Research on CCUS technology development trend in China based on bibliometrics and patent analysis

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Abstract. Carbon dioxide capture, utilization and storage (CCUS) has great emission reduction potential and is one of the important means to achieve carbon neutrality. Focusing on the development trend of CCUS technology, this paper searches the related research and patents of CCUS technology in CNKI database and incopat patent database, adopts the methods of bibliometric analysis, co-word network analysis, visual analysis and content analysis, using network analysis integration software and visual analysis system, the research situation in this field is deeply explored and visualized from the aspects of the amount of articles published, high-frequency authors, research hot-spots, core journals, patent layout, etc., and the future research is prospected. Results show that since 2006 CCUS technology research focus continued ascension, core authors has not yet formed, thesis research is given priority to with scientific research institutes, patent application is given priority to with enterprise, carbon capture technology is mature, oil displacement is one of the most effective way to carbon utilization in China .The future technology trend is to integrate CCUS with the scenario of carbon-neutral, improve top-level design, business model and incentive policies of CCUS, strengthen the promotion of CCUS technology research and demonstration project promotion.

Keywords: CCUS; CCS; Using carbon; Hot spots and trends; Knowledge map

1 Introduction

In 2020, China officially set the goal of achieving carbon peak by 2030 and carbon neutral by 2060.Clean energy, energy efficiency, and carbon capture and storage (CCS) are the most effective means to achieve "carbon peak and carbon neutral" goals[1-2]. As an important emission reduction technology, CCS is an important technology choice for China to implement low-carbon development strategy. Research shows that if CCS technology is not adopted, the cost of realizing 0.45‰ carbon dioxide equivalent by 2050 will increase by 138%.Due to the high investment and operation cost of CCS technology, additional energy consumption, safety and system inte-

V. Escudero et al. (Eds.): BADS 2022, AHCS 11, pp. 425–432, 2023.
https://doi.org/10.2991/978-94-6463-102-9_46

gration problems of large-scale demonstration projects, technical support is considered in advance for the peak-removal problem after emissions peak in 2030, and CO_2 utilization is added on the basis of CCS, namely carbon capture, utilization and storage (CCUS). Foreign researchers have carried out a lot of research on carbon capture. Lee and others capture CO_2 by solid absorbent to reduce CO_2 emissions from different combustion process sources, the adsorbent used is recycled by heating or decompression. As a mature technology for capturing CO_2, the separation efficiency can reach 90%. Dutcher and others captured CO_2 by amine group technology, due to the high reversibility of the reaction, it can be effectively applied to engineering projects. While our progress in energy efficiency and clean energy has led the world, but CCUS technology research started late. Since 2006, policies on CCUS technology have been issued one after another, with an average of 3-4 policies issued every year, CCUS technology is regarded as one of the key technologies [3]. In view of CO_2 emission problems in cement, steel, power, transportation, construction, coal chemical and refining plants and other key industries, each industry has formed a variety of CO_2 capture, utilization and storage technologies according to its own industry characteristics. Studies related to the optimization of capture technology, project environmental monitoring and risk assessment are also carried out [4-5]. Therefore, from the perspective of bibliometrics and patent analysis, this study comprehensively applies a variety of measurement methods, in order to provide reference for the research and practice of CCUS technology, the trend of CCUS technology in China is predicted and some suggestions are put forward.

2 Research methods and sample selection

The existing literature information analysis mainly includes statistical analysis, bibliometric analysis, social network analysis, Pub Med analysis and other techniques and methods. Quickly capture high-value information and track disciplinary frontiers. Word frequency analysis generally involves data retrieval, cleaning and processing, vocabulary extraction, statistical analysis and other stages [6]. Therefore, this study takes CNKI database as the retrieval tool, and the retrieval condition is "TI = carbon dioxide capture, utilization and storage + CCUS + CO_2 capture, utilization and storage", the search keyword is "fuzzy", the time span was from 2000 to 2021, and 182 Chinese literatures were retrieved. In order to ensure the objectivity, scientificity and feasibility of the research, a variety of data cleaning methods of data filtering method, data splitting method and data dimensionality reduction method are comprehensively used, after excluding 17 non-research documents about meeting minutes, meeting notices, news comments, technical introduction and online reports that are inconsistent with the theme. Finally, 165 records were obtained. Using Excel as a statistical tool, literature metrology analysis method, visual analysis method and content analysis method are used to mine and analyze the research situation in this field from the aspects of the number of articles published, high-frequency authors, research hot spots, core journals, patent layout and so on. Track the research hot-spots, predict the development trend, and draw relevant conclusions.

