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

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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

- Total energy demand
- Carbon intensity per unit energy

GHG and air pollutant emissions
Demand-side approach to decarbonizing the economy

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

GHG and air pollutant emissions

Total energy demand

Carbon intensity per unit energy
Hard to abate

Total energy demand

Carbon intensity per unit energy

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

Demand-side approach:
Improve energy efficiency to reduce total energy demand.
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.
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.
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.
Synergies and Trade-offs between Reducing Air Pollutant and GHG Emissions

% Change in National Total CO$_2$(eq) Emissions

% Change in Premature Deaths Resulting from Reductions in Air Pollution

Synergies

Trade-offs
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

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

Synergies
- Increasing co-benefits

Trade-offs
- RH_2015
- CCIS_HIGH

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

Health (air-quality) and Climate Impacts

- Synergies
- Trade-offs

Increasing costs

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

TAC=Annualized Capital Cost + Annual Operating Cost
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).
Subsidizing Grid-Based Electrolytic Hydrogen Will Increase GHG Emissions in Coal Dominated Power Systems

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

The lowest electrolytic LCOH$_2$ by source and province in 2025 (2021USD/kgH2)

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

Corresponding decrease in CO$_2$ emissions from producing renewable-based rather than grid-based hydrogen in 2025

Solar-based H$_2$  Wind-based H$_2$  Grid-based H$_2$
Subsidies on grid based H\textsubscript{2} increase CO\textsubscript{2}e emissions even compared with coal-based H\textsubscript{2} because grid electricity still heavily relies on coal.

Economic support for non-fossil electrolytic hydrogen is critical to avoid an increase in CO\textsubscript{2}e emissions as H\textsubscript{2} production rises.

Large decreases in CO\textsubscript{2}e result from producing renewable- rather than grid-based H\textsubscript{2} in 2025.
Synergies between sectors can help reduce hard-to-abate emissions

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 approach:
Improve energy efficiency to reduce total energy demand

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

China’s emissions by sector

~30% of emissions come from Industry
Co-production of steel and chemicals can mitigate hard-to-abate carbon emissions

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

Introduction
1. Chemical and steel production contributes ~10% of global CO₂ 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 H₂ and CO in ~300 steel plants and ~200 coal chemical plants in China.
2. Identify cost-effective plant-level connections for transporting H₂ 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

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 H₂ production) that cannot be reduced by electrification.

Potential large consumer of green H₂

Onsite production and use of green H₂ for chemical production can reduce emissions and spur green H₂ growth.

China’s strategic plans highlight onsite use of green H₂

A demonstration project within a coal chemical enterprise in Ningxia Province has deployed utility-scale solar power to produce green H₂ 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.

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 H₂ need to be explored.
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.

- 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

- Largest emitter of CO₂ 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)
Supply Side: ~4200 Municipal Wastewater Treatment Plants

Water: Reclaimed for cooling, etc.
Sludge: Fuel for co-combustion

Cost-effective linkages?

Demand Side: ~2400 Coal-fired Power Plants (~5100 Units)

Objectives:
Max (Carbon mitigation)
Max (Freshwater conservation)

Constraints:
$\Delta$ Economic costs of each linkage $\leq 0$

Optimization algorithm
Techno-economic analysis
Life cycle assessment

Optimize based on geographic proximity
Benefits of energy-water infrastructure synergies

- 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.
Mauzerral Synergies and Co-benefits Group

https://scholar.princeton.edu/mauzerral