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RESEARCH ARTICLE

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An adaptive policy-based framework for China's Carbon Capture and Storage development

Abstract China's political leadership has taken an increasingly public and proactive stance on climate change since 2014. This stance includes making a commitment that Chinese carbon dioxide (CO_2) emissions will peak around 2030 and enacting measures through the 13th Five-Year Plan to support energy efficiency, clean energy technology, and carbon management. Chinese policymakers consider carbon capture and storage (CCS) a critical bridging technology to help accelerate the decarbonization of its economy. This paper reviews and analyzes Chinese CCS support policies from the perspective of an adaptive policymaking framework, recognizing uncertainty as an inherent element of the policymaking process and drawing general lessons for responding to changing circumstances. Notably, the political support for CCS in China remains fragmented with uncoordinated government leadership, undecided industry players, and even with opposing voices from some leading scientists. There is scope for expanding the framework to provide more granularity, in particular relating to the development of a CCS infrastructure and the development of storage-focused CO2-EOR. Overall, given the role CCS can play to decarbonize China's power and other industrial sectors, a commitment to CCS from top policymakers and major stakeholders is needed.

Keywords CCS, policy, climate change, China

1 Introduction

China is taking an increasingly proactive stance on climate change issues. As part of the 2015 Paris Accord, the country has committed to reducing the carbon intensity of its economy by 60% to 65% by 2030 compared with its 2005 levels and peak its carbon dioxide emissions no later than 2030. Such a commitment is an ambitious task given China's high dependence on fossil energy, mainly coal, to fuel an economy that continues to grow at approximately 6% annually (China National Statics Bureau, 2017).

China's decarbonization effort heavily relies on deploying large-scale renewable and nuclear energy supported by efficiency improvements. However, the cost of meeting China's anticipated long-term climate change mitigation goals can be approximately 25% higher without CCS (ADB, 2015). Therefore, China is developing and demonstrating carbon capture and storage (CCS) technologies to decarbonize its fossil-based energy systems and is currently among the global leaders in this area. China is now on its way to launch its first integrated large-scale CCS demonstration project by 2020, along with the implementation of several advanced CCS research and development (R&D) programs. This paper reviews and analyzes the status of CCS development from a policy perspective and outlines a course of further policy actions. Unlike a technology roadmap (e.g., ADB, 2015), which focuses mainly on cost-efficient deployment scenarios, this study takes an adaptive policy perspective. The policy-centered approach acknowledges the political, economic, technological, and institutional context for CCS in China, the inherent uncertainty associated with the development of large-scale and complex technologies such as CCS, and the need to balance the interests of various actors when formulating and implementing policies.

Coal has been the dominant fuel in China's power sector, accounting for 73% of the country's power generation in 2015 and 66% in 2016 (IEA, 2016). Continued resource-intensive industrial development has turned China into the world's largest CO_2 emitter, a

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position it has held since 2007. The problem is compounded by the deteriorating air quality of many of China's major cities and severe water contamination across the nation (Council on Foreign Relations, 2017). China's political leadership has realized that the country cannot continue to operate its economy at the expense of the environment and has enacted several measures to address these environmental issues. These measures include implementing the first-ever amendments to its Environmental Protection Law (enacted in 1989) in January 2017.

China's climate policy exhibits a similarly marked change in attitude. At the 2009 United Nations Climate Change Conference (COP15), China announced two key emission reduction targets for 2020: Reducing CO_2 per unit of gross domestic product (GDP) by 40%–45% compared with that of 2005 levels and increasing the share of non-fossil energy to 15% of primary energy consumption (UNFCCC, 2010). In 2011, China included several additional energy and environmental targets in its 12th Five-Year Development Plan. In November 2014, the United States–China Joint Announcement on Climate Change stated that China intends to peak its CO_2 emissions no later than 2030 and increase the non-fossil fuel share of its total primary energy consumption to 20% by 2030 (White House, 2014).

