China's carbon capture, utilization and storage (CCUS) policy

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China's Carbon Capture, Utilization and Storage (CCUS) Policy: A critical review

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Abstract

Carbon capture, utilization and storage (CCUS), has been deemed an essential component for climate change mitigation and is conducive to enabling a low-carbon and sustainable future. Since the 12th Five-year Plan, China has included this technology as part of its future national carbon mitigation strategies. China's policy framework in relation to CCUS has had a strong influencing role in the technology's progress to date. This paper employs the "policy cycle" to analyze China's existing CCUS regulatory framework at the national and provincial level, evaluate its performance and clarify its shortcomings in light of the comparisons of policy movements undertaken in other countries. The results indicate that China's CCUS policy is insufficient for further development of the technology and many issues remain to be solved. This includes the lack of an enforceable legal framework, insufficient information for the operationalisation of projects, weak market stimulus, and a lack of financial subsidies. These factors may be the reason we have seen low participation rates of Chinese companies in CCUS and little public understanding of what the technology offers. To overcome these challenges, suggestions are provided for improving China's CCUS legal and policy framework.

Keywords: CCUS, China, law and policy, achievements and challenges, suggestions and prospects

Abbreviations: CCS, carbon capture and storage; CO_2-ECBM, enhanced coalbed methane by CO_2 injection; CO_2, carbon dioxide; CCUS, carbon capture utilization and storage; U.S., United States of America; GHG, greenhouse gas; FYP, Five-year Plan; CGS, carbon geological storage; MOST, Ministry of Science and Technology; NDRC, National Development and Reform Commission; MOEP, Ministry of Environmental Protection; EOR, enhanced oil recovery; TSC, The State Council; CBRC, China Banking Regulatory Commission; MOLR, Ministry of Land and Resources; SAC, Standardization Administration of China; NEA, National Energy Administration; MOIIT, Ministry of Industry and Information Technology; CMA, China Meteorological Administration; CNY, Chinese yuan; R&D, research and development; U.K., United Kingdom; GCCSI, Global CCS Institute; IEA, International Energy Agency; CSLF, Carbon Sequestration Leadership Forum; ACCA21, the Administrative Center for China's Agenda 21; IEC, Increase in Energy Consumption. GSC, Geological Survey of China; SCNPC, Standing Committee of the National People's Congress; GDRC, Guangdong Development and Reform Commission; PPP, public participation policy; PCF, Public Comment Form.

Highlights

- The development of China's CCUS policy framework is reviewed.
- Since 2011, China's national Five-year Plans referring to CCUS influence provincial policies as they all share similar objectives.
- China's national policies influence China's research and engineering practices related to CCUS.
- While China has progressed a number of CCUS projects, they have failed to meet the proposed targets in technology roadmap released during the period of the 12th Five-year Plan.
- Recommendations to amend the regulatory framework for CCUS in China are provided.

1 Introduction

In the last century of rapid industrialization, environmental degradation and climate change have not been seriously considered internationally, because they have been viewed as the price to pay to alleviate poverty [1]. To address these issues, carbon capture and storage (CCS) has been identified as a priority technology [2, 3] and it is predicted to contribute up to 32% of carbon dioxide (CO_2) emission reductions by 2050 [4]. Although CCS has been examined and demonstrated in the global community since the 1990s, it is not well recognised in China. This lack of awareness in China may be due to Chinese society's extreme caution towards imported technologies, like CCS, and towards policies that might be seen as political interference in the name of environmental protection [5].

China's concern over CCS technology was not publicly mitigated until 2005 when *China's Coalbed Methane Technology/CO_2 Sequestration Project* was completed. In this project, the primary target was to enhance coal bed methane production by injecting CO_2 (CO_2-ECBM). However, the performance of CO_2 storage in low-permeable coal seams was unexpectedly successful [6], which may be why the Chinese government's attitude towards CCS changed. Almost simultaneously, China had to confront the additional burden of being the largest CO_2 emitter in the world [7]. To assist the country in maintaining its rapid industrialization through the exploitation of fossil fuel resources, China decided to pay more attention to CCS, as well as to include 'CO_2 utilization' in the CCS concept. This eventually led to a change in terminology: "carbon capture, utilization and storage" (CCUS) rather than "CCS" became the adopted name for the technological process in China.

Similarly, there have been a number of achievements in the deployment of CCUS internationally, which are intricately related to the legal and policy support being shown for the technology. At both the macro and micro levels, public policies are designed to present solutions to societal problems through clearly defined goals [8]. Strict policy interventions, in particular, direct incentives have been found to be important for addressing environmental challenges which have considerable uncertainties and need longer timeframes to address [9, 10]. Other well-known consequences for new technologies that can arise from policy changes include technical innovations, accelerated market penetration and reductions in upfront costs [11]. This has been evidenced from the implementation of policies aiming to reduce carbon emissions successfully, which has resulted in an increase in the size of the market share of clean energy technologies including renewable energy, clean coal technologies, nuclear power and the introduction of electric vehicles in the transportation sector [12-15]. As a result, pioneers in the CCUS domain, for instance, the United States of America (U.S.) and Norway, decided to promulgate and amend a series of specific and relevant regulations to promote

CCUS development. These have involved infrastructure licenses, greenhouse gas (GHG) permits, environmental benefits or credits, financial assurance, indemnification for misconducted operations, tax exemption, site closure certificates and long-term liabilities [16-18].

Investigations to map international CCS/CCUS policies to date are insufficient as they tend to cover mostly European [18-22] and North American countries [23-25]. In the research domain of China's CCUS, hundreds of studies have been conducted including studies of development trends and challenges [26-31], detailed project implementation [32-35], storage capacity evaluations [36-38], environmental impacts [39-41] and other issues. However, descriptions of the CCUS policy framework only constitute a small component of the discussions in the literature, and comprehensive CCUS policy analysis in China is missing. Indeed, China has made certain changes in its regulatory system to support CCUS development. A good example is the Five-year Plan (FYP), a fundamental national guideline, which began to emphasize this technology since the beginning of the 12th FYP (in 2011). Therefore, this paper aims to, from the public policy perspective, examine China's CCUS policy framework and evaluate how it works.

Considering that policies under discussion now are dependent on decisions made before and also lead to future policies [42-44], this paper employs the "policy cycle" created by Howlett and Ramesh (2003) to analyze China's CCUS policies. The cycle includes five steps: *agenda-setting* referring to the identification of a public problem, which requires the government to intervene; *policy formulation*, where the policy objectives and potential policy instruments are defined, discussed, accepted or rejected; *policy adoption* or *decision-making*, which confirms the most appropriate policies; *policy implementation*, representing the conversion of new laws and programs into practice; and *monitoring and evaluation*, whereby industry and policy experts monitor the routine tasks, measure whether the outcomes have attained the intended goals, and evaluate the long-term consequences, leading to amendment or redesign [43, 45-47]. Generally, *policy formulation* and *policy adoption* are strongly related and it is impossible to find a clear-cut distinction between them [43].

Following the above analytical process, this paper first sets China's CCUS policy system as the agenda. Then, Section 2 elaborates the objectives and primary policy instruments related to China's CCUS, which belongs to *policy formulation* and *adoption,* over the three development stages. The political issue of how policies are put into effect is not a focus of this study; however, comprehensive evaluations from four aspects, which include research and development, project implementation, international cooperation as well as gaps arising from the proposed goals, are presented in Section 3. After Section 4 reviewing the regulatory framework in the U.S., Australia, Norway and Japan and confirming several defects in China's CCUS policy supporting system, Section 5 makes suggestions regarding how to ensure China's approach to CCUS is more systematic and effective. Section 6 completes the paper with some conclusions.

2 The framework of China's CCUS policies

It should be noted that China's policy system differs from those of Western countries where sometimes the State legislation can be independent of the national system (see more details in [48]). China's policy scheme has several advantages compared to Western's, for example, the stabilization of national long-term development plans regardless of the alternation of parties with different positions and ideologies, and high efficiency as well as promptly effective responses to emerging challenges and opportunities. This represents that if the central government expresses a strong passion for CCUS for climate reasons, it will be researched, planned, tested and deployed expeditiously.

China, a socialist country, runs a top-down political scheme. Its fundamental policy is the FYP released by the central government, which is an overall blueprint of the economic and social development for the entire country over a five-year period. Under its guidance, various ministries issue detailed FYPs (called "sub-FYPs" in this context) describing a particular area, for example, the 10th FYP for Environmental Protection, the 11th FYP for the Development of Traditional Chinese Medicine, the 12th FYP for Education Development and the 13th FYP for Energy Development. Then, taking these national requirements and actual regional situations into account, provinces, municipalities and autonomous regions announce local FYPs and their local sub-FYPs. Normally and subsequently, supplementary guidelines or rules are protocolled by both national and regional authorities to assist the implementation of the FYPs.