3 CCUS technology research situation in China

3.1 Statistical analysis of annual papers

Research shows that the CCUS technology research of Chinese scholars was first included in CNKI in 2009, Xi 'an Thermal Research Institute Co., Ltd. took the lead in carbon dioxide capture, utilization and storage technology research of coal-fired power plants. It can be divided into three stages as a whole: during 2009-2012,which is still in the exploratory stage; during 2013-2019, it basically showed a gradual upward trend; during 2009-2012,It shows a rapid. It can be seen that with the proposal of the strategic goal of carbon neutrality at peak carbon in China, the research on CCUS technology in the academic field has gradually become white-hot. There is a turning peak in the number of papers, which indicates that after China realizes rapid emission reduction, in the stage of deep decarbonization, CCUS and other cutting-edge technologies will usher in commercial promotion. It can be foreseen that in the context of industrial transformation and upgrading, low cost, low energy consumption, safe and reliable CCUS technology system and industrial cluster provide technology choice for low-carbon utilization of fossil energy. This will also provide an effective technological guarantee for tackling climate change and provide technological support for sustainable economic development. A subsubsection. The paragraph text follows on from the subsubsection heading but should not be in italic.

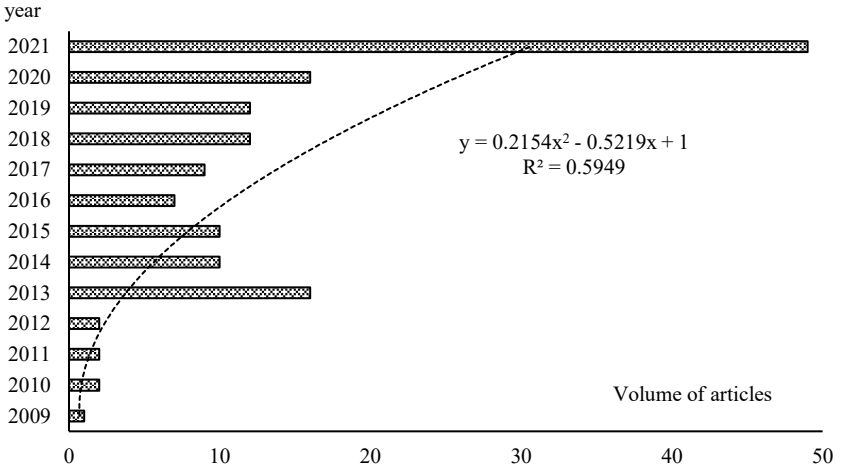

Fig. 1. Chronological distribution of CCUS technical papers in China

3.2 Statistical analysis of high-yield authors

The study shows that li Qi, Li Xiaochun and Li Yueqing, the authors who published the most in this research field, each published 7 articles. 86.34% of the authors only wrote one paper, which indicates that the authors are scattered.

According to statistics, li Qi, Xiaochun Li, Yueqing Li, Zhang Xian, Wei Ning, Bofeng Cai and Libin Cao are the most prolific authors with more than 5 articles in this field. In order to display the high-frequency authors in the field of CCUS technology more directly, weighted statistical method is used to quantify the weight of authors in this field. Yueqing Li (7.00%), Xuemei Lu (2.00%), Zewei Yu (2.00%), Xian Zhang (1.88%), Ligong Nie (1.73%), Du Xue (1.67%), Li Qi (1.66%) can be regarded as the key authors in the field of CCUS technology. However, these authors account for less than 50% of the total number of publications, and a stable core group of authors has not been formed in the field of CCUS technology research.

Table 1. Key frequency of high frequency in thin film solar cell field (5 times or more)

Keyword	Frequency	Keyword	Frequency	Keyword	Frequency
CCUS Technology	57	Geological Sequestration	11	Geological sequestration of carbon dioxide	5
The CO_2 Capture	27	CO_2 Sequestration	10	Cost	5
Carbon Reduction	17	Coal-fired Power Plants	8	Coal Chemical Industry	5
Carbon Neutral	15	Demonstration Project	8	Carbon up to the Peak	2
Energy Conservation and Emissions Reduction	15	Carbon Capture/ Capture Technology	6	Technical and Economic Evaluation	2
Carbon Capture	15	Carbon Capture, Utilization and Storage	6	Business Model	5
CO_2	15	Economic Evaluation	4	Investment Decisions	5
CO_2 Flooding	14	Source Matching	6	Supercritical CO_2	5
Using Carbon	14	Shengli Oilfield	6	The Optimization Model	5
CCS	12	Utilization and Storage	6	Uncertainty	5

3.3 Statistical analysis of high-frequency key

After data cleaning, 150 literatures were listed with 410 keywords. In order to facilitate standardized statistical analysis, keywords with different expressions of the same meaning are combined, classified and expressed uniformly, and keywords with only one word frequency are filtered ,a total of 70 keywords were obtained after cleaning. Keywords that appeared more than 10 times were statistically sorted out and the research hotspots were found to be: CCUS technology, CO_2 capture, carbon emission reduction, carbon neutralization, CO_2 flooding, geological storage, etc., and it is predicted that these hot spots will be the research trend in the future.

