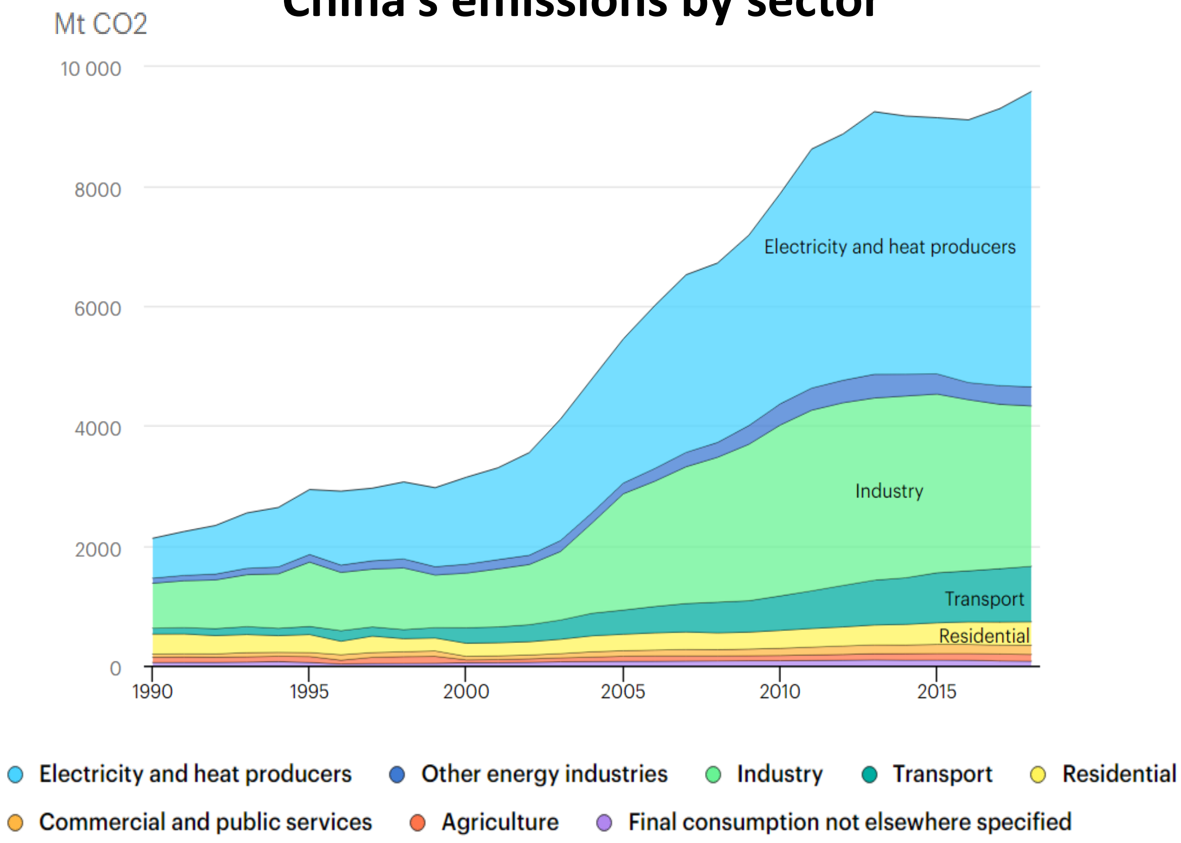
1. Identify opportunities to reduce energy demand;
2. Identify opportunities to decarbonize energy supply;
3. **Examine process synergies to decarbonize the remaining hard-to-abate sectors.**

Synergies between hard-to-abate industries can facilitate decarbonization

Industrial sector emissions need more attention. *Infrastructure synergies provide new opportunities for cost savings and environmental benefits*

- **Co-production of steel and chemicals**, *Nature Chemical Engineering*, 2024
- **Deploying on-site green hydrogen to decarbonize China's coal chemical sector**, *Nature Communications*, 2023.
- **Benefits of infra-structure symbiosis between coal power and wastewater treatment**, *Nature Sustainability*, 2022.