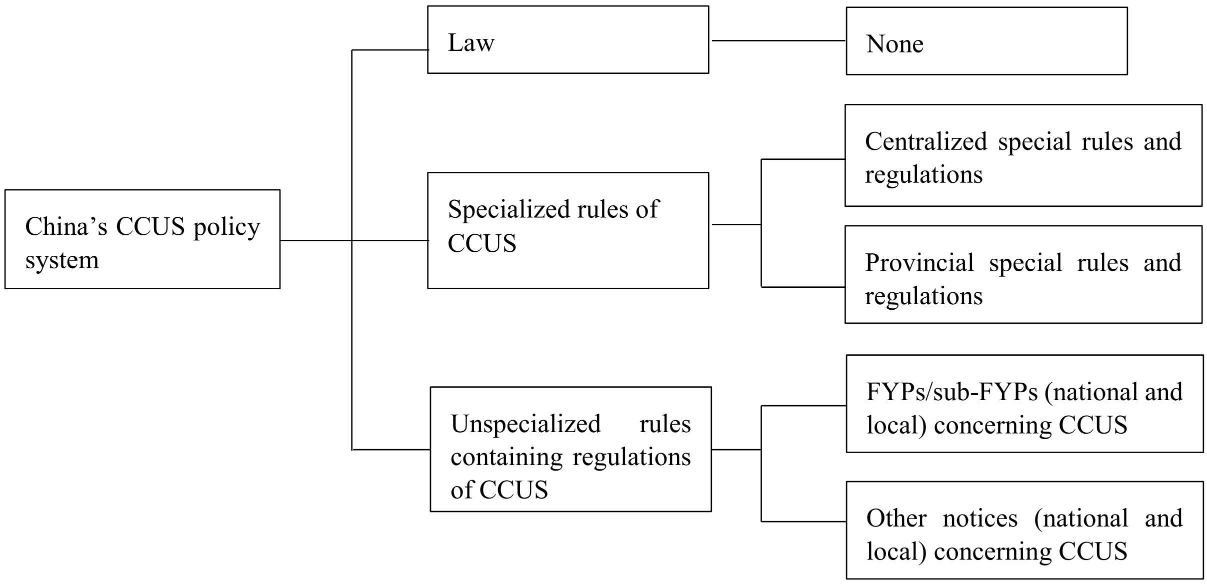

Figure 1 Framework of China's CCUS law and policy

As to CCUS, China's policies over the past decade suggest a growing interest, with the government recognising that CCUS technology will be a significant contributor for controlling greenhouse gas (GHG) emissions, despite still having barriers to overcome. Thus far, China has formulated a CCUS policy system essentially based on specialized rules and other related regulations (Figure 1). This section introduces the specialized rules from the beginning to the present time, followed by presentations of three groups of unspecialized guidelines which are categorized according to which FYP they follow.

2.1 Specialised rules of CCUS

Unlike renewables, which China regulates by the *Law of Renewable Energy* or other related laws [49], China does not enact any specific laws for CCUS. Instead, there are five special notices or plans issued by different authorities at the national level while provinces (including autonomous regions and municipalities) have not issued any (Figure 2).

After the completion of the CO_2-ECBM project in 2005, it took four years to announce the first specific outline, which aimed at identifying storage capacity. In 2013, the second specialized plan—*12th FYP for National CCUS Technology Development*—came into force, which indicated CCUS technology had become a part of national strategies. This plan comprehensively put forward objectives and requirements for CCUS development from a technical point of view. It encouraged extending the deployment scale from regional pilots to national demonstration and covered various aspects of CCUS in its different chapters such as Situation and Demand; Fundamental Principles; Development Objectives; Priority Development Direction; Key Tasks; and Supporting Measures [50]. The *Notice on Promoting CCUS Test Demonstration* was then promulgated in 2013 by the National Development and Reform Commission (NDRC), facilitating CCUS development from the perspectives of subsidy schemes, standards establishment and international cooperation. Furthermore, it initially put forward to enhance individuals' perception of this technology through knowledge sharing and dissemination. This was then highlighted by the *Notice on Strengthening the Environmental Protection of CCUS Demonstration Projects* in the same year. These two Notices are the only Chinese governmental rules referring to public attitudes towards CCUS to date.

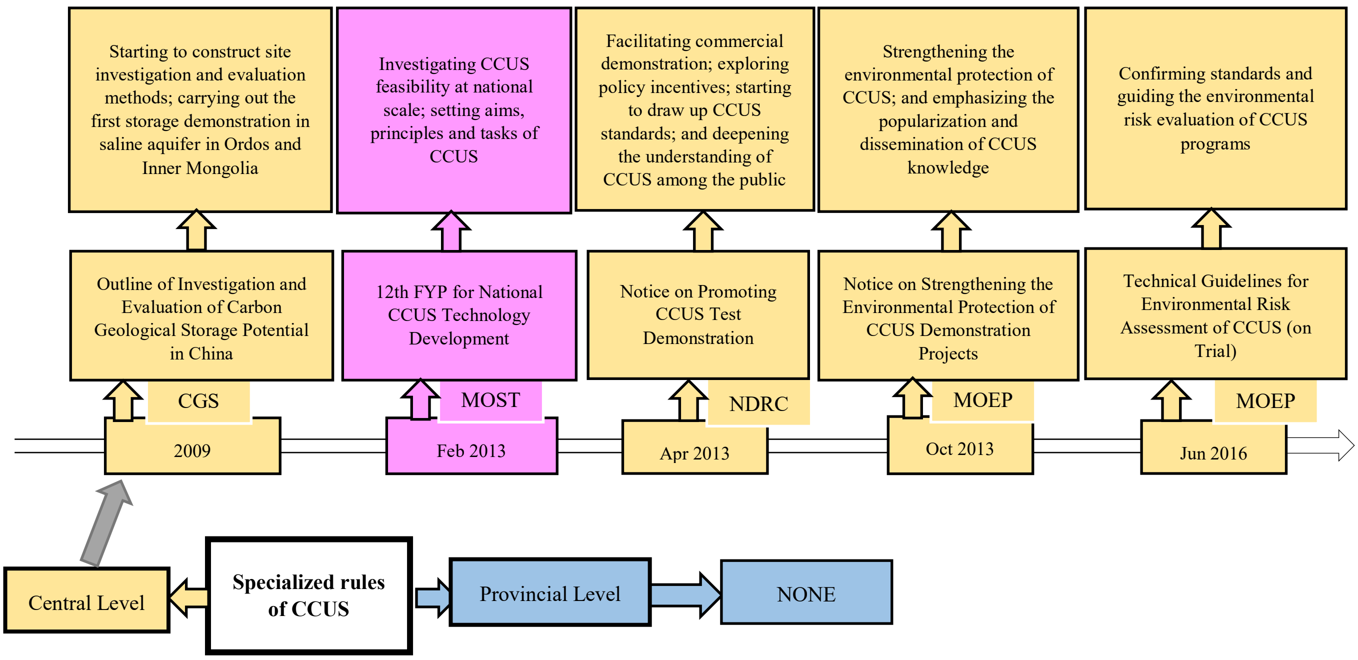

Figure 2 Specialized CCUS rules (PURPLE represents national FYPs or sub-FYPs, YELLOW represents other national polices, and BLUE represents provincial regulations)

The environmental risks associated with CCUS mainly include concerns around CO_2 leakage from storage sites [51]. Even though such risks are comparable to the risks in similar existing industrial operations such as underground natural gas storage and enhanced oil recovery (EOR) [52], the safety of long-term storage over many hundreds or thousands of years has not been proven [53]. To minimize negative influences, in addition to the latter *Notice (see the above paragraph),* the *Technical Guidelines for Environmental Risk Assessment of CCUS (on Trial)* was put into effect in 2016. The *Notice* aimed to establish a system to prevent and control environmental risks. The *Technical Guidelines* provided strict technical regulations to assess CCUS-related risks, for example, pollutions to shallow groundwater, soil, rivers, lakes and air, and to manage CCUS projects for safe, environmentally friendly and effective operations.

2.2 Unspecialized rules/plans containing CCUS

In addition to special CCUS rules, other regulations governing environmental and climate protection also involve CCUS. Generally, these notices gradually increase the significance of CCUS as a priority technology for a sustainable future. The development of the CCUS regulatory framework can be divided into three stages, and each stage has similar objectives.

2.2.1 Stage 1 (during 11th FYP from 2006 to 2010)

China's policies have provided support for CCUS since the beginning of the 11th FYP. However, the 11th FYP itself did not refer to CCUS at all. The primary drivers in this period were several national plans on climate change mitigation, as shown in Figure 3.