In the following year, China reaffirmed its intention to reduce CO_2 emissions per unit of GDP by 60%–65% from 2015 levels and increase the forest stock volume by 4.5 billion cubic meters from 2005 levels by 2030 (White House, 2015). In the same document, China committed to initiate national economy-wide emissions trading in 2017 and demonstrate its first one million ton integrated CCS project in Shanxi Province by 2020. China has incorporated many of its announced climate targets into its 13th Five-Year Plan (2016–2020), the country's most important economic planning document. Table 1 summarizes its current targets.

China's central government and state-owned energy companies have been aggressively pursuing the development of CCS since 2006 because coal is likely to continue to play an important role in its primary energy mix over the next 30–50 years. Accordingly, cost-effective CCS that can be employed on a large scale in the power sector and various industrial sectors, including steel, cement, and refineries, will enable China to meet its decarbonization goals (Metz et al., 2005; ADB, 2015).

2 CCS path to market

CCS is a technically feasible but highly capital-intensive climate mitigation technology. CCS accounts for 14% of the total required emission reduction in the IEA's "2-degree scenario" (2DS) from 2014 to 2060; the percentage considerably rises to 32% in its Beyond 2DS for the same time period (IEA, 2017). The International Panel on Climate Change (IPCC, 2014) considered that the cost of achieving the 2DS can increase by approximately 138% in the absence of CCS. Supporting the maturation of emerging low-carbon energy technologies into cost-effective CO_2 mitigation technologies often requires policy intervention. A particular challenge along the path to maturity is the so-called "valley of death": Points during the development and commercialization phases where funding (public and private) is increasingly stretched, unavailable, or simply insufficient. The "valley of death" is only one of several challenges in developing an emerging technology. The existing environmental economics literature contains discussions of various types of market failures and public policy proposals to correct such challenges. IEA (2012), Krahé et al. (2013), and Grubb (2014) analyze these issues specifically in a CCS context. The crucial points contained in this literature are as follows:

- Innovative emerging clean technologies will not make it to deployment without appropriate policy incentives; and
- The nature, scale, and scope of policy incentives must be calibrated to the specific needs of particular technologies. Policy incentives also need to change as technologies develop.

CCS is particularly prone to "valley of death" issues, reflecting the magnitude of the upfront capital investment required to scale-up CCS and the large implementation risks associated with deploying CCS technologies. Under the existing climate policy regime, the only attractive business case for CCS project developers is to use the captured CO_2 for enhanced oil recovery (EOR). These obstacles highlight the development and commercialization challenges of CCS compared with other emerging low-carbon energy technologies in China and the rest of the world. Policy incentives will need careful calibration to address these issues if they are to be successful.

The literature on innovation (e.g., Grübler et al., 2012) suggests that the path to market for CCS comprises several

Table 1 Climate change-related targets in the current and recent five-year economic development plans

Targets	12th FYP 2011–2015	13th FYP 2016–2020
Energy consumption per unit of GDP	16% reduction (18.2% achieved)	15% reduction
CO_2 emissions per unit of GDP	17% reduction (20% achieved)	18% reduction
Non-fossil fuel consumption of primary energy consumption	11.4% at the end of 12th FYP (12% achieved)	15% at the end of 12th FYP
Total energy consumption cap		Five billion tons of coal equivalent
Carbon intensity		40%–45% reduction 2020–2005

development phases that link and partly overlap (Fig. 1). The demonstration phase establishes the technical viability of CCS for practical deployment (IEA, 2012). In the market formation phase, the technology is exposed to limited market-based learning, which in turn reduces risk and cost and enhances investor confidence in the technology. This form of early market experience can come from sector-specific deployment in niche markets that have the lowest cost for CCS initiatives, such as CO_2 EOR. Diffusion, the final stage of the deployment path, involves the wide-scale deployment of CCS driven by economies of scale, infrastructure, and regulatory developments that together enable CCS to compete as a mature technology with other options to reduce CO_2 emissions. As will be discussed in the next section, CCS in China has almost completed its demonstration phase and is now facing the challenges of sector-specific demonstration and deployment. The analysis conducted in this study focuses on these technology development phases.

