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Supplemental information

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Supplemental Information

China's Multi-sector Shared CCUS Networks in a Carbon-neutral Vision

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Supplementary note 1: Six major regions of China.

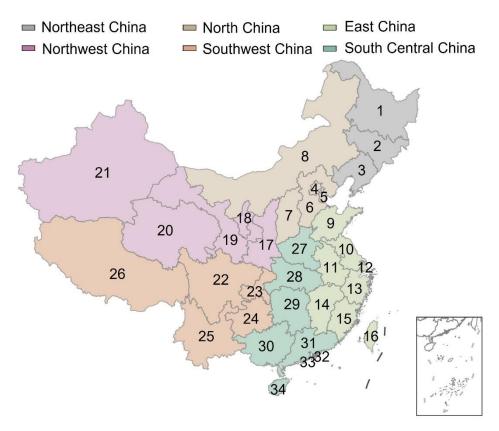


Figure S1. Six major regions and 34 provincial administrative regions of China, related to Figure 3, Figure 4 and Figure 7.

Supplementary note 2: Abbreviations of the provinces of China.

The number in Table S1 corresponds to the number in Figure S1 one by one.

Table S1. Abbreviations of the provincial administrative regions of China, related to Figure 3, Figure 4 and Figure 7.

Number	Province	Abbreviation	Number	Province	Abbreviation
1	Heilongjiang	HEIL	18	Ningxia	NINX
2	Jilin	JILI	19	Gansu	GANS
3	Liaoning	LIAO	20	Qinghai	QING
4	Beijing	BEIJ	21	Xinjiang	XING
5	Tianjin	TIAN	22	Sichuan	SICH
6	Hebei	HEBE	23	Chongqing	CHON
7	Shanxi	SHNX	24	Guizhou	GUIZ
8	Inner Mongolia	NEMO	25	Yunnan	YUNN
9	Shandong	SHAD	26	Tibet	XIZG
10	Jiangsu	JINU	27	Henan	HENA
11	Anhui	ANHU	28	Hubei	HUBE
12	Shanghai	SHAN	29	Hunan	HUNA
13	Zhejiang	ZHEJ	30	Guangxi	GUAX
14	Jiangxi	JINX	31	Guangdong	GUAD
15	Fujian	FUJI	32	Hong Kong	XIGA
16	Taiwan	TAIW	33	Macao	AOME
17	Shaanxi	SHAA	34	Hainan	HAIN

Supplementary note 3: CCUS source-sink matching.

Table S2. A summary of the sets, main decision variables and key parameters, related to STAR METHODS.

Category	Symbol	Definition	Comments
Set	S	nodes representing the CO2 emission hubs	-
	R	nodes representing the CO2 storage hubs	-
	U	nodes connected to the current node	-
	G	sectors	-
	D	pipeline diameters	-
Decision a_i^g the annual CO ₂ capture		the annual CO2 capture from the sector g of	Unit: Mt
variable		the emission hub i	
	a_i	the total annual CO2 capture from all the	Unit: Mt
		sector of the emission hub i	
	b_j	the annual CO ₂ sequestered in the storage	Unit: Mt
		site j	
	t_{pq}	the annual CO2 flow transported from the	Unit: Mt
		node p to the node q	
	N_{pq}^d	the number of the pipelines with the	-
		diameter of d	
	W_{j}	the number of injection wells at the storage	-
		site j	
Parameter	t_{oil}	the CO ₂ replacement rates for oil	based on ref. ¹⁻⁵
	k_{oil}	conversion ratio	based on ref.1-5
	l_{oil}	wellhead price	based on ref. ^{2,6,7}
	δ	capture rate	90%
	τ	lifetime of CO ₂ storage	30 years
	r	discount rate	8%
	n	lifetime of a CCUS project	30 years
	I_j	the injectivity for one injection well at the	based on ref. ^{1,4,8}
		storage site j	
	T^g	projected demand of CO2 capture for the	see Figure 2.
		sector g by the China TIMES model	