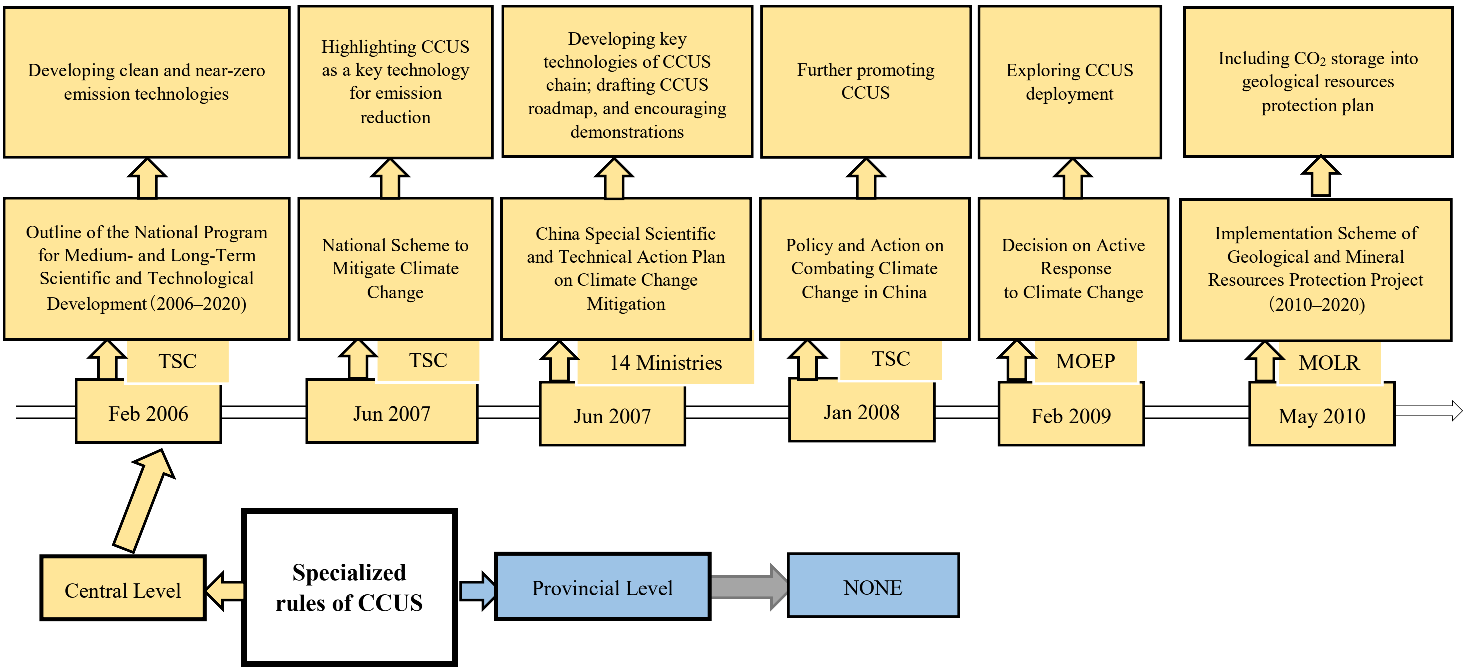

Figure 3 Unspecialized policies containing CCUS during 10th FYP (from 2006 to 2010) (YELLOW represents other national policies, and BLUE represents provincial regulations)

The *Outline of the National Program for Medium- and Long-term Scientific and Technological Development (2006—2020)* represented the start of China's low-carbon development. Rather than stating detailed techniques, it demanded that clean and near-zero technologies were urgent. Thereafter, when China overtook the U.S. in producing the largest amount of emissions in the world in 2007, the country immediately announced the *National Scheme to Mitigate Climate Change* and *China Special Scientific and Technical Action Plan on Climate Change*, both of which included CCUS as a key countermeasure and proposed development objectives for this technology. Thereafter, the CCUS roadmap started to be drafted, followed by other two national policies being promulgated. By the end of the 11th FYP, the Ministry of Land and Resources[1] (MOLR) incorporated carbon geological sequestration into the geological protection plan to regulate CO_2 storage procedures [54].

Nevertheless, no regional rules were released over this period, which indicated that CCUS was in the early stage.

2.2.2 Stage 2 (during 12th FYP from 2011 to 2015)

Policies during this period were guided by the 12th FYP, which expressed the urgency to confront global climate change. Compared with Stage 1, at the national level, sub-FYPs started to emphasize CCUS in terms of scientific research and standardisation, not only for its contributions to GHG emissions control but also for its positive effects on the progress of coal industry technologies, the development of energy systems as well as the practice of low-carbon strategy (see Figure 4 for more details). In addition, the significance of CCUS was highlighted by two sub-FYPs, which identified CCUS as one of the three critical tasks for clean coal development and one of the ten technologies for climate change mitigation.

Besides, China decided to raise funds to support CCUS development through green finance. The *Notice on Submitting Green Credit Statistical Forms* released in July 2013 by China Banking Regulatory Commission (CBRC) recognized clean coal technologies including CCUS as one of the twelve broad categories of green finance areas and required to collect their credit and loan status. In December 2015, the NDRC and the People's Bank of China issued the *Green Bond Issuance Guideline* and the *List of Projects Supported by Green Bonds (2015)*, respectively, representing that green bond became a legally financial instrument for CCUS investment.

The other improvement during this period was that local authorities started to include CCUS in their work agendas, although their coverage was limited to emissions reduction only. In many provinces, for example, Jilin Province, several emission-intensive industries, including the thermal power, coal, chemical, cement, petroleum and steel sectors, were considered essentially to be equipped with CCUS technology going forward.

Within the period of the 12th FYP, both national and provincial policies involved CCUS technology. In spite of the different angles they considered, their primary goals were similar—commencing capture tests and deploying demonstration projects. Moreover, requirements were no longer confined to technical aspects; other areas like standard establishment and intellectual property protection were taken into account as well. Also, green finance has become a choice and a driver at the national level to raise money for CCUS.

[1] China's State Council Institutional Reform was conducted in 2018. Several new ministries were created and several were scrapped. The reform of ministries can be found at https://npcobserver.com/2018/03/14/a-guide-to-2018-state-council-institutional-reforms/

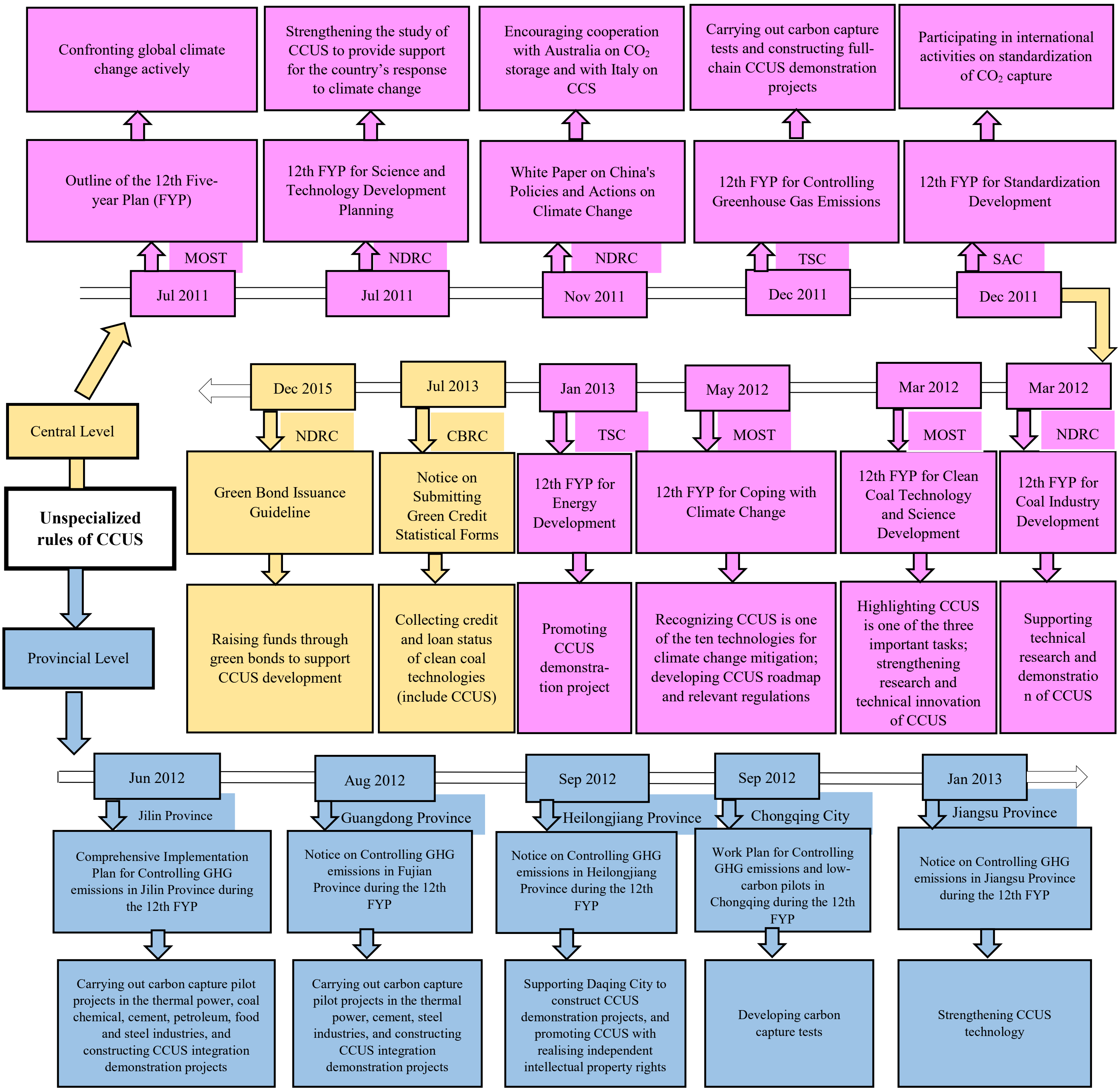

Figure 4 Unspecialized policies containing CCUS during 12th FYP (from 2011 to 2015) (PURPLE represents national FYPs or sub-FYPs, YELLOW represents other national polices, and BLUE represents provincial regulations)