3 Status of CCS in China

Chinese government funding has proven highly effective in "pushing" CCS along its initial development path. The country has supported early CCS R&D through various science and technology programs, as summarized in Appendix A. Research subsidies, which are estimated at approximately 3 billion CNY (ADB, 2015), have delivered progress in the following areas.

3.1 Integrated demonstration projects

Table 2 presents a full list of current demonstration projects. Projects outside the power generation sector are particularly noteworthy: the coal-to-liquids facility with saline aquifer storage operated by Shenhua Energy Group and the combined CCS and CO_2 EOR project by Yanchang Petroleum in Shanxi Province. By 2020, the latter project is expected to become China's first integrated million-ton-per-year CCS facility.

3.2 Capture-side research, development, and demonstration projects

CO_2 capture projects without geological storage include Huaneng's 80000 t CO_2/year integrated gasification combined cycle-CCS project in Tianjin, the 120000 t CO_2/year post-combustion capture demonstration project at a supercritical coal-fired power plant in Shanghai also operated by Huaneng, and the 35 megawatt (MW) oxy-combustion demonstration project by the Huazhong University of Science and Technology. A main function of these projects is to discover the cost of CO_2 capture in China (Table 3).

3.3 Geological storage capacity estimation

From 2001 to 2012, the Chinese Geological Survey assessed the potential for geological storage of CO_2 in the Chinese subsurface, focusing on major basins (Guo et al., 2015). CO_2 storage potential in China is estimated to be nearly 1900 gigatons of CO_2, combining saline aquifer storage and depleted oil and gas fields (ADB, 2015).

3.4 CO_2 utilization research

CO_2 utilization technology has the potential to help offset the high cost of carbon capture, thereby providing an early opportunity for commercial CCS projects. The Ministry of Science and Technology (MOST) has been supporting CO_2 utilization research. Research topics that received funding over the past 10 years include the use of CO_2 to produce a biodegradable polymer, CO_2 EOR, CO_2-enhanced shale gas recovery, and algae cultivation for biofuels or fertilizers that use CO_2. With the support from MOST, a Chinese company in Jiangsu Province has been utilizing nearly 10000 t CO_2 a year since 2007 to produce polypropylene carbonate, which can be used for biode-

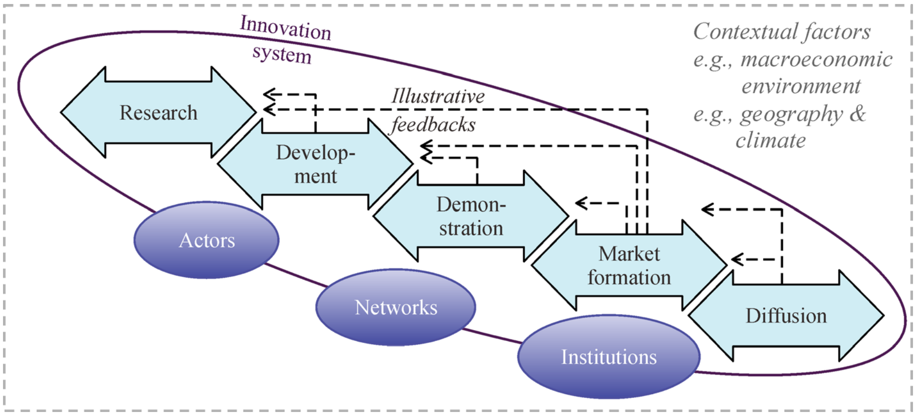

Fig. 1 Energy technology innovation process (adopted from Grübler et al., 2012)

Table 2 Operational integrated CCS projects in China (compiled by authors from various sources)

