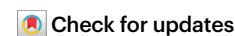


Governance challenges for domestic cross-border carbon capture and storage

Xiaoyu Zhang, Fengting Li & Yifan Gu



Governance of domestic cross-border carbon capture and storage faces great challenges, which varies across political systems, economic structures and socio-cultural backgrounds, yet is often overlooked. Overcoming these challenges requires a comprehensive and coordinated approach built on synergistic cluster governance.

Carbon dioxide (CO₂) emissions in 2024 may have soared to an unprecedented high, rendering the imperative to cut CO₂ emissions more pressing than ever to achieve the targets set by the United Nations Sustainable Development Goals^{1,2}. Carbon capture and storage (CCS) represents the only engineering solution capable of largely reducing and neutralizing emissions from carbon-intensive sources³. The *Global Status of CCS 2023* report identifies 392 commercial CCS projects globally, and this number is expected to continue to grow rapidly in the future⁴.

Current research and practice on CCS governance indicates that scale effects and the cluster approach are vital for fully realizing the emissions reduction potential of CCS, as well as for achieving commercial viability and sustainable development^{5,6}. At present, more than 70% of the annual CO₂ capacities of commercial CCS facilities globally involve cross-border operations, including several notable CCS clusters such as the midwestern Corn Belt (Fig. 1a) and Haynesville formation (Fig. 1b) in the United States, the North Sea in Europe (Fig. 1c) and the Ordos Basin in China (Fig. 1d). Within the cluster, carbon capture initiatives typically target high-emission industrial areas, while optimal storage sites are often situated in geologically favourable but spatially distant locations. This spatial mismatch may require the transportation of CO₂ across borders between different administrative divisions, such as countries or regions. The legal and regulatory differences across borders, along with local protectionism, can lead to conflicts of interest among stakeholders involved in carbon capture, transportation and storage across different administrative regions, which will inevitably hinder the healthy development of CCS. Therefore, it is essential to give due attention to recognize and effectively address the unique characteristics of borders in CCS governance.

In view of that, international cross-border CCS has already garnered attention in both academic research and practical applications. For example, Europe – particularly the countries bordering the North Sea – has utilized longstanding cooperation and robust legal frameworks, such as the International Maritime Organization 2012 London Protocol's CO₂ Specific Guidelines and the European Council's CCS Directive (Directive 2009/31/EC)⁷. These frameworks are used to develop a mature governance system for cross-border CCS

initiatives. By contrast, domestic cross-border CCS, which involves internal divisions such as states or provinces, has received less attention. However, in large countries such as China and the United States, domestic cross-border CCS governance continues to face challenges similar to those encountered at the international level, including local protectionism, divergent political interests and public acceptance⁸. However, owing to insufficient inter-regional collaborative legislation and the complex relationship between central and local authorities, the challenges faced by domestic cross-border CCS projects are not diminished by their domestic context. Moreover, the diverse political systems, economic structures and cultural backgrounds of these countries necessitate a greater focus on governance heterogeneity in domestic cross-border CCS. Consequently, they represent an intriguing yet underexplored area of research.

Domestic cross-border governance

Considering the challenges associated with domestic cross-border CCS governance, China and the United States serve as appropriate examples for study. Both nations emphasize CCS in their ambitious environmental strategies and possess cross-border CCS clusters. Moreover, the political and socioeconomic backgrounds of the two countries differ markedly, leading to distinct cross-border governance challenges.

China, as a socialist nation, exemplifies the efficient planning and execution of major projects through its whole-nation system, owing to its resource mobilization capabilities. With state-owned land and centralized leadership, it encounters low resistance in cross-border legislation and project construction. However, cross-border CCS governance in China is challenged by economic decentralization, which is coupled with political centralization, fostering strong enthusiasm among local governments to engage in competition and develop their local economies. However, there is limited enthusiasm for CCS projects that are still in pre-commercial stages and do not yet yield economic benefits. Notably, if local governments are required to bear responsibility for storing CO₂ from neighbouring provinces, this may lead to intergovernmental shirking. The emitting province benefits from industrial activities while externalizing negative externalities to the storing province, which, if faced with environmental risks and regulatory costs without direct economic gains, may resist to accept external CO₂. Furthermore, the stringent performance evaluation system imposed on local governments may hinder cross-border collaboration. There is an implicit concern that provincial governments included in the cross-border CCS compete to claim emissions reductions, leading to double counting and local protectionism, which could undermine the cost effectiveness of the CCS industry chain. The rectification of these issues often exceeds the scope of local governments' responsibilities and is ultimately undertaken by the central government.

