iScience, Volume *26*

Supplemental information

China's multi-sector-shared CCUS networks in a carbon-neutral vision

Haotian Tang, Wenying Chen, Shu Zhang, and Qianzhi Zhang

Supplemental Information

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

Haotian Tang[1,2], Wenying Chen[1,2,3,*], Shu Zhang[1,2], Qianzhi Zhang[1,2]

[1]Research Center for Contemporary Management, Tsinghua University, Beijing 100084, China
[2]Institute of Energy, Environment and Economy, Tsinghua University, Beijing 100084, China
[3]Lead contact
[*]Correspondence: chenwy@tsinghua.edu.cn

Number of pages: 9
Number of tables: 4
Number of figures: 3

Table S1. Abbreviations of the provincial administrative regions of China.
Table S2. A summary of the sets, main decision variables and key parameters.
Table S3. A general description of the elements in China TIMES.
Table S4. A summary of parameters related to the estimation of CO_2 emissions.

Figure S1. Six major regions and 34 provincial administrative regions of China.
Figure S2. The simplified diagram of reference energy system embodied in China TIMES.
Figure S3. The most elementary layout aiming only at the power sector and onshore storage.

Supplementary note 1: Six major regions of China.

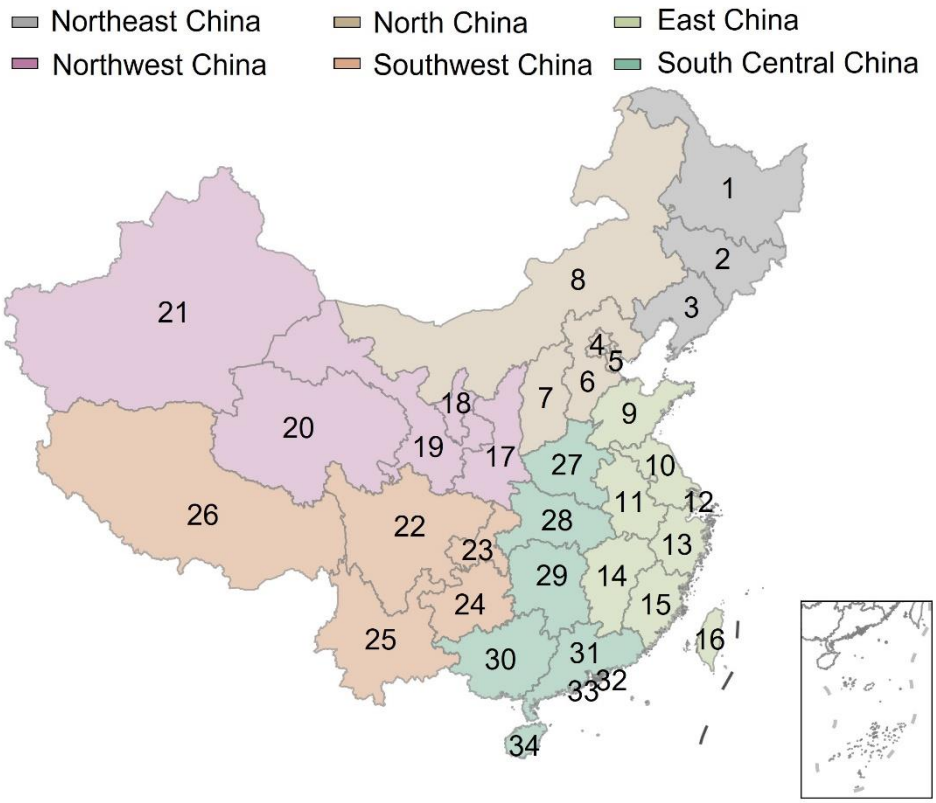

Figure S1. Six major regions and 34 provincial administrative regions of China, related to Figure 3, Figure 4 and Figure 7.

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 CO_2 emission hubs	-
	R	nodes representing the CO_2 storage hubs	-
	U	nodes connected to the current node	-
	G	sectors	-
	D	pipeline diameters	-
Decision variable	a_i^g	the annual CO_2 capture from the sector g of the emission hub i	Unit: Mt
	a_i	the total annual CO_2 capture from all the sector of the emission hub i	Unit: Mt
	b_j	the annual CO_2 sequestered in the storage site j	Unit: Mt
	t_{pq}	the annual CO_2 flow transported from the node p to the node q	Unit: Mt
	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 storage site j	based on ref.[1,4,8]
	T^g	projected demand of CO_2 capture for the sector g by the China TIMES model	see Figure 2.

Supplementary note 4: Bottom-up energy system modeling.