Integrated projects	CO_2 sources	Capture	Transport	Utilization/storage	Operational year
CNPC-Jilin CO_2 EOR demonstration	Natural gas processing	Pre	Pipeline (approximately 50 km)	EOR (300000 t CO_2/year)	2007
CNPC-Daqing Oil Field CO_2 EOR demonstration	Natural gas processing	Pre	Truck & Pipeline	EOR (200000 t CO_2/year)	2003
Sinopec-Shengli CCS Project	Power generation	Post	Trucks (approximately 80 km)	EOR (40000 t CO_2/year)	2010
Shenhua Ordos CCS project	Coal-to-liquids	Pre	Truck (approximately 11 km)	Saline (100000 t CO_2/year)	2011–2014
Sinopec-Zhongyuan CO_2 EOR project	Chemical	Pre	Truck	EOR (120000 t CO_2/year)	2015
Xinjiang Dunhua	Petrochemical	Post	Truck	EOR (100000 t CO_2/year)	2015

Table 3 Current CO_2 capture cost in China (compiled by authors from various sources)

Capture type	Cost	Scale
Post-combustion- power sector	CNY 300/t CO_2 (approximately \$46/t CO_2)	200 kton/year
Pre-combustion- power sector	CNY 298/t CO_2 (approximately \$46/t CO_2)	80 k–100 kton/year
Oxy-demonstration- power sector	CNY 500–600/t CO_2 (approximately \$75/t CO_2) for 35MW (First-of-a-kind power-plant);	100 kton/year (based on the project plan)
Coal-to-chemical	CNY 200/t CO_2 (approximately \$30/t CO_2)	460 kton/year

gradable plastics.

Despite substantial progress, challenges have also existed. Given the high up-front capital investment required by CCS demonstration projects and current low oil prices, some previously announced large-scale CCS demonstration projects have not materialized. The project planned by Sinopec, one of China's state-owned oil companies, to capture one million tons of CO_2 annually from a power plant for CO_2 EOR in the company's Shengli Oil Field by 2015, is a case in point. The power plant started its operation in 2010, and MOST supported the research component of this project from 2012 through the National Key Science and Technology Project Program. With continued low oil prices, Sinopec postponed taking the final investment decision, arguing that the economics of the project did not meet the investment criteria of the company. This example demonstrates the technology "valley of death": The cost of further deployment is increasing and cannot be met without direct governmental subsidies, and private capital is insufficient to cover the difference.

3.5 Industrial-scale demonstration

The next stage of CCS development is expected to focus on limited industrial-scale demonstration of CCS in specific sectors. A reasonable and viable deployment scenario for CCS in this phase can include the following:

- *CCS in industrial applications*

Application of CCS in the industrial sector is attractive because it has limited options to reduce emissions without CCS. Alternative industrial processes to produce steel and cement and refine chemicals are unavailable. This condition differs from the situation in the power sector, wherein CCS is one of several low-carbon energy technologies available to decarbonize electricity generation. Moreover, capture costs in the industrial sector tend to be lower than those in the power sector because the industrial sector can capture CO_2 from flue gases in a pure and concentrated form. The application of CCS is particularly warranted in coal-to-chemical processes due to the large amounts of highly concentrated CO_2 coal conversion productions.

- *CCS as part of CO_2 EOR*

CO_2 EOR operations can provide a particularly cost-effective form of storage. The costs associated with identifying and exploring the storage formation can be crucial for aquifer storage but are negligible for EOR projects because the exploration work has already occurred in the primary oil recovery process. Moreover, the benefit of enhanced oil revenue from CO_2 injection helps to offset the costs of CO_2 storage.

The following figures help to illustrate the potential opportunity of CO_2 EOR for China. Assuming that CO_2 is delivered free of charge, Ward et al. (2018) estimates that approximately 750 million tons of CO_2 from existing CO_2 sources can be stored through CO_2 EOR projects that have

Table 4 Total economic storage (project NPV⩾0) when CO_2 is delivered free of charge. Storage numbers are for present-day CO_2 and for a reference situation of unlimited CO_2 supply (Ward, 2017)

	CO_2supply constrained by availability (million tons CO_2)	Unlimited CO_2 supply (million tons CO_2)
Pre-tax	1900	12070
Post-tax	751	10919

a zero or positive net present value (NPV). If the constraint regarding availability from currently operating CO_2 sources is relaxed, then CO_2 EOR projects with a zero or positive NPV can store approximately 11 billion tons of CO_2. Most of this potential storage comes from Shengli and Daqing oil fields.