The United States functions within a federal framework, wherein authority is divided between the federal government and individual state governments. Within this system, it is imperative that a local

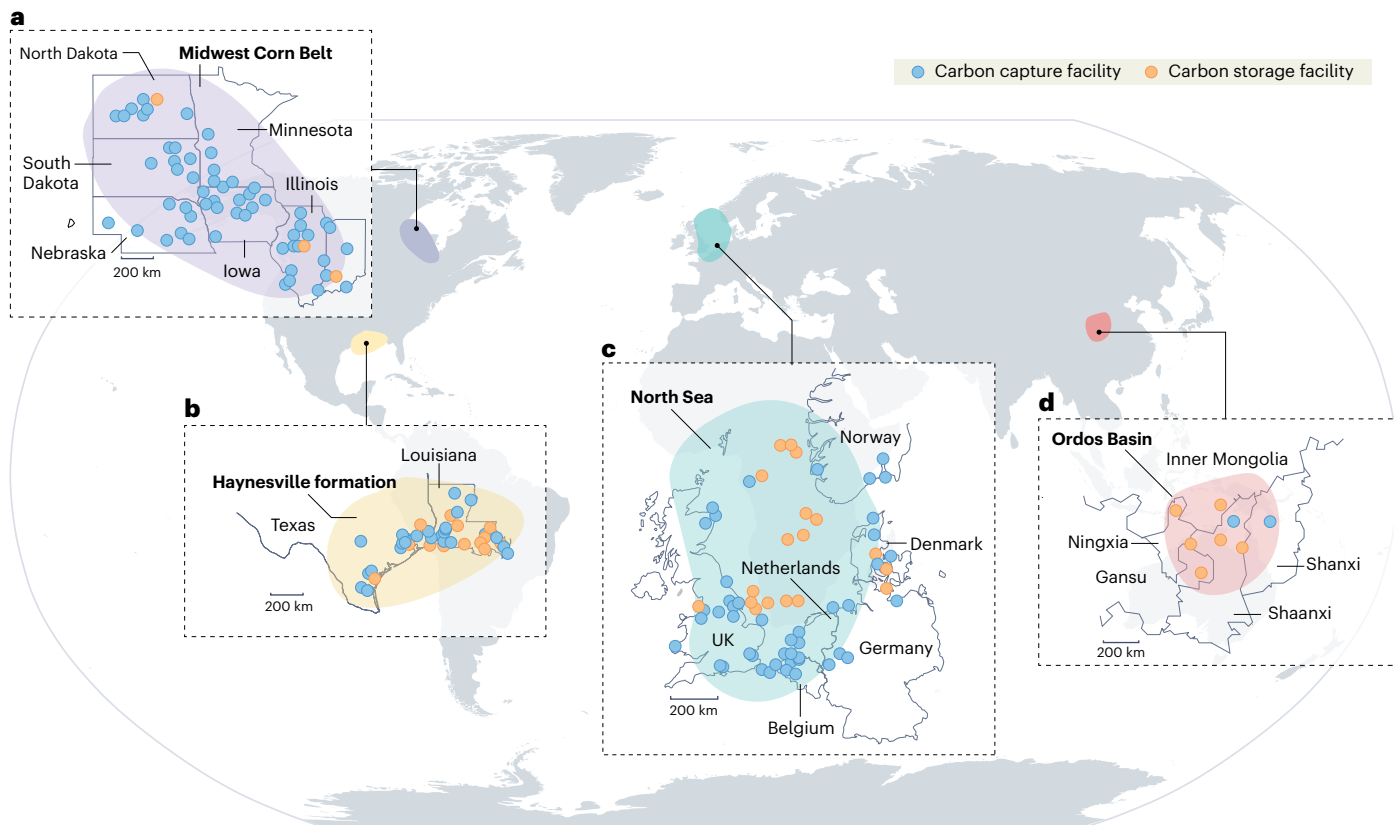


Fig. 1 | Typical cross-border CCS clusters in different regions. a–d, Maps showcasing the distribution of commercial CCS facilities both under construction and that are operational, highlighting key regions where cross-border CCS operations may occur across North America (**a,b**), Europe (**c**) and China (**d**), including the midwestern Corn Belt (**a**), Haynesville formation (**b**), North Sea (**c**) and Ordos Basin (**d**). Data for the United States and Europe are sourced from the US Carbon Capture Activity and Project Map (<https://www.catf.us/ccsmapus/>).