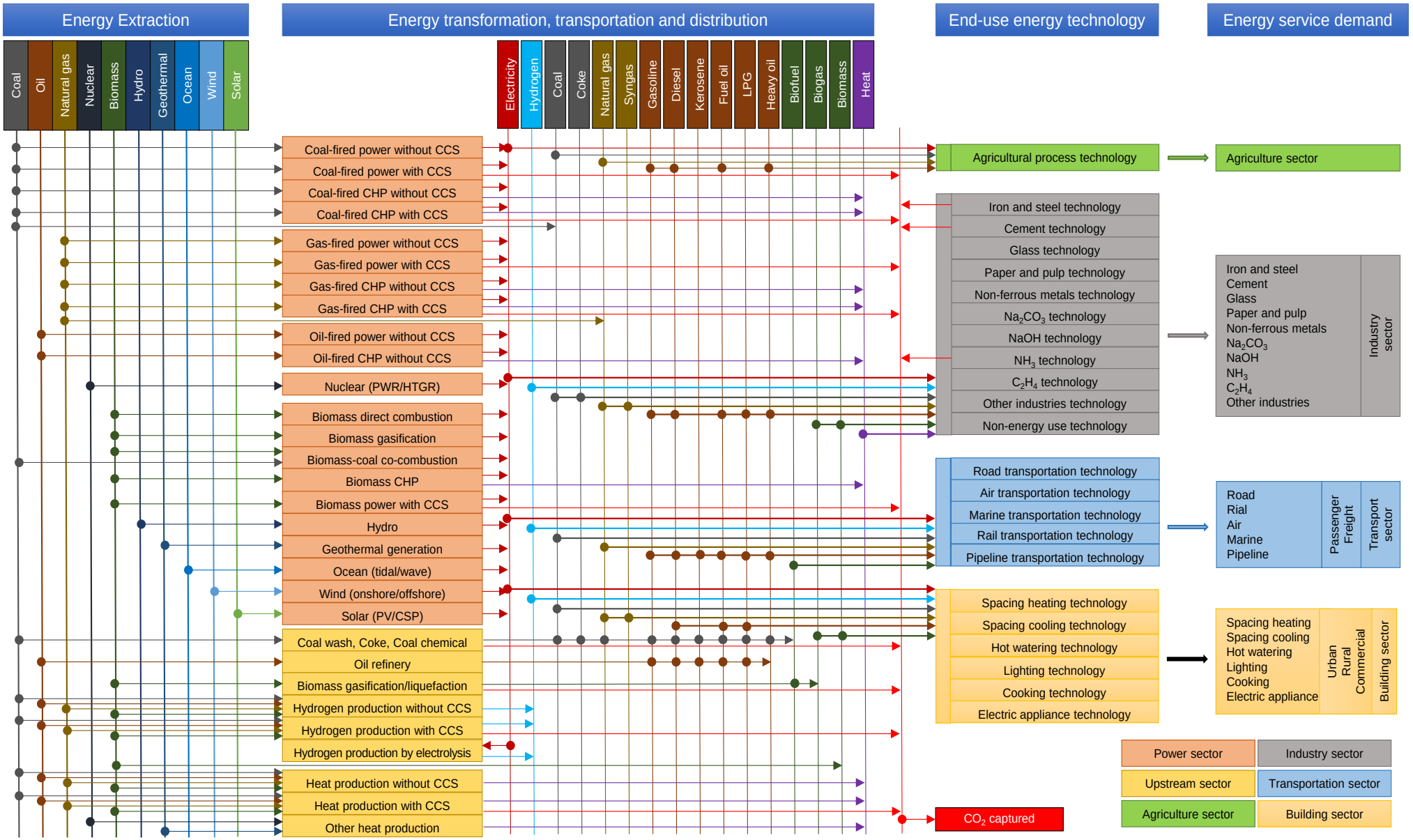

Figure S2. The simplified diagram of reference energy system embodied in China TIMES, related to STAR METHODS.

Table S3. A general description of the elements in China TIMES, 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 consideration	China announced to achieve carbon neutrality before 2060, with the emission 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.