- *Establishing a CO_2 transportation network*

A transportation network that can be accessed by multiple CCS operators is essential for realizing the full scope of emission reductions from CCS. In China, most CO_2 deliveries for utilization or storage is by truck, which is an expensive and unsuitable way to transport large volumes of CO_2. As CCS development manifests against a backdrop of uncertainty regarding future infrastructure demand, a substantial need exists for coordination project operators for capture, transport, utilization, and storage, a task that public policy is best placed to address.

4 Policy drivers and potential instruments

The government has numerous policy instruments to choose from to support CCS development and deployment. IEA (2012) provides an overview of the main instruments. The paper suggests that capital grants, such as competitive or administrative direct government capital contributions toward CCS construction, are appropriate or even essential for the demonstration phase. However, sector-specific CCS deployment is unlikely to be feasible with public grants alone. A mix of policy instruments appropriate for this phase includes the following:

- Capital or production subsidies: Investment and production tax credits that reduce the tax liability for a firm that operates CCS assets, including capture, transport, and storage.
- Performance standards: A portfolio obligation requiring CCS-fitted fossil-based plants to produce a certain percentage of output.
- Infrastructure support: Government acting either directly or through agents to provide infrastructure planning for system development. Due to long lead times, which are usually 6 to 10 years to build facilities such as pipelines (ZEP, 2013), CO_2 transportation and storage infrastructure development must start early.

A broad range of competing and conflicting evidence indicates that policy priorities, political aspirations, public acceptance levels, local economic and industrial conditions, and institutional structure play determining roles in eventual policy implementation. A range of policy considerations, including economic, fiscal, industrial, regional development, and environmental factors, will impact public support for CCS. Environmental, industrial, and regional development factors are likely to outweigh the economic and fiscal dimensions in China. As such, China supported its policy objective to become a leader in the renewable energy industry with a raft of policy instruments, including capacity targets, subsidies, standardizing renewable energy products, tax rebates for equipment manufacture, and customs duties for equipment export (see Appendix B). Issues of cost-effectiveness and the appropriate allocation of risk and reward do not appear to have been major factors in the choice of policy instruments supporting renewables (Zhao et al., 2014).

4.1 Demonstration and sector-specific deployment

Whether the Chinese Government's policy support for CCS will be as comprehensive and generous as its support for renewable energy remains unclear. However, capital grants are evidently likely to be the preferred means of supporting CCS in China during the demonstration phase and in driving sector-specific deployment. This concept is at variance with the accepted economic view that grant funding should be restricted to the demonstration phase to avoid overstretching the fiscal resources of the government. However, the Chinese government has traditionally been good at using capital grants or direct support to deliver large-scale industrial projects, such as the Three Gorges Dam and early high-speed train development and nuclear power projects. A growing voice from the CCS community has been advocating the government to include ongoing CCS deployment in China's National Major Construction Projects Program, most of which is entirely financed by the central government.

In contrast to grant funding, government support via portfolio standards or tax policy is difficult because it requires the involvement of various government ministries and agreement at the State Council level. Given the present lack of coordination on issues related to CCS among the involved ministries and their competing policy priorities, the practical barrier to securing broad agreement for such policies is high.

However, this assessment may not apply to storage-focused CO_2 EOR projects. First, CO_2 EOR projects are subject to the well-established petroleum production regime of China, which focuses on optimizing oil production to maximize associated taxation and resource rent revenues. The oil production regime is managed through numerous provisions, which include *inter alia*, the requirement of production sharing, the imposition of a resources tax set at 6% of the crude selling price, and a 25% tax on corporate earnings (US EIA, 2016). Second, since 2014, oil produced via CO_2 flooding can benefit from a 30% resource tax exemption. Adjusting the fiscal regime to provide favorable treatment to CO_2 EOR projects is an appropriate support measure due to the huge CO_2 storage potential.