2.2.3 Stage 3 (during 13th FYP from 2016 to present)

Compared with Stage 1 and Stage 2, more sub-FYPs indicated CCUS, which received much more attention from multiple industries (Figure 5). For instance, nationally, in the electricity sector, CCUS was evaluated as a reliable and green generation technology; it was one of nine critical projects listed in the *Technological Innovation 2030*; and its large-scale deployment was one of the five key tasks for climate change mitigation. Furthermore, as one of the *Catalogues of National Key Energy-saving and Low-carbon Technologies*, CCUS was required to expand its scale from 1% to 10% of "the rate of adoption" with a total investment of 37.5 billion CNY during the following five years to realize an emission reduction of 390 million tonnes. It was also expected that CCUS could be linked to renewable energy as well as to realize long-distance transportation. Currently, China uses tanks to transport carbon dioxide rather than pipelines in most projects. In so doing, it lags behind the U.S. where the pipeline network has been more than 1,000 km. Therefore, long-distance pipeline construction and transportation is part of China's future plan for CCUS promotion. From the finance perspective, seven ministries or departments formulated the *Guidelines on Establishing a Green Financial System*, aiming to employ the Public-Private Partnership model to encourage cooperative provisions of green technology infrastructure between public and private sectors.

In relation to regional regulations, climate change was still the reason for promoting CCUS. However, clear objectives were put forward by many provinces quantifying the project scale, investment value and emission-reduction capacity. For example, Hubei Province decided to construct a 35 MW Oxy-combustion demonstration project and Inner Mongolia planned to run China's first 100,000 tonnes of the full-chain CCUS demonstration project.

During the 13th FYP, CCUS was more prominent than at previous stages. All regulations within this stage shared the same objective: that of realizing low-cost and large-scale deployment. National sub-FYPs awarded CCUS unprecedented importance in future development strategies, and an increasing number of provinces planned to deploy CCUS with definite targets.

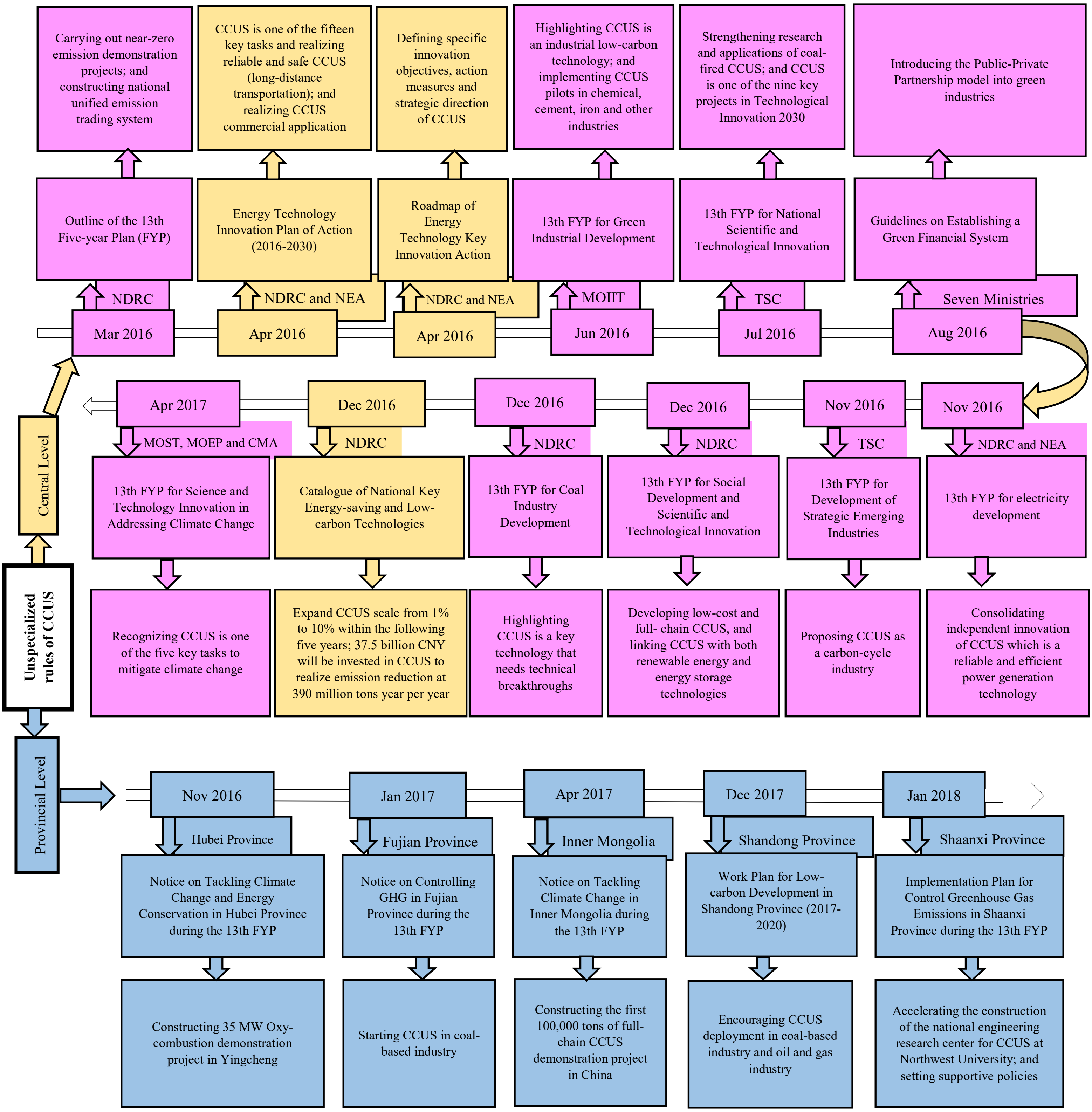

Figure 5 Unspecialized policies containing CCUS during 13th FYP (from 2016 to present) (PURPLE represents national FYPs or sub-FYPs, YELLOW represents other national polices, and BLUE represents provincial regulations)

In summary, it can be seen that China's CCUS policy system has made significant progress over the past decade. Although China has not promulgated laws to regulate CCUS, a relatively complete policy system has been formed for this technology, which is mainly based around national sub-FYPs in terms of climate change mitigation, energy-related development and technical innovation. Furthermore, regional jurisdictions gradually increased interventions in CCUS for the purpose of GHG emission reductions only. However, they may be the most direct and flexible means to promote CCUS because sometimes they deliver faster and more convenient effects than national policies.

3 Implementation of China's CCUS policies

It can be concluded from Section 2 that the policies intended to accelerate China's CCUS development derive from four perspectives: advances in research and development, project implementation and trials, enhancement of international cooperation, and short- and medium-term objectives for ongoing project implementation. To fulfill these targets, increased investment was dedicated over time. According to incomplete statistics, during the 11th FYP, CCUS attracted an investment of 200 million CNY from the government budget and an additional one billion CNY from the corporate and other private sectors, which increased to 400 million CNY and 2.3 billion CNY respectively during the 12th FYP [55]. The total funding provided for CCUS during the 13th FYP is not available at present, as its period has not ended.

3.1 Research and development

Academic publications tend to record and reflect the research and development (R&D) of a field. To track how China's CCUS technology progresses, CCUS-related journal papers from 2002 to present were collected from the Web of Science using bibliometric methodologies from Qiu and Liu's research [28].

Figure 6 shows the number of articles published by Chinese institutions. It demonstrates that the 11th FYP is a turning period, where the number increased from 0 at its beginning to 45 at its end and the global rank climbed dramatically from 11th to 4th. Since the 12th FYP, the quantity of research outputs rose dramatically, along with the rank increasing to 2nd in 2014. This is followed by a larger growth in the 13th FYP where more than 200 papers were produced each year and when China became the largest contributor in the research domain of CCUS globally.