Supplementary note 4: Bottom-up energy system modeling. Energy Extraction End-use energy technology Energy service demand Energy transformation, transportation and distribution Coal-fired power without CCS Agricultural process technology Agriculture sector Coal-fired power with CCS Coal-fired CHP without CCS Iron and steel technology Coal-fired CHP with CCS Cement technology Gas-fired power without CCS Glass technology Gas-fired power with CCS Iron and steel Paper and pulp technology Cement Gas-fired CHP without CCS Non-ferrous metals technology Glass Gas-fired CHP with CCS Paper and pulp Na₂CO₃ technology Non-ferrous metals Oil-fired power without CCS NaOH technology Na₂CO₃ NaOH Oil-fired CHP without CCS NH₃ technology NH_3 C₂H₄ technology Nuclear (PWR/HTGR) C₂H₄ Other industries Other industries technology Biomass direct combustion Non-energy use technology Biomass gasification Biomass-coal co-combustion Road transportation technology **Biomass CHP** Air transportation technology Road Passenger Freight Biomass power with CCS Rial Marine transportation technology Air Hydro Rail transportation technology Marine Geothermal generation Pipeline Pipeline transportation technology Ocean (tidal/wave) Wind (onshore/offshore) Spacing heating technology Solar (PV/CSP) Spacing heating Spacing cooling technology Urban Rural Commercial Building secto Spacing cooling Coal wash, Coke, Coal chemical Hot watering technology Hot watering Oil refinery Lighting Lighting technology Cooking Biomass gasification/liquefaction Cooking technology Electric appliance Hydrogen production without CCS Electric appliance technology Hydrogen production with CCS Hydrogen production by electrolysis Power sector Industry sector Heat production without CCS Transportation sector Upstream sector Heat production with CCS

Figure S2. The simplified diagram of reference energy system embodied in China TIMES, related to STAR METHODS.

Other heat production

Agriculture sector

CO₂ captured

Building sector

 $\textbf{Table S3.} \ \textbf{A} \ \textbf{general description of the elements in China TIMES}, \ \textbf{related to STAR METHODS}.$

Element	Comments		
Input data ^{9,10}	(1) vintaging of the energy infrastructure		
	(2) historical energy activities		
	(3) fossil fuel reserves and renewable potential		
	(4) emission factors		
	(5) energy service demand projections driven by socio-economic indicators		
	(6) technical and economic performance parameters (e.g., CAPEX, OPEX,		
	lifetime, capacity factor, efficiency, growth limit, etc.)		
	(7) policy constraints		
Output data ^{9,10}	(1) the optimal mix of technologies and fuels at each period		
	(2) all infrastructure investment decisions		
	(3) energy and product prices		
	(4) international trade volume		
	(5) associate emissions		
Policy	China announced to achieve carbon neutrality before 2060, with the emission		
consideration	scope including CO ₂ and other non-CO ₂ greenhouse gases, which is consistent		
	with the modelled pathway of this research where China's energy system		
	achieves CO ₂ -neutral in 2050. ^{11,12}		

Supplementary note 5: Proposed CCUS layouts under scenario S3.

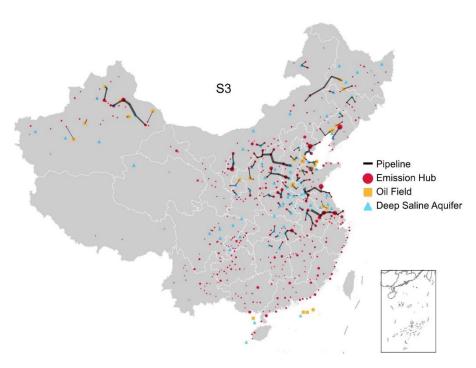


Fig. S3 The most elementary layout aiming only at the power sector and onshore storage, related to STAR METHODS.

Supplementary note 6: Parameters related to the estimation of CO₂ emissions.

Table S4. A summary of parameters related to the estimation of CO_2 emissions, related to STAR METHODS.

Sector	Symbol	Definition	
	(Unit)		
Coal-fired p	ower plants: $E = IC \times H$	$R \times CF \times EF \times 9.2427 \times 10^{-12}$	
Power	E (Mt)	Annual CO ₂ emission	
sector ^{1-5,13}	IC (MW)	Installed capacity	
	HR (Btu/kWh)	Heat rate	
	CF	Capacity factor	
	EF (kgCO ₂ /TJ)	Emission factor	
Iron and ste	el plants, cement plants,	ammonia plants: $E = PC \times CF \times EF$	
Industry	E (Mt)	Annual CO ₂ emission	
sector ¹⁻⁵	PC (Mt product)	Plant capacity, namely the maximum output of industrial	
		products (crude steel, cement clinker, ammonia) per year	
	CF	Capacity factor	
	EF (tCO ₂ /t product)	Emission factor	

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