Given the costs and risks involved, transportation infrastructure is most likely to develop incrementally from point-to-point links between individual emitters and storage sites and without the scale required to support the timely and efficient development of local or regional clusters. Such a development path can pose a substantial practical barrier to efficient and timely CCS development in China. Cluster-scale infrastructure development will require strategic coordination and the pooling of cluster investments and financing. The government is the best place to provide this strategic leadership and support the development of the key transportation infrastructure by underwriting a proportion of the network costs. The role of government regulation is to ensure access to the network for individual CCS operators on fair and reasonable terms and guarantee the fair recovery of network costs. Given the long lead times for infrastructure development, early government involvement is essential for the timely development and cost-effective deployment of CCS.

4.2 Commercial deployment

In the long-term, China can include CCS in its national carbon policy regime. In principle, economy-wide carbon pricing involves the efficient allocation of the emission reduction burden across the economy to ensure CO_2 is mitigated at the least cost. The Chinese government launched the first phase of a national emissions trading program in December 2017. The country has already gained experience in emissions trading through seven pilot projects that operated between 2013 and 2015. The first phase of the national emissions trading program only regulates the power sector. The first round of the emissions trading program does not include CCS. However, establishing an emissions trading system sends a signal to the business community to incorporate carbon constraints in their operational and investment decisions. In this manner, a carbon price can potentially complement and reinforce sectoral policies designed to promote CCS. The government is currently working with experts on the specifics of incorporating CCS into the emissions trading scheme. Their priority is to resolve the permit allowance allocation method and the monitoring, reporting, and verification of requirements.

Senior officials from the National Development and Reform Commission (NDRC) and the Ministry of Finance have also discussed the possibility of implementing a nationwide carbon tax after 2020 to support the diffusion and deployment of low-carbon energy technologies. Despite the current US administration's critical view of climate change and the Paris accord, China has repeatedly stated its intention to proceed with its planned climate efforts, providing the predictability and consistency needed to underpin its emissions reduction policy.

4.3 Policy implementation

The discussion has thus far focused on identifying a complementary set of policy instruments that can support the development of CCS into a mature technology. These instruments include capital grants supporting large-scale CCS demonstration and construction, a favorable fiscal regime for CO_2 EOR, and government action to develop CO_2 transportation infrastructure. The emissions trading program of China can provide general support as it expands to include the entire economy in 2030. The resulting economy-wide carbon price can potentially provide further support for CCS on a technology-neutral basis.

The policy instruments must be deployed in an integrated way that effectively reflects the objectives of an overarching policy framework. The policy framework must reflect the inherent uncertainties associated with the development and deployment of new low-carbon energy technologies such as CCS. The uncertain nature and rate of innovation in low-carbon energy technologies mean that technological progress is unlikely to be linear. Policy frameworks must be able to quickly and effectively respond to such uncertainty in case they become a barrier to desirable technological progress or unduly distort technological development and deployment.

Experience suggests that the most effective policy frameworks are holistic, objective, and adaptable. In general, policy frameworks are holistic in that they consider technological development in its entirety and seek to provide an interrelated set of targeted stimuli that complement and reinforce incentives for efficient, innovative, and timely development and deployment. Holistic policy frameworks help to avoid unintended consequences that can potentially derail or fundamentally distort such timely and effective technological development and deployment.

Effective policy frameworks also seek to establish clear, outcomes-based policy objectives. They are not bound by timetables or timelines, recognizing that technological development is inherently uncertain and rarely proceeds according to a pre-determined administrative program. Furthermore, they do not prescribe how to achieve a policy goal. Instead, these frameworks seek to create and reinforce incentives to encourage participants to work out the timeliest and most innovative way to meet the objective by using whatever cost-effective combination of technologies and commercial arrangements are available.

Most importantly, effective policy frameworks are adaptable. They can change the range and combination of policies or quickly and effectively moderate policy priorities. Thus, the policy framework is ensured to remain relevant and effective in response to changing technological developments, commercial innovation, relative costs, unanticipated developments, and evolving policy priorities. In practice, regular policy evaluation and review based on operational evidence and other information gathered from the incremental implementation of support programs can build adaptability into the policy process. Three- to five-year timeframes are probably appropriate in this context, and they are likely sufficient for testing and assessing policy interventions while enabling timely responses to new circumstances that avoid potentially harmful "policy lock-ins." A five-year timeframe is also consistent with the review period proposed under the Paris Agreement (Falkner, 2016).