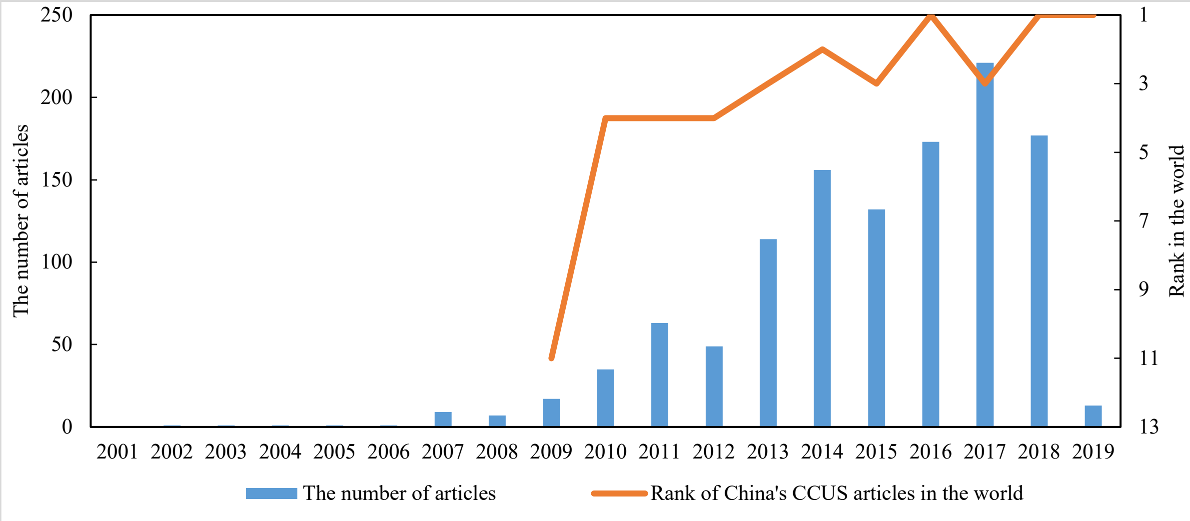

Figure 6 The number of articles published by Chinese institutes

In order to investigate the most favoured research topics in China's CCUS technology and compare them with other countries', high-frequency keywords are collected and listed in Table 1. As seen in the table, at the global level, the majority of the top 10 keywords relate to CO_2 capture, which includes constituent elements of the capture unit such as adsorption, separation and flue gas. However, examining China's results alone shows a difference. "Storage" is the most used term, followed by "sequestration" and "CCS". "Injection" issues as well as formation "permeability" are also widely used. This comparison concludes that within the CCUS system, storage is much more of a focus than capture in China.

Table 1 Comparisons of research keywords between China and other countries

Ranking	China	Global [28]	Ranking	China	Global [28]
1	Storage	Carbon dioxide	6	Capture	Performance
2	Sequestration	CO_2 capture	7	Carbon capture	Flue gas
3	CCS	Adsorption	8	Injection	Metal-organic framework
4	CO_2	Separation	9	Simulation	Capture
5	China	Carbon dioxide capture	10	Permeability	Absorbent

3.2 Project implementation and trials

To date, a number of R&D projects including tests, pilots and demonstrations have been planned, operated and completed, some of which are funded supported by the Chinese government (see Appendix 1). As a major energy consumer, CO_2 capture from electricity or coal-chemical industries and EOR in operational reservoirs were the main areas of CCUS deployment in China. However, the full-chain demonstration practice was not realized until April 2015 when *Shenhua Group Ordos CCS Demonstration Project* launched, where CO_2 was captured from tail gas of a coal-to-liquids process and then transported 11 km by tankers to be injected into deep saline aquifers [35]. Eventually, 0.32 million tonnes of CO_2 was stored successfully without leakage [32, 36]. Experience over the past 10 years has strengthened China's confidence in enhancing the CCUS scale, and all planned projects in the next decade are fully concentrated on the full value chain large-scale deployment.

3.3 Enhancement of international cooperation

As CCUS is an "imported" technology, China's movements lag behind developed countries such as the United States (U.S.), United Kingdom (U.K.) and Australia. Therefore, since the beginning of the 12th FYP, the majority of CCUS regulations described in Section 2 encouraged intensifying international cooperation to facilitate domestic CCUS development. Activities including project collaborations, workshops, memorandums and other knowledge sharing events (Table 2) have been organised among government agencies, energy-related companies, research institutes, non-governmental organisations and other communities. For instance, China has signed a number of memorandums with Europe, the U.K., Australia, the U.S. and Canada to exchange experience in project deployment, standard design for environmental protection, establishment of policy frameworks and financing schemes. Global efforts and investment contribute to the successful implementation of 14 CCUS projects across China's mainland (see Appendix 2).

Table 2 Other types of cooperation

Cooperative Partner	Approach	Example	Time
GCCSI	Workshop	Annually	Since 2009
Clean Energy Ministerial	Conference	Annually	Since 2010
U.S.	Research	China–U.S. Clean Energy Research Center	Since 2010
Netherlands	Research	Center for China-Netherlands CO_2-ECBM and CO_2 Saline Aquifer Storage Exchange	Since 2011
IEA	Workshop	MOST–IEA Cooperation on CCUS	Since 2012
CSLF	Project funding	CSLF Capacity Building Projects (US$743,500)	Since 2012
U.K.	Knowledge-sharing	U.K.–China (Guangdong) CCUS Center	Since 2013
Asian Development Bank	Research	Roadmap for CCS Demonstration and Deployment in China	Since 2015

3.4 Short- and medium-term objectives for project implementation

At the initial stage of CCUS technology in China, the MOST and the Administrative Center for China's Agenda 21 (ACCA21) released *China's CCUS Technology Roadmap* in 2011 [56]. It proposed CCUS as a technically feasible and economically affordable option to address climate change and promote sustainable economic and social development. The Roadmap also set milestones of the deployment scale, the increase in energy consumption (IEC) and the cost for each element of CCUS by 2015, 2020 and 2030 respectively (see Table 3 for more details).

Among all categories, the cost and the IEC are difficult to evaluate. The primary reason is that the Roadmap did not classify technical routes to quantify the two issues. For instance, pre-combustion, post-combustion and oxy-combustion capture are three popular capture technologies, each of which requires different pressure and temperature conditions to implement, resulting in different performances. It is, therefore, difficult to match the performances of various processes with general targets. Therefore, this research compares the rest periodical indicators.

As of 2015, public data suggest only two indicators (transportation scale and storage rate) have met the scheduled objectives. The failure of the capture unit was probably due to the high capital cost, which led to the cancellation and postponement of many new planned and retrofitted power generation stations [57]. The poor performance of CO_2 utilisation component might be caused by a lack of CO_2 supply that could improve oil and gas production [27, 58].

Performance towards the 2020 milestone was better. As of December 2018, four indicators have almost reached or even surpassed targets. They were system scale, pipeline transportation distance and deliverability, as well as storage rate. The capture performance, similar to that of 2015, is predicted to be barely accomplished by 2020, as the highest capture scale to date is 0.6 Mt/a (see Appendix 1).

Table 3 Visions of CCUS development in China [27, 56, 59, 60]

Year		2015			2020			2030
Scale expectation		Pilot test and demonstration			Full-chain demonstration at one-million scale			Industrializati-on capacity
Comparison		Target	Actual	Performance	Target	Actual (as of December 2018)	Performance	Target
System	Scale (Mt/a)	>0.3	0.28	Almost	1.0	1.0	Done	>1.0
	IEC	<25%	-	-	<20	-	-	<17 %
	Cost (CNY/t)	350	-	-	300	-	-	240
Capture	Scale (Mt/a)	0.3–1.0	0.1	Unfinished	1.0	0.6	Unfinished	>1.0
	IEC	<20%	-	-	<15%	-	-	<12
	Cost (CNY/t)	210	-	-	180	-	-	140
Transport	Pipeline distance (km)	>80	50	Unfinished	200	200–250	Done	>1000
	Cost (CNY/t/km)	90	-	-	80	-	-	70
	Deliverability (Mt/a)	0.3	0.5	Done	>1.0	1.0	Almost Done	-
Utilization	Scale (Mt/a)	1	0.47	Unfinished	>2.0	-	-	>2.0
	Oil/Gas production (Mt/a)	0.3	0.12	Unfinished	0.6	-	-	1
	Storage rate	40%–50%	>86%	Done	50%–60%	96%	Done	60%
Storage	Storage capacity (Mt/a)	0.3	0.1	Unfinished	1.0	0.6	Unfinished	>1.0
	Cost (CNY/t)	50	-	-	40	-	-	30

4 Defects of China's CCUS policy framework

This section first reviews the CCS/CCUS laws and policies in America, Australia, Norway and Japan. All these countries are staunch proponents of CCUS and have amended old laws and policies or enacted and introduced new ones to champion the technology's development and deployment. Then the current CCUS policy framework in China is compared to identify its defects.

4.1 CCS/CCUS laws and policies in other countries

4.1.1 America

Like China, America uses the term "CCUS" to extend its exploitation of fossil fuels. Its policy framework, nonetheless, is more mature than China's.

Since GHGs were included as pollutants by the U.S. Supreme Courts in 2007, CCUS has been positioned as an essential technology between fossil-fueled electricity generation and GHG emissions reduction [61]. Following this, new emission limits for power plants [16] and comprehensive regulations in relation to the disposal of hazardous materials within separation processes [62] came into force through a series of new Acts at the federal level, for example, *American Power Act (2010)*. These political actions, however, did not convince regional governments to support capture technology. Many state jurisdictions rejected constructing new capture-based coal-fired power plants since citizens refused to pay for the construction cost of the added capture units [61].