China's emissions by sector



~30% of emissions come from Industry

Co-production of steel and chemicals can mitigate hard-to-abate carbon emissions

nature chemical engineering
2024

Yang Guo, Jieyi Lu, Qi Zhang, Yunling Cao, Lyujun Chen & Denise L. Mauzerall

Introduction

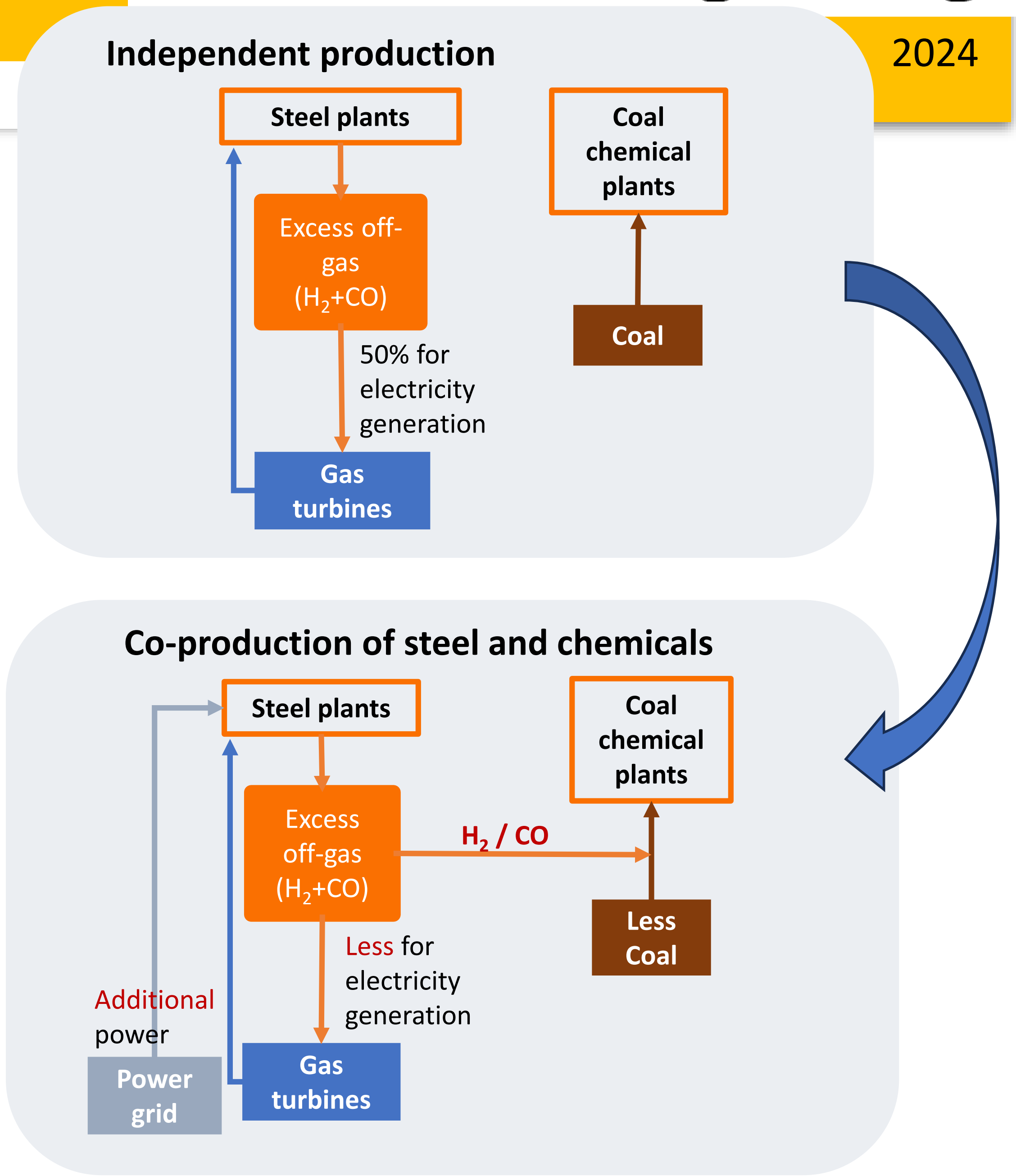
1. Chemical and steel production contributes ~10% of global CO_2 emissions.
2. Production currently relies on fossil fuels for both heat and feedstocks.
3. Co-producing steel and chemicals is technologically ready.
4. We examine the GHG mitigation potential and costs of co-producing steel and chemicals in China.