A holistic, objective, and adaptable policy framework should be designed so as "not to be optimal for the best estimate future, but [should seek to be] robust across a range of plausible futures" (Walker et al., 2001). Existing literature suggests various tools to endow policy frameworks with the adaptability needed to support effective implementation (Swanson et al., 2010). IEA (2012) adopts a particularly relevant approach to CCS, relying on "gateways" or "milestones" that link governmental policy to the achievement of certain technology performance thresholds. The policy gateways include the following three key components:

- Type of policies used in each stage of the CCS development cycle.

- Criteria for determining changes in support policy.

- Contingency plans outlining how the government will respond if gateways are missed.

The government offers a medium-term commitment to specific policies through the gateway process. This commitment provides the private sector with a high degree of consistency and predictability within the objective-based goals and bounds established by the overarching CCS policy framework.

Figure 2 specifies possible "gateways" pertaining to the demonstration and sector-specific deployment phases.

Comparison of the actual state of CCS in China with the metric presented in the table suggests that CCS policy has completed most of the demonstration phase milestones and should prepare to tackle sector-specific demonstration.

Formulating the policy response for when "gateway" milestones have not been fully achieved can be difficult in practice. The response will considerably depend on the nature of the failure and the surrounding circumstances. For example, a range of potentially credible responses is available for a case where operating projects are insufficient to justify the inclusion of CCS in the emissions trading scheme. These responses include extending the capital grant-funding program, targeted R&D funding to address observed technological barriers, or potentially mandating CCS construction. Alternatively, the government may continue to introduce a moderate economy-wide carbon pricing scheme, accepting that it may not lead to CCS deployment.

Whatever path is taken, the government must be cautious and avoid responses that are inconsistent with a holistic, objective, and adaptive policy approach. Incremental change demonstrably based on objective evidence is desirable rather than radical amendments that are likely to undermine confidence in the overall policy framework and the government's commitment to its implementation. Policy responses must be credible and be perceived to be credible by key stakeholders to achieve the desired effect.

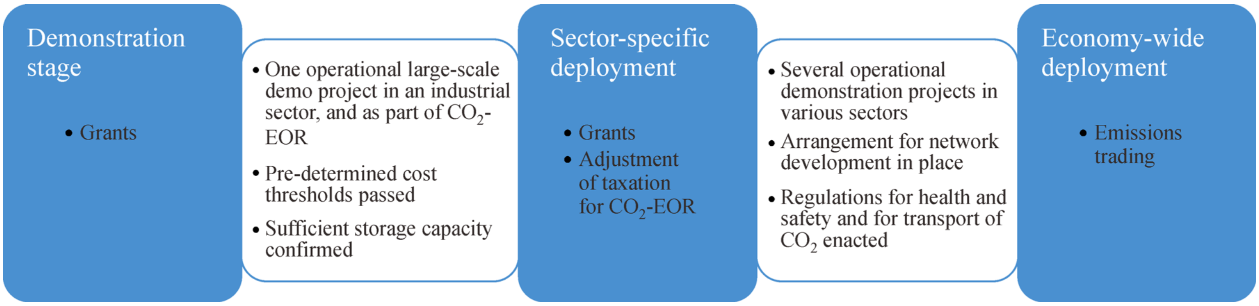

Fig. 2 Potential CCS policy gateways in China

5 Conclusions

This paper discusses the key features of an adaptive policy framework that can support and drive the development of CCS. After a decade's effort on CCS R&D, China is ready to move the technology to the demonstration phase or early sector-specific deployment. Capturing CO_2 from industrial applications and utilizing the CO_2 for EOR may provide China with an early opportunity to achieve an integrated industrial-scale CCS demonstration: a path to early commercial deployment. The Chinese government can consider various policy incentives to support CCS development in the short-term. Based on China's past experiences, the use of capital grants to support the demonstration and sector-specific deployment of CCS may be the most effective and efficient approach. In the long-term, CCS must be integrated into China's national carbon policy regime to allow it to fully veap the behefits the technology offers. Thus far, governmental support for CCS remains fragmented in China due to uncoordinated government leadership, undecided industry players, and competing voices from some leading scientists. Given the beneficial role of CCS in decarbonizing the power sector of China and other industrial sectors, commitment to CCS from senior policymakers and major stakeholders is needed. CCS will be most effectively delivered through a holistic, objective, and adaptable policy framework.