By comparison, both the transportation and storage components receive legal support at the federal and state level. The governance of pipelines is relatively mature in America [17], as a number of federal departments and state authorities have already enacted laws and rules to regulate, monitor and enforce the safety of pipeline transportation over the past two decades [63-65]. In terms of geological sequestration, many Acts and standards, for example, *Federal Requirements Under the Underground Injection Control (UIC) Program for Carbon Dioxide Geologic Sequestration Wells Final Rule* and *Clean Coal FutureGen For Illinois Act of 2011*, were developed to regulate operational norms, classify liability holders and provide subsidies. It is suggested that what America needs to do in the future from the political viewpoint is to extend legal coverage to the "post-EOR injection" and "post-closure storage" phase [66] and to consider including storage in aquifers rather than only EOR and ECBM in the CCUS legal framework .

4.1.2 Australia

Australia's policy framework towards CCUS ranks first in the Global CCS Institute (GCCSI) evaluations [67, 68]. The basis of Australia's CCS regulatory frameworks is the *Regulatory Guiding Principles for Carbon Dioxide Capture and Geological Storage* endorsed in 2005 by all Australian jurisdictions [69]. Its approach to regulations is varied and comprehensive at the federal and state level. At the federal level, the government amended petroleum rules, for instance, *Offshore Petroleum and Greenhouse Gas Storage Act 2006*, to enable CCS activities in offshore waters. At the state level, stand-alone legislations have already been enacted, such as the *Greenhouse Gas Geological Storage Act 2008* in Victoria and the *Greenhouse Gas Storage Act 2009* in Queensland [70-73]. In addition, Western Australia legislated the *Barrow Island Act 2003* specifically for a storage project in the Gorgon area [73].

Importantly, each Australian CCUS-related Act puts the operation permit at the top. Without permits, it is illegal to take action during any stages of the CCS project lifecycle, such as project planning, site screening, injection testing, storage and monitoring after project closure [71]. Permit holders must meet additional conditions in case the operation is not undertaken as planned; otherwise, the permission would be suspended or cancelled. A "serious situation", although defined differently in different states, includes the leakage or possible leakage of a substance, a substance injected into a formation has behaved or will behave otherwise than as predicated, the impacts on the geotechnical integrity and the unsuitable of a formation for permanent storage [70]. If any "serious situation" should occur, the permission will be canceled immediately by the responsible Minister. Consequently, to avoid potential cessation of CCS projects, permit applicants need to present high-standard preventative risk management schemes to ensure all dangers, particularly threats to the environment and public health, can be eliminated and appropriately controlled across the permit area.

4.1.3 Norway

Norway is the first country in the world to set targets for CO_2 reduction [74] and is also the pioneer in both CCS deployment and CCS policy-making. This is mainly attributed to its "domestic conflict" where economic growth needs the support of producing and exporting oil and gas with increasing CO_2 emissions while the country and its citizens hold high ambitions for emission reductions targets [18].

Political debates around CCS in Norway can be traced to the 1990s. In 1994, two planned gas-fired power plants caused huge concerns because they were considered to increase domestic emissions by 6% [18]. This helped CCS build a role as a "technologic glue" in the battle between energy and climate change [21], leading to the Sleipner project and Snøhvit project storing CO_2 in offshore depleted oil and gas fields. After that, support voices around CCS technology did not appear until the mid-2000s when the new government's commitments state "CCS-based" was the only approved type of gas power plants to accomplish the hope of "CO_2 free" [75]. Thereafter, Norway began to promote CCS at the international level. The *International CCS Action Plan* was drafted as a part of the *Climate Settlement 2007* for the purpose of making Norway a net carbon neutral country and stimulating other countries to set goals for climate change mitigation [21]. Through international cooperation and independent efforts, Norway has completed several feasibility-research and deployed some large-scale CCS projects.

4.1.4 Japan

Japan is another of the early countries to highlight CCS as an instrument to reconcile economic growth with climate change mitigation. Despite having only five CCS projects are in operation or completed [59], Japan demonstrates strong policy governance over CCS activities. For example, the *Law Relating to Prevention of Marine Pollution and Maritime Disaster* in 2007 legalized CO_2 injection into underground saline aquifers and set exceptionally high standards for CCS activities, mainly mainfesting in four aspects: CO_2 capture process (amine-based chemical absorption) and CO_2 concentration (>99%); environmental impact assessment; deployment permission license; and responsibility for long-term monitoring [18]. These requirements are then reinforced by the *Safety and Environmental Guideline for CCS Demonstration Projects* released in 2009 [76].

In April 2014, considering the dramatic changes in energy environments inside and outside Japan, the Cabinet of Japanese Government issued the *Strategic Energy Plan* under the *Basic Act on Energy Policy*. The plan requires for its fulfilment a practical use of CCS technology around 2020 and the construction of CCS-ready facilities as early as possible to support the commercialization of CCS.

4.2 Comparisons with China's CCUS policy

Appropriate laws and policies may aid the advancement of new technology. China's CCUS regulations do provide driving forces for its development. However, the successful practices of the U.S., Australia, Norway and Japan clearly point to the shortcomings of China's CCUS policy system (Table 4). These include the lack of an enforceable legal framework, a lack of detailed information for the operationalization of projects, weak market stimulus and a lack of financial subsidies.

Table 4 Shortcomings of China's CCUS policy framework

Measures	U.S.	Australia	Norway	Japan
Enforceable legal framework (legislate CCUS, high-operational rules and simple approval process)	√	√	√	√
Complete law/policy provisions	√	√	√	√
Market stimulus	√	√	√	

Financial subsidies	√	√

4.2.1 A lack of an enforceable legal framework

The insufficiency of China's CCUS policy regime is reflected in three aspects: no legislation of CCUS, limited coverage and complicated approval process.

First, unlike the chosen comparison countries, China has not enacted or amended laws for CCUS. What constitutes the policy framework is general guidelines, rules and outlines, all of which have a relatively low legal effect compared with laws [26]. Compared with renewable energy which is regulated by the *Law of Renewable Energy*, CCUS receives lower policy guarantees and no legal responsibility is allocated to technical guidelines, construction plans, environmental protection, financing scheme and punishment standards for illegal behaviours. In the short term, the legislation of specific laws or modifications of existing policies may not touch on the rights and obligations of CCUS participants, which in turn probably even weakens the authority of the policy framework.

Second, the coverage of CCUS policies is limited although the number of them has increased. Most of them concentrate on the storage process but neglect the capture and the transportation units. These policy provisions are inadequate even for those storage rules. In addition, requirements of technical maturity and environmental protection are formulated; nevertheless, other significant aspects for the promotion of any new technology, like social engagement, finance options, and legal liability, have not been deeply considered yet.

Third, the approval process of CCUS projects is complex in China[2]. CCUS is an integrated technology and it is not under the uniform management of one department. Whereas, in China's energy policy system, projects with respect to electricity, transportation, oil and gas, water and soil are under the charge of the National Development and Reform Commission, the National Energy Administration, the Ministry of Ecology and Environment, the Ministry of Natural Resources, the Ministry of Transport, and the Ministry of Finance. This kind of institutional separation, therefore, imposes on any CCUS projects a heavy burden where they have to pass multiple examinations and gain approvals by different authorities.

4.2.2 Insufficient information for the operationalization of projects

In addition to the deficiency of the policy system, the provisions of existing policies have low operability. Overall, the provisions related to CCUS are too principled and generalized. Most of the stipulations refer to the current status, priority development directions, critical tasks and prospects. However, specific measures that are necessary to implement this provision are not provided. For example, who should evaluate whether a target is achieved or not and what the gaps are at present, and what kind of responsibilities the government, the companies and the persons in charge should take during the period of CCUS deployment.

By comparison, the key to the successful development of CCS/CCUS in America, Australia, Norway, Japan is the high-operationalization of their legislation. Taking the *Greenhouse Gas Storage Act 2009* (Queensland) as an example [77], after a preliminary introduction of the provisions, it explains the ways for involved enterprises to apply for continuous permits under unusual circumstances, like a delay of the original construction plan. All relevant applications

[2] The approval guideline of CCUS projects in China is unavailable at present. Therefore, to understand the complexity, please refer to the comparison of the brief approval procedure of wind power projects between China and New South Wales (Australia) in the Complementary Materials, which clearly demonstrates that China's approval formalities over energy projects are more complicated.

should be submitted more than 20 business days before the end of the initial working period, and no movements are allowed to be undertaken until the amended proposal is approved. It also thoroughly clarifies the issues regarding GHG exploration permissions, such as what procedures should be taken by applicants, what the work plan should include, which period the project is allowed to request, how the criteria are different when approving licenses at the initial and post-injection stages, and what kind of responsibility the permit holders should bear if they fail to meet obligations.