Data for China are derived from the *Global Status of CCS 2023* report and field research by the authors⁵. The base map of China (**d**) was sourced from the Amap Open Platform and downloaded from the DataV.GeoAtlas mini-program. The base maps of the United States and Europe (**a–c**) were downloaded from the amChart platform (<https://www.amcharts.com/svg-maps/>). Publ. note: Springer Nature is neutral about jurisdictional claims in maps.

and unambiguous allocation of powers, functions and responsibilities between the federal and state entities exists. In the context of the governance of cross-border CCS, federal-level legislation has thus far only offered financial incentives, with a notable absence of engagement in operational licensing and regulatory oversight. Federal agencies, such as the Federal Energy Regulatory Commission, have demonstrated limited appetite for extending their regulatory jurisdiction to encompass CCS^{9,10}. Consequently, operators are compelled to traverse a labyrinthine array of licensing and regulatory procedures across various states, a situation that frequently results in delays or the outright prevention of the implementation of cross-state CCS projects. Furthermore, the decentralized political structure of the United States often results in policy inconsistencies and inefficiencies in the execution of policy, a phenomenon that is starkly manifested in the realm of cross-border CCS practice. The Heartland Greenway CO₂ pipeline project was cancelled because of cross-border regulatory obstacles and vehement community opposition. Should other projects encountering comparable resistance be cancelled or postponed, nearly a quarter of the United States' onshore storage capacity could potentially be impacted, posing substantial ramifications for the short-term prospects of emissions reductions in the country¹⁰.

Synergistic cluster solutions

For cross-regional issues, a goal-oriented governance model based on maximizing the interests of all parties is crucial. Governance efforts for domestic cross-border CCS should be dedicated to achieving the objectives of clustering and synergistic collaboration. Therefore, we propose synergistic cluster governance as a strategic solution to unite a group of geographically proximate facilities, organizations, authorities and stakeholders to collaborate towards shared goals. At the core of synergistic cluster governance are the principles of clearly defined responsibilities and authorities, transparency, and fairness. Advancing cross-border CCS necessitates a comprehensive and coordinated approach built on synergistic cluster governance.

For countries with different contexts, synergistic cluster governance is a universal strategy for addressing domestic cross-border CCS. Based on its principles, it is essential to establish a clear legal framework, a diverse economic operating model and a fair compensation methodology. The varying regulatory standards and competing economic interests must be carefully considered during the planning and design phases of CCS projects. Through harmonized regulations and collaborative efforts within the cluster, building on transparent information, open dialogue and a trustworthy agreement, these

BOX 1

China's cross-border CCS practices

Recent years have witnessed China's cross-border CCS endeavours, which, through a combination of top-down policy design and bottom-up practical exploration, have demonstrated the viability of establishing a cross-border CCS policy framework from scratch utilizing the proposed solutions. For instance, China's central government has initiated representative cross-border CCS projects within its 14th Five-Year Plan for a Modern Energy System, highlighting the strategic importance of CCS. The plan includes developing innovative business models, increasing financial incentives, enhancing international technological collaborations and establishing demonstration projects in the Ordos Basin, spanning Shaanxi, Inner Mongolia, Gansu, Shanxi and Ningxia. The Ordos Basin stands as the paragon of structural stability on China's

mainland, boasting the simplest tectonic framework and the sparsest development of recent fault lines. The Shaanxi Provincial Department of Ecology and Environment has stated that they will incorporate CCS industrial planning and cluster integration with neighbouring provinces within the Ordos Basin into Shaanxi's long-term development strategy for CCS. Within the established policy framework, Chinese enterprises have actively engaged in bottom-up exploration of cross-border CCS practices. Sinopec, Shell, China Baowu and BASF are partnering for a pioneering 10 million tonne CCS project in East China, emphasizing river transport for capturing and storing CO₂ from industries along the Yangtze River as a cross-border natural carrier. This project will provide important references for future cross-border CCS initiatives centred around river basins.