Methods

1. Estimate supply and demand for H_2 and CO in ~300 steel plants and ~200 coal chemical plants in China.
2. Identify cost-effective plant-level connections for transporting H_2 and CO.
3. Quantify changes in GHG and costs in co- vs. independent production.

Findings

1. Co-production can reduce GHG emissions (-7%) and costs (-1%) without policy support, but a high carbon price increases benefits (-22% in GHG and -10% in costs).
2. Co-production reduces costs for coal chemical plants but increases costs for steel plants.
3. 60% of GHG mitigation and cost reductions can be achieved via 24% of all connections.



Deploying Onsite Green Hydrogen Can Help Decarbonize China's Coal Chemical Sector

nature communications

Yang Guo, Liqun Peng, Jinping Tian, Denise L. Mauzerall, 2023

Coal chemical plant

- China's coal chemical sector is rapidly expanding to meet growing demand for chemicals.
- ~25% of China's 2020 coal consumption was used in coal chemical sector.
- Most GHG emissions from the coal chemical sector result from chemical reactions (coal-based H_2 production) that cannot be reduced by electrification.

Potential large consumer of green H_2

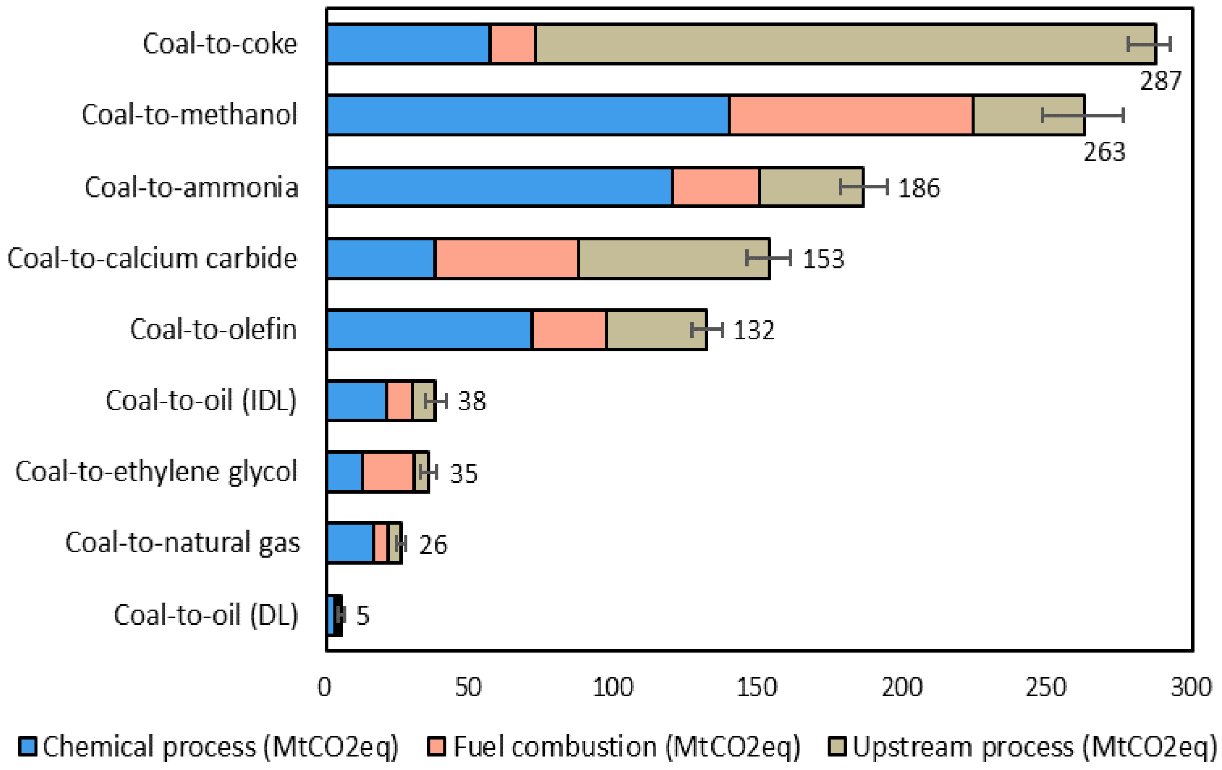
Green hydrogen production

- Onsite production and use of green H_2 for chemical production can reduce emissions and spur green H_2 growth.
- China's strategic plans highlight onsite use of green H_2
- A demonstration project within a coal chemical enterprise in Ningxia Province has deployed utility-scale solar power to produce green H_2 for coal-to-olefin processes

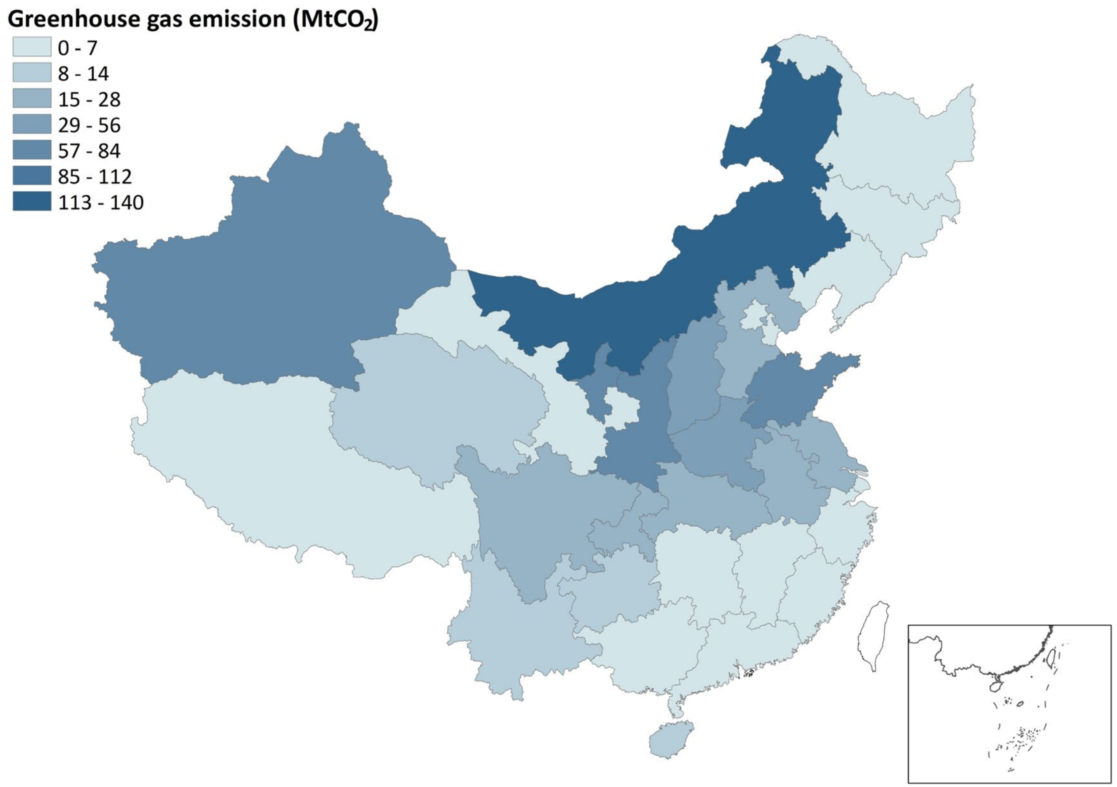
Great decarbonization opportunity for the coal chemical sector