4.2.3 Weak market stimulus

In China, CCUS projects are mainly located in either economically developed provinces or fossil-fuel resource-rich regions. This might because many emission-intensive provinces that also have a large population express little interest in CCUS due to the lack of feasible underground formations to store CO_2 within their administrative areas, and thus risks might be triggered in event that high-concentrated captured CO_2 cannot be treated. Moreover, companies that are not state-owned are commonly unwilling to participate in CCUS activities without a highly welcoming market [78]. On the other hand, even if they express interest, it is not easy to acquire implementation licenses from the government. Moreover, concerns over the ecosystems, human health, investment environment as well as catastrophic scenarios are common around storage areas [79]. Because of the weak market participation, caused by such situations, CCUS has difficulties becoming widespread.

4.2.4 A lack of financial subsidies

The development of China's CCUS has also been impeded by the limited subsidies for new projects. In 2019, the central government plans to assign subsidies at around 86.6 billion CNY to renewable energy sources; however, both the whole value chain of CCUS and its components are not taken into account [80]. Furthermore, unlike the U.S. where the 45Q tax credit is introduced to provide a credit of up to US$50 per tonne for CO_2 that is geologically buried and up to US$35 a tonne for EOR or other CO_2 utilization processes [81], China to date does not have a direct tax stimulus policy for CCUS. Therefore, the high capital cost which is the most substantial barrier for CCUS [82] remains unsolved. To be economically feasible, some companies intend to increase electricity price, passing the costs on to customers. However, this is not accepted by the general public and in turn, decreases their support for CCUS technology [83].

5 Recommendations for improvements

To ensure the rapid development and successful deployment of CCUS technology in China, more systematic and efficient laws as well as policies are necessary. The practical measures, which China can use for reference, can be summarised as legalising CCUS technology, extending the coverage of regulations, adjusting policies in a timely manner, increasing and attracting interests from potential participants, and providing strong financial support.

5.1 Improve the force of CCUS legal framework

China needs to prioritise the legislation of CCUS laws. First of all, in the short-term, the continuity and consistency of existing regimes should be ensured. Policies that have demonstrated maturity and practicability can be gradually raised to the level of laws to enhance their authority and binding force. As CCUS is mostly described in climate policies, the *Law of*

Climate Change Mitigation is the most promising way. Given that CCUS may refer to several energies, such as electricity, oil, gas and even renewables, a fundamental law in the energy sector, the *Law of Energy* is highly recommended to be considered. Moreover, a specific bill, the *Law of CCUS*, is expected to integrate provisions introduced by centralised FYPs and sub-FYPs as well as other national administrative rules. In these laws, industry guidance, technical support, price control, cost allocation, financing schemes, supervision measures and legal liability should be clarified in detail with high operation ability for all participants including emission-sources plants, fossil-fuel enterprises, transportation sectors, government agencies, third parties and individuals.

Apart from the above elements, CCUS public participation should be strengthened by the legal framework as well. It is suggested that limited public engagement among local communities and beneficiaries may lead to postponement or cancellation of large energy projects that have already been fast-tracked through the decision-making process [84], which is particularly evident for climate change mitigation infrastructure, such as windfarms and CCS [85]. By legalizing an open channel to have lay people, industry and environmental interest groups express their standpoints, either positive or negative, public participation policy (PPP) would enhance environmental awareness [86], achieve greater acceptance and create behavioural change [85]. China has formally implemented the *Measures of Public Participation in Environmental Impact Assessment* on 1 January 2019 [87]. It involves a series of legally required procedures during the lifecycle of construction projects, including but not limited to holding feasibility study meetings within the influenced community before submitting project proposals; providing the link and channel of the Public Comment Form (PCF) which is formulated uniformly by the Ministry of Ecology and Environment; stipulating the minimum days for information disclosure (at least 10 days through the internet platform, newspapers and bulletins where the local community is familiar with); organizing rounds of public hearings and expert reasoning meetings for the projects that are largely concerned by the citizens; and reporting the complete public participation process and results in the Environmental Impact Statement. This has a body of overlaps with the UK's PPP which is well praised globally [84]. As a young legal requirement, however, its implementation status should be closely monitored. Besides, it would be more practical if a specialized CCUS PPP is designed, as the full-chain CCUS deployment covers several industries and influence more communities than traditional energy projects.

Besides, these provisions should also be continually tracked and re-assessed. In fact, China's CCUS industry is experiencing rapid development and is facing various challenging problems for large-scale deployment. Therefore, it is necessary to record and analyze the implementing conditions of CCUS laws in a timely manner, and then make requisite revisions accordingly. Regular re-evaluations will enable the government, policymakers and the public to monitor the effects and defects of the CCUS legal framework and then optimize it.

5.2 Enhance the practicability of CCUS regulations

Detailed and enforced versions of regulations are needed. Improving the preciseness of any policy will increase the workload of legislators but can reduce the deviation and loopholes that may emerge when implementing policies. Interested parties would be more willing to fulfil their obligations if the policies have high standards of practicability. Clear requirements can help potential operators prepare their applications while make strict assessment procedures for authorities in deciding whether a license can be approved and in evaluating whether the mandatory objectives are completed. Also, the regulation should encourage third party access to CCUS infrastructure, and priority should be given to open technology or open access CCUS projects to maximise knowledge-sharing benefits.

Furthermore, to ensure CCUS policy framework can take effect in regional jurisdictions, provinces, municipalities, and autonomous regions should abide by national requirements to promulgate local regulations in light of their actual conditions, establish CCUS registration databases and improve local supervision and management systems. It is also critical to encourage setting up national and provincial CCUS related not-for-profit institutes or think tank to support policy, regulation and standard formulation in China.

5.3 Stimulate market vitality

An active energy market can attract more participants in China's CCUS industry. At the national scale, the reform of the energy market is recommended to relax control over market access, allowing diverse enterprises, for example, foreign enterprises and private companies, to engage in energy businesses. By doing so, the energy market would maintain high activeness and run under healthy competition, which potentially ensures licenses can be approved to the most qualified applicants.

Nonetheless, this change may not increase enthusiasm regionally particularly in the economically backward areas. To promote CCUS more broadly, establishing a cross-provincial cooperation mechanism among neighbouring provinces is desirable. For instance, Jiangxi Province and Hunan Province, both of which are highly emission-intensive but have limited storage options [38], could form a regional collaborative network with Guangdong Province where the enormous storage potential and many CCUS implementary plans have been confirmed [30, 88-90]. Under this circumstance, the problems over no treatment for captured CO_2 will not be concerned any more, and in turn, regional economic and social development can be stimulated through cooperation.

5.4 Provide sufficient financial support

The successful development of CCUS is inseparable from adequate funding, as is illustrated by the development and use of the technology in Japan [91] and America [92]. With the increase of deployment scale, CCUS chains need to meet high technical and operational standards, long life-cycles and high production intensity. This leads to an increase in the capital investment and thus makes CCUS projects less affordable as well as decreases stakeholders' willingness to continue their involvements.

Promoting large-scale CCUS deployment needs various financially supportive measures. Financial resources from public policies can reduce the uncertainty associated with new green technologies once the upfront costs have been paid [10]. Direct economic support, for example, specific CCUS funds at all levels of government, is the most effective driver for relevant research and deployment. More targeted subsidies on electricity produced by capture plants are needed to offset the high capture cost. Diverse green finance products, such as credits, bonds and funds are worth being promoted and extended to provide an adequate financial guarantee for the infrastructure construction. It is also encouraged to reduce or even exempt tax and set mandatory market quotas or guaranteed purchases of electricity, oil and gas produced from the CCUS chain. These measures would increase stakeholders' participation willingness and ensure their financial benefits. Indirect support for CCUS project, for example, allocating CCUS plants with higher electricity generation quota at benchmark tariff or allocating higher carbon allowance quota in the emission trading system should also be recommended to encourage early CCUS demonstration projects.

In the meantime, the provincial and municipal energy departments, in conjunction with other relevant institutions, shall monitor, regulate and disclose the use of subsidy funds, the prices of electricity, oil and gas, as well as the management situation of involved corporations. Then establishing a two-dimension supervisor system with the public to remind operators of business risks and obligations they should undertake.

It should be significantly noted that any kinds of financial supports must be decided considering national or regional actual conditions and the market environment. Unreasonable economic interventions always result in excessive market distortions. The ultimate goal of subsidies is to improve CCUS deployment and eventually rid it of subsidies, rather than just help it survive.

6 Conclusions

China is positioning itself as a global climate leader, and its actions have an enormous impact internationally. This is in contrast to its rising demand for fossil fuels that rose rapidly because of its rapid economic growth and social development. To take steps towards a more sustainable development path, China has worked to establish a policy framework to promote CCUS deployment.

This research follows the “policy cycle” to analyze China’s CCUS policies. Results suggest that without any law formulation, China’s FYPs are the primary drivers for CCUS advances. The formal inclusion of CCUS in policy commenced in the 12th FYP and was strengthened in the 13th FYP. There are only five specialised regulations at the national level. A series of unspecialised policies extend the functions of CCUS technology from only for GHG emission reductions to multiple objectives such as energy-saving, efficient power generation, the carbon-cycle and national strategy.