An adaptive policy framework comprising several policy gateways has the potential to enable the government to apply a flexible and incremental policy approach. This approach is better suited to the inherent unpredictability that may affect the development of emerging low-emission technologies such as CCS. The adaptive policy framework also provides a way of delivering the level of policy predictability and consistency essential for private investment.

Appendix A

Table A1 Overview of policies to "push" CCS in China (compiled by authors from various sources)

Year	Ministry	Policy	Main Contents
2006	State Council	National Medium- and Long-Term Program for Science and Technology Development (2006–2020)	Develop highly efficient, clean, and zero-carbon fossil technologies.
2007	State Council	China's National Climate Change Program (2007–2010)	Further develop CCUS technologies.
2007	14 ministries including MOST	China's Scientific and Technological Actions on Climate Change (2007–2020)	Include CCS in the priority areas.
2011	MOST	The 12th Five-Year Plan on Science and Technology	Regard CCUS as one of the strategic low-carbon technologies.
2011	State Council	The 12th Five-Year Plan on Greenhouse Gas Reduction	Demonstrate CCUS technologies in the power sector, steel industry, cement industry, and coal-chemical industry.
2012	16 ministries led by MOST	The 12th Five-Year Plan on Climate Change Science Program	Focus on cost reductions and business model of CCUS technologies; further enhance international cooperation, including capacity building and technology standardization.
2012	Four ministries	Blueprint for Climate Action in Industrial Sector	Explore CCUS technologies under the Chinese context.
2013	NDRC	Promoting CCUS Industrial Demonstration	Encourage industrial players to demonstrate CCUS technologies.
2013	State Council	National Medium and Long-term Plan on Major Scientific and Technological Infrastructure	Further study and develop CCUS technologies for climate change.
2013	Ministry of Environmental Protection	Calling for Environmental Protection for CCUS Demonstration Projects	Environmental guidelines.
2014	NDRC	National Climate Change Action Plan 2014–2020	Implement integrated CCUS demonstration projects; include CCUS as an important low-carbon technology.
2014	MOST and MIIT	Special Program for Energy Saving and Emissions Reduction Technology	
2014	NDRC	Upgrading and reforming of Energy Saving and Emissions Reduction of Coal Power Sector 2014–2020	Further study of CCUS technologies.

Appendix B

Lessons from renewable energy development in China
The development of renewable energy in China has considerably benefited from various industry policy instruments. For example, installed wind power capacity was only 0.567 gigawatts (GW) in 2003 but reached 149 GW in 2016. The following steps were taken to support this scale-up:

2009 NDRC introduced a feed-in tariff for onshore and offshore wind.

2010 Ministry of Finance removed import duty on wind and hydro technological equipment.

2012 Ministry of Science and Technology issued a wind power technology development program.

2013 12th Five-Year Special Planning.

NDRC issued a notice on the improvement of the grid connection and feed-in of wind electric power generation.

NDRC announced feed-in-tariffs for offshore wind power.

2016 NDRC published the 13th Wind Energy Development Five-Year Plan.

2017 Chinese government announced spending of more than 360 billion USD through 2020 on renewable power sources, such as solar and wind.

The policy instruments enacted to support renewables range from strategic planning to specific policy instruments, including grants, subsidies, feed-in tariffs, and research, development, and demonstration support. A powerful advocacy coalition, which includes senior political leadership, policymakers at the ministry level, state-owned enterprises, industry associations, and prominent research institutes, is behind more than a decade's consistent policy push.

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