externalities can be mitigated. Moreover, clear and harmonized guidelines for monitoring, reporting and verification of emissions within clusters are crucial to prevent double-counting. Financial subsidies, tax credits and trust funds are vital for reducing initial investment costs and ensuring the long-term viability of CCS clusters¹¹. Additionally, the establishment of regional carbon markets for CCS credits could enable the trading of emissions reductions within and between clusters. Local protectionism can be effectively mitigated through introducing a cross-border compensation mechanism. Regions that achieve actual emissions reductions, such as those hosting carbon capture facilities, may offer compensation for the permanent sequestration undertaken in storage areas. Likewise, in the context of cross-border CCS operations, regions possessing advanced CCS technology could be encouraged to extend industrial chain support to their less-developed neighbours as a form of 'compensatory' assistance.

Still, it is important to note that synergistic cluster governance must be customized to effectively address the distinct challenges faced by different countries. For example, it is essential for China to combine central oversight with the responsibilities of regional stakeholders. This could involve establishing independent agencies directly under central government control in areas with concentrated CCS activities, with responsibilities for planning, approval and regulation concentrated within these agencies. At the same time, operational rights should be delegated adequately, clearly defining the implementation responsibilities of various stakeholders, including local governments, enterprises and the public. China has already undertaken preliminary planning and policy exploration regarding domestic cross-border CCS (Box 1). However, breaking borders remains a complex and lengthy process, necessitating sustained efforts from various stakeholders, including the government, state-owned enterprises and the public, to engage in exploration, correction and refinement over an extended period for China. In the case of the United States, federal government should become involved in cross-border CCS governance. It is recommended that the federal government accelerates legislation on key issues related to cross-border CCS, such as permitting, safety and the expropriation of non-federal lands.

The future of cross-border CCS lies in adopting synergistic cluster governance that prioritizes collaboration, economic incentives and

a commitment to transparency and accountability. By fostering an environment of mutual trust and cooperation within clusters, nations can effectively address the challenges of climate change while promoting sustainable development and enhancing global environmental integrity. Nevertheless, recognizing the right path and walking it are two vastly different prospects. Cross-border CCS should not merely be a buzzword but rather a steadfast approach for a sustainable future.

Xiaoyu Zhang¹, Fengting Li^{1,2,3} & Yifan Gu^{1,2,3}✉

¹College of Environmental Science and Engineering, State Key Laboratory of Pollution Control and Resource Reuse, Tongji University, Shanghai, China. ²Shanghai Institute of Pollution Control and Ecological Security, Shanghai, China. ³Key Laboratory of Cities' Mitigation and Adaptation to Climate Change in Shanghai, China Meteorological Administration (CMA), Tongji University, Shanghai, China.

✉ e-mail: 159219yifan_gu@tongji.edu.cn

Published online: 28 February 2025

References

1. Thomas, C. D. et al. *Nature* **427**, 145–148 (2004).
2. Ripple, W. J. et al. *BioScience* **74**, 812–824 (2024).
3. Yan, Y. L. et al. *Energy Environ. Sci.* **14**, 6122–6157 (2021).
4. *Global Status of CCS 2023* (Global CCS Institute, 2024).
5. Mormann, F. *Nat. Sustain.* **7**, 839–841 (2024).
6. Kazlou, T., Cherp, A. & Jewell, J. *Nat. Clim. Change* **14**, 1047–1055 (2024).
7. Roggenkamp, M. M. & Banet, C. *European Energy Law Report XIII* (Intersentia, 2020).
8. Anders, S., Liebe, U. & Meyerhoff, J. *Nat. Clim. Change* **14**, 692–695 (2024).
9. Parfomak, P. W. *Siting Challenges for Carbon Dioxide (CO₂) Pipelines* CRS Report No. IN12269 (Congressional Research Service, 2023); <https://go.nature.com/3WY8voY>
10. Khoo, T. Cancellation of Heartland Greenway CO₂ pipeline underlines US regulatory bottlenecks. *S&P Global* (14 November 2023); <https://go.nature.com/4hC8bOF>
11. Wang, N., Akimoto, K. & Nemet, G. F. *Energy Policy* **158**, 112546 (2021).

Acknowledgements

This research was funded by the National Key Research and Development Program of China (2022YFE0110500), National Natural Science Foundation of China (22376161, 52373216), the Fundamental Research Funds for the Central Universities of China, and National Undergraduate Training Program for Innovation and Entrepreneurship (202410247082).

Competing interests

The authors declare no competing interests.