This framework through the FYPs has facilitated CCUS research and development, project implementation and global cooperation. However, China is still far from meeting periodical milestones set out in its CCUS roadmap. Compared with the policy systems of four nations that have pioneered CCS/CCUS, there are four apparent barriers in China’s CCUS regulatory framework: a lack of an enforceable legal framework; insufficient information for the operationalisation of projects; weak market stimulus; and inadequate financial subsidies.

Further development of CCUS in China calls for the government to improve the force of its CCUS legal system. To do this, it needs to legislate this technology, simplify the relevant policy regimes, improve the policy practicability, stimulate market vitality and provide sufficient financial support. We also recommend China to set up national and provincial level CCUS entites (such as CCUS Centre, CCUS committee) and encourage other ministries (for instance, NDRC, NEA) to enhance knowledge sharing for propagandising CCUS projects in the country.

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Appendix 1

Key CCUS projects in China funded by the government or domestic companies

Project	Year of Operation	Main area	Scale	Capture capacity (Mt/year)	Status	Industry
Sinopec Zhongyuan Carbon Capture Utilization and Storage Pilot Project	2006	Capture and CO_2-EOR	Pilot	0.12	Operational	Chemical Production
Sinopec Shengli Oilfield Carbon Capture Utilization and Storage Pilot Project	2008	Capture and CO_2-EOR	Pilot	0.04	Operational	Natural Gas Processing
Huaneng Gaobeidian Power Plant Carbon Capture Pilot Project	2008	Capture and utilisation (food)	Pilot	0.003	Completed	Power Generation
Jilin Oil Field EOR Demonstration Project	2008	CO_2-EOR	Demonstration	0.10-0.35	Operational	Natural Gas Processing
Shanghai Shidongkou 2nd Power Plant Carbon Capture Demonstration Project	2009	Capture	Demonstration	0.10 - 0.12	Operational	Power Generation
Chongqing Hechuan Shuanghuai Power Plant CO_2 Capture Industrial Demonstration Project	2010	Capture and utilisation (welding)	Demonstration	0.10	Operational	Power Generation
Sinopec Shengli Oilfield Carbon Capture Utilization and Storage Pilot Project	2010	Capture and CO_2-EOR	Pilot	0.03 - 0.04	Operational	Power Generation
Shenhua Group Ordos Carbon Capture and Storage (CCS) Demonstration Project	2011	Storage	Demonstration	0.1	Completed	Coal-to-liquids
ITRI Calcium Looping Pilot	2013	Capture (cement industry)	Pilot	1 tonne/hour	Operational	Cement Production
Daqing Oil Field EOR Demonstration Project	2014	CO_2-EOR	Demonstration	0.20	Operational	Chemical Production
Karamay Dunhua Oil Technology CCUS EOR Project	2015	CO_2-EOR	Demonstration	0.10	Operational	Chemical Production
PetroChina Changqing Oil Field EOR CCUS	2017	CO_2-EOR	Demonstration	0.05 - 0.10	Operational	Coal-to-liquids
CNPC Jilin Oil Field CO_2-EOR	2018	Full-chain	Large-scale	0.60	Operational	Natural Gas Processing
Haifeng Carbon Capture Test Platform	2018	Capture	Large-scale	0.03	Operational	-
Beijing Shuangang LanzaTech New Energy Technology	2018	Utilization	Large-scale	0.09	Operational	Iron and Steel Production
Sinopec Qilu Petrochemical CCS	2019	Full-chain	Large-scale	0.40	In construction	Chemical Production
Guohua Jinjie CCS Full Chain Demonstration	2019	Full-chain	Large-scale	0.15	Advanced Development	Power Generation
Yanchang Integrated CCUS Demonstration	2020-2021	Full-chain	Large-scale	0.41	In construction	Chemical Production
Sinopec Eastern China CCS	2020s	Full-chain	Large-scale	0.50	Early Development	Fertiliser Production
Sinopec Shengli Power Plant CCS	2020s	Full-chain	Large-scale	1.00	Advanced Development	Power Generation
Shenhua Ningxia Coal-to-liquids Project	2020s	Full-chain	Large-scale	2.00	Early Development	Coal-to-liquids
China Resources Power (Haifeng) Integrated CCS Demonstration	2020s	Full-chain	Large-scale	1.00	Early Development	Power Generation
Huaneng GreenGen IGCC Large-scale System (Phase 3)	2020s	Full-chain	Large-scale	2.00	Early Development	Power Generation

Appendix 2

CCUS cooperation between China and other nations [26, 29, 93-98]

Cooperative project	Areas	Funding sources	Main objectives
China–Canada Development of China's Coalbed Methane Technology/Carbon Dioxide Sequestration Project (2002–2006)	Storage and ECBM	Canadian Climate Change Development Fund (CDN $5million); China United Coalbed Methane Corporation Ltd (not exceed 250 million CNY)	Training and transferring to China the CO_2-ECBM/ CO_2 sequestration technology; storing CO_2 in unmineable deep coal beds in poorer western China
China–EU Near Zero Emissions Coal (NZEC) Cooperation (2006–2009)	Capture and storage	U.K.'s NZEC initiative (£3.5 million)	Including the COACH Project, aiming to capture CO_2 emissions from coal-fired plants and store them in exploited oil or gas fields or in sealed geological strata to demonstrate advanced near-zero coal technology
China-E.U. MOVECBM Project (2006–2008)	ECBM and storage	EU (€2,670,737 for five work packages in total)	Word Package 5 aims to help China to prepare a pilot ECBM site
China-U.K. Chinese Advanced Power Plant Carbon Capture Options (2007–2011)	Capture	U.K. Department of Energy & Climate Change (£85,383)	Developing and defining options for integrating carbon plants with Chinese coal power plants, and identifying onions of crucial stakeholders towards relevant technologies
Support of Regulatory Activities For Carbon Capture and Storage (STRACO$_2$) (2008–2009)	Regulatory framework	EU (€106,678); The Administrative Center for China's Agenda 21; Chinese Academy of Sciences	Supporting the development of a regulatory framework for CCS in the E.U., and learning the E.U.'s expertise to explore the structure of China's CCS regulations, mainly focusing on Safety and Liability; Site Qualification and Certification; Incentivization and Financing; Crosscutting Issues; and CCS Policies in China
China-Canada CO_2 Injection in Deep Coalbeds/Storage to Exploit Coal Seam Gas Project (2008-2010)	ECBM	Canadian Government; China United Coalbed Methane Corporation Ltd	Carrying out laboratory and field tests to explore a systematic technology of CO_2-ECBM in deep coal seams
China–U.S. Tianjin Dagang CCS Project (2008–unknown)	Full-chain	Eestech (an America company); Tianjin Dagang Huashi Power Generation, China	Helping Dagang to use two 330MW power units to demonstrate CCUS
Sino–Japan CCS Cooperation (2008–2011)	Capture and EOR	Japanese Government; Chinese NDRC; Chinese Oil companies	Developing a CCUS project in China to recover 3–4 million tonnes of CO_2 per year from two coal-fired power plants
China–Australia Geological Storage of CO_2 (CAGS), Phase 1 (2009–2012)	Storage	Australian Government Department of Resources, Energy and Tourism (AU$2.86 million)	Helping to accelerate the development and deployment of geological storage of CO_2 in both China and Australia
China-Australia Geological Storage of CO_2 (CAGS), Phase 2 (2012–2015)	EGR and storage	Australian Department of Industry and Science (AU$1.389 million);China Clean Development Mechanism Fund (AU$700,000)	Formulating site selection methodology and criteria; assessing the potential of CO_2 enhanced shale gas recovery in Ordos Basin through laboratory tests; identifying status and gaps for CO_2 saline aquifer storage projects; examining environmental impacts and risks; designing a roadmap for Xinjiang Province
Sino–Italy Cooperation on Application of CCS to Coal-Fired Power Plants (2010–2012)	Full-chain	China's Ministry of Science and Technology; Italian Ministry of Environment, Land and Sea;	Conducting a pre-feasibility study on CCUS application in China from perspectives of site selection, technological choices, capture system, transport methods, scale design, and economic assessment
Australia–China Post Combustion Capture (PCC) Feasibility Study Project (2010–now)	Capture	Australian Government Department of Resources, Energy and Tourism (AU$12 million)	Phase 1 has completed, with a focus on undertaking a feasibility study of an industrial-scale PCC project with CCS in China; Phase is underway to construct and operate pilot and demonstration facilities
China-Australia Geological Storage of CO_2 (CAGS), Phase 3 (2016–2018)	Environment monitor, capture, EOR and storage	Co-funded by Australian and Chinese government	Monitoring CO_2-EOR at Yanchang Oilfield and focusing on Xinjiang Province from three areas: evaluation CCUS potential in Junggar Basin and carrying out pre-feasibility research for Xinjiang Guanghui Fuyun coal-to-gas CCUS pilot project (1 million tonnes/year)
Horizon 2020: Low Carbon Industrial Production Using CCUS (2016–now)	Full-chain	E.U.–China Co-Funding Mechanism (CFM) (200 million CNY for 2016)	Investigating how captured CO_2 can be utilised and stored, either in the project or planned as a future phase

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