China's coal chemical sector emits ~9% of China's GHG emissions

GHG Emissions for Each Chemical Product



GHG Emissions for Coal Chemical Production by Province



Guo et al., *Nature Communications, 2023*

More R&D on ways to decarbonize the coal chemical sector is needed.
GHG mitigation potential and synergies between coal-chemicals and green H_2 need to be explored.

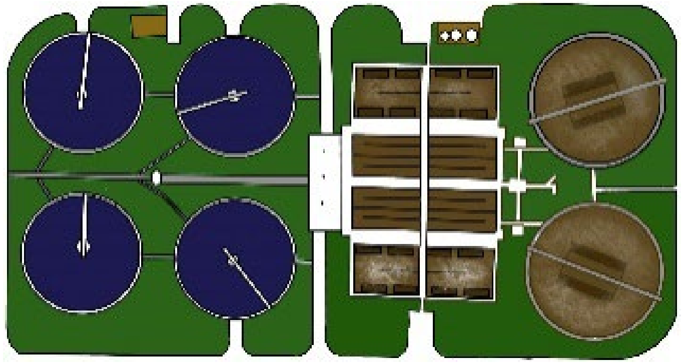
Article
https://doi.org/10.1038/s41893-022-00963-z

Benefits of infrastructure symbiosis between coal power and wastewater treatment

Yang Guo[1,2], Denise L. Mauzerall[1,3], Yizheng Lyu[2], Wanqiu Hu[2], Jinping Tian[2] and Lyujun Chen[2]

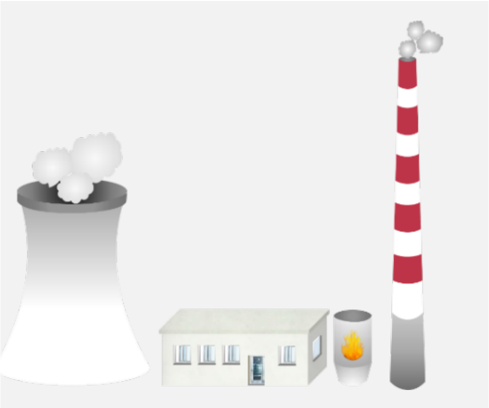
nature sustainability

2022



Sludge for co-combustion

Reclaimed water for cooling, etc.



Municipal Wastewater Treatment Plants

- Stable, large-volume of water output
- Promising water source for industrial use
- Sludge generation and land scarcity pressures are both increasing.
- Sludge incineration for energy can be useful for decarbonization and disposal