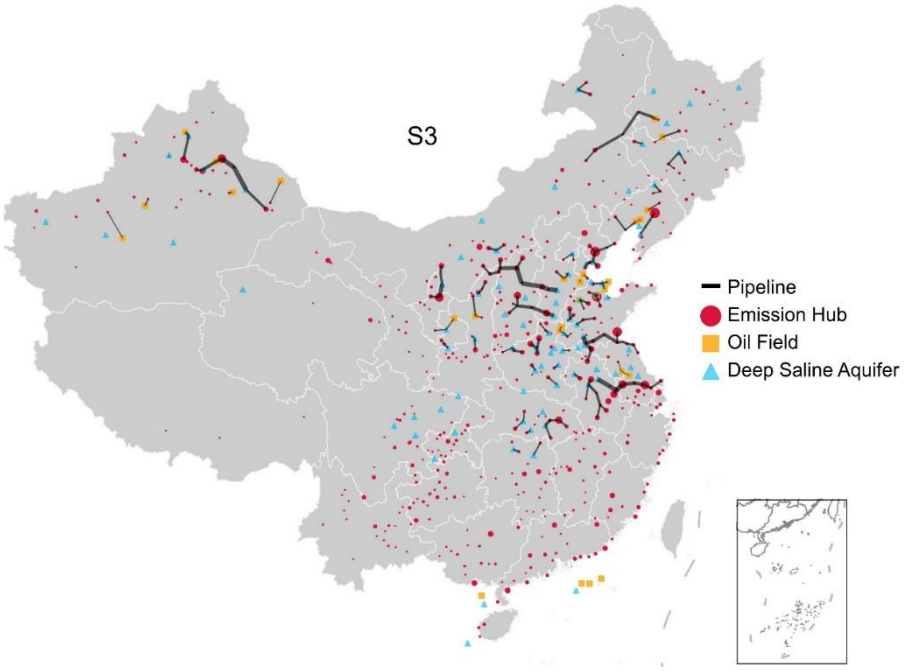

Fig. S3 The most elementary layout aiming only at the power sector and onshore storage, related to STAR METHODS.

Supplementary note 6: Parameters related to the estimation of CO_2 emissions.

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

Sector	Symbol (Unit)	Definition
Coal-fired power plants: $E = IC \times HR \times CF \times EF \times 9.2427 \times 10^{-12}$		
Power sector[1-5,13]	E (Mt)	Annual CO_2 emission
	IC (MW)	Installed capacity
	HR (Btu/kWh)	Heat rate
	CF	Capacity factor
	EF ($kgCO_2$/TJ)	Emission factor
Iron and steel plants, cement plants, ammonia plants: $E = PC \times CF \times EF$		
Industry sector[1-5]	E (Mt)	Annual CO_2 emission
	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

References

1. Chen, W., Le Nindre, Y.-M., Xu, R., Allier, D., Teng, F., Domptail, K., Xiang, X., Guillon, L., Chen, J., Huang, L., and Zeng, R. (2010). CCS scenarios optimization by spatial multi-criteria analysis: Application to multiple source sink matching in Hebei province. International Journal of Greenhouse Gas Control *4*, 341-350.
2. Sun, L., and Chen, W. (2013). The improved ChinaCCS decision support system: A case study for Beijing–Tianjin–Hebei Region of China. Applied Energy *112*, 793-799.
3. Sun, L., and Chen, W. (2017). Development and application of a multi-stage CCUS source–sink matching model. Applied Energy *185*, 1424-1432.
4. Sun, L., and Chen, W. (2022). Impact of carbon tax on CCUS source-sink matching: Finding from the improved ChinaCCS DSS. Journal of Cleaner Production *333*, 130027.
5. Tang, H., Zhang, S., and Chen, W. (2021). Assessing Representative CCUS Layouts for China's Power Sector toward Carbon Neutrality. Environmental Science & Technology *55*, 11225-11235.
6. Wei, Y.-M., Kang, J.-N., Liu, L.-C., Li, Q., Wang, P.-T., Hou, J.-J., Liang, Q.-M., Liao, H., Huang, S.-F., and Yu, B. (2021). A proposed global layout of carbon capture and storage in line with a 2 °C climate target. Nature Climate Change *11*, 112-118.
7. Wei, Y.-M., Li, X.-Y., Liu, L.-C., Kang, J.-N., and Yu, B.-Y. (2022). A cost-effective and reliable pipelines layout of carbon capture and storage for achieving China's carbon neutrality target. Journal of Cleaner Production *379*, 134651.
8. Dahowski, R.T., Davidson, C.L., Li, X.C., and Wei, N. (2012). A $70/tCO2 greenhouse gas mitigation backstop for China's industrial and electric power sectors: Insights from a comprehensive CCS cost curve. International Journal of Greenhouse Gas Control *11*, 73-85.
9. Loulou, R., and Labriet, M. (2008). ETSAP-TIAM: the TIMES integrated assessment model Part I: Model structure. Computational Management Science *5*, 7-40.
10. Loulou, R. (2008). ETSAP-TIAM: the TIMES integrated assessment model. part II: mathematical formulation. Computational Management Science *5*, 41-66.
11. Zhang, S., and Chen, W. (2022). Assessing the energy transition in China towards carbon neutrality with a probabilistic framework. Nature Communications *13*, 87.
12. van Soest, H.L., den Elzen, M.G.J., and van Vuuren, D.P. (2021). Net-zero emission targets for major emitting countries consistent with the Paris Agreement. Nature Communications *12*, 2140.
13. Global Energy Monitor (2020). Global Coal Plant Tracker.