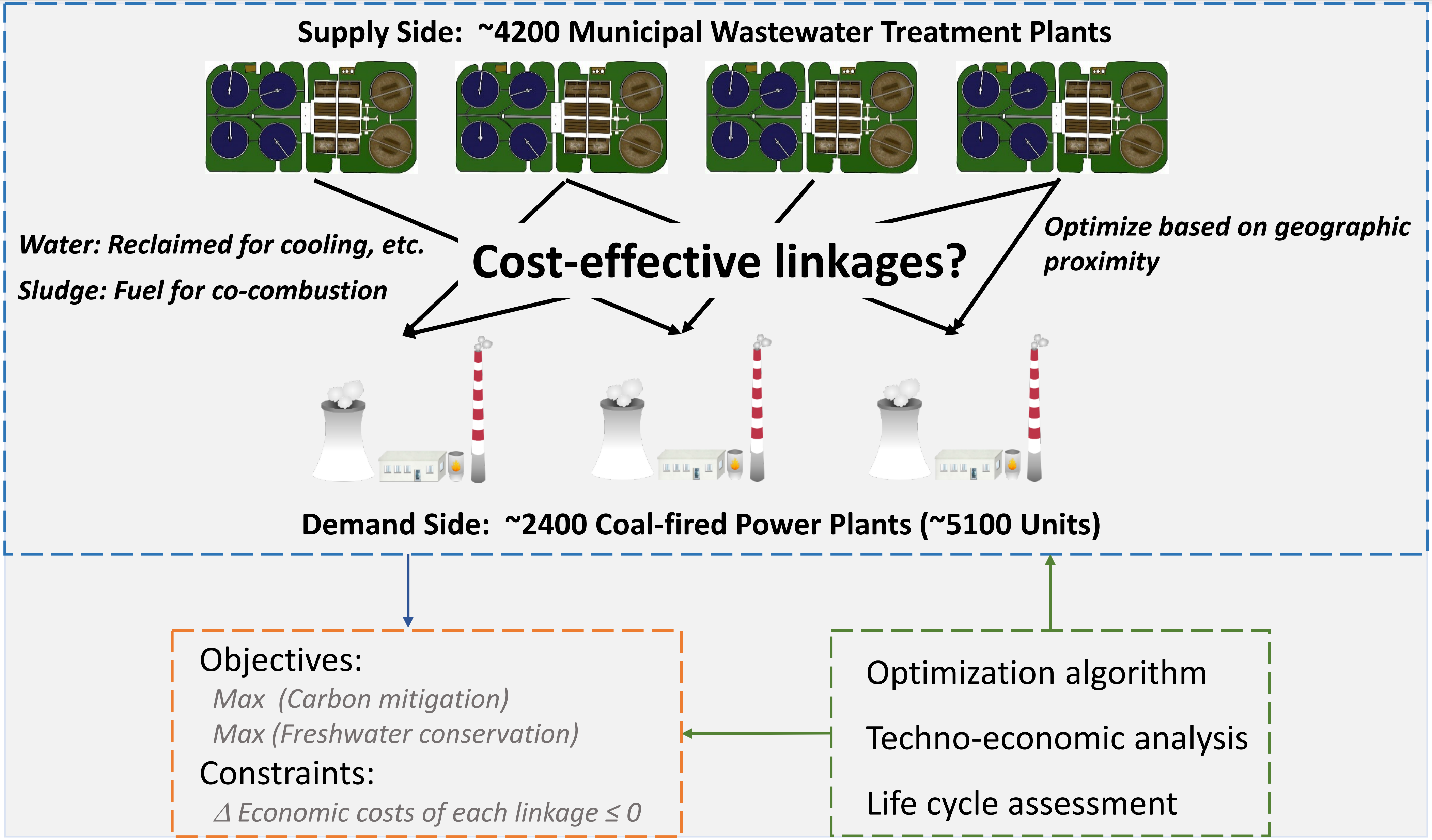
Coal-fired Power Plants

- Largest emitter of CO_2 and second largest consumer of water (ranked after agriculture sector) in China
- Decarbonization pressure from both market competitiveness (decreasing renewable energy costs) and policy (carbon neutrality targets)

In the past focus has been on independently optimizing each type of infrastructure. However, Infrastructure synergies provide new opportunities for cost savings and environmental benefits.

Methodology

nature sustainability 2022



Benefits of energy-water infrastructure synergies

nature sustainability
2022

- **Infrastructure synergies provide both environmental and economic benefits**
  - Carbon reduction: ~30% of carbon from wastewater treatment sector
  - Freshwater conservation: ~60% of water consumed by coal power sector
  - Cost savings: 7.5 (3.4–12) billion CNY/yr.

- **A few linkages achieve the majority of reductions**
  (based on high-resolution modeling)
  - ~30% of sludge linkages + ~40% of water linkages = ~80% of carbon, water and economic benefits

- **Infrastructure synergies are cost-effective opportunities to help reach China’s climate and water conservation targets.**

Mauzerall Synergies and Co-benefits Group

https://scholar.princeton.edu/mauzerall

PRINCETON UNIVERSITY