3.4 Statistical analysis of core journals and funding

The hot areas of CCUS technology can be further tracked through the journal distribution statistics of CCUS technology research. The 165 research papers counted in this study were published in a wide range of journals, totaling 102.There was no-significant difference in the distribution of journal articles, with 8 articles being the most and 1 article being the least. Among them, more than 5 papers have been published in *China Petroleum Enterprise*, *Low Carbon World*, *Environmental Engineering*, *Proceedings of the CSEE* and other journals.

3.5 Statistical analysis of research institutions

According to statistical analysis, the institutions published in CCUS technology research are mainly distributed in enterprises, universities and research institutes, dominated by universities, supplemented by enterprises and institutes. According to regional analysis, the top 6 research institutions in the field of CCUS technology are as follows: Institute of Rock and Soil Mechanics, Chinese Academy of Sciences (17.11%),China Agenda 21 Management Center (10.53%),Institute of Environmental Planning, Ministry of Environmental Protection (6.58%),Tsinghua University (6.58%), North China Electric Power University (6.58%), and China University of Mining and Technology (5.26%).

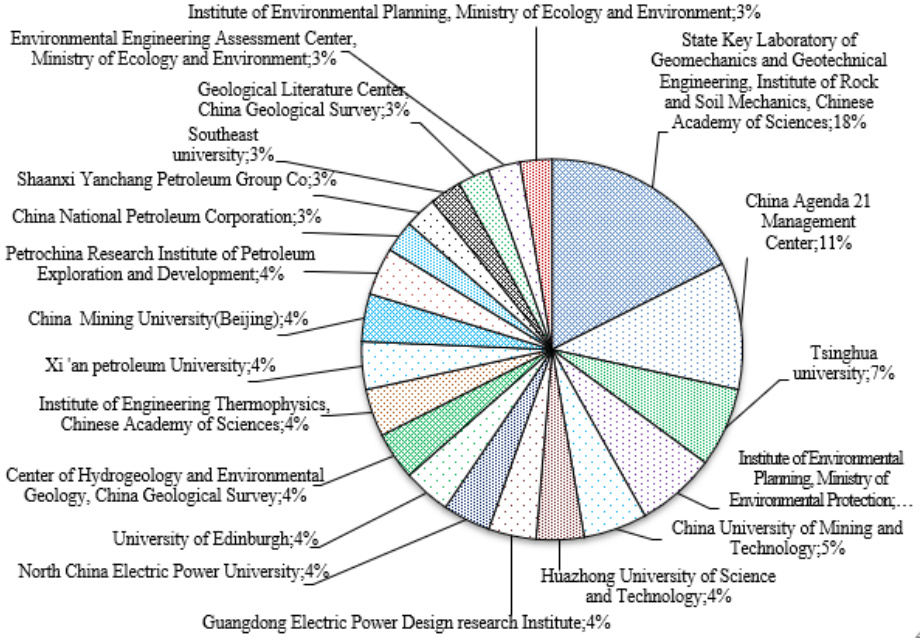

Fig. 2. The top 20 major research units in CCUS field

4 Analysis of hot spots and trends in CCUS technology field in China

The research of patent institutions at home and abroad shows that more than 90% of the new technology information in the world will be reflected in patent literature at the earliest. Through patent retrieval, the development trend of relevant technology can be effectively tracked, and the investment of RESEARCH and development funds and time can be effectively shortened. A search of incopat patent database revealed that from 2000 to 2021, China applied for 43 CCUS technology-related patents, far higher than Japan (32), the United States (26), Germany (17) and South Korea (7). In 2021, China's patent applications in this field peaked at eight. In general, the top 6 provinces and regions in the number of patent applications in this field in China are Shandong (16.28%), Beijing (13.95%), Jiangsu (9.30%), Hubei (9.30%), Guangdong (6.98%) and Shaanxi (6.98%). In terms of authorized patents in China, there were 12 authorized patents for inventions and 4 for utility models. The majority of CCUS technology patent applicants in China are enterprises, with 66.67% of the patents held by enterprises, 25% by colleges and universities, and 8.33% by scientific research institutions. According to international Patent Classification (IPC), the proportion of patents in each section of CCUS technology field is as follows: E21B (33.33%), G06Q (16.67%), H04L (16.67%), B01D (8.33%), C01B (8.33%), F23J (8.33%), F23L (8.33%), G01N (8.33%), G06F (8.33%), G16C (8.33%), H01L (8.33%), H01P (8.33%), H01Q (8.33%), H04W (8.33%), H05K (8.33%). It can be seen that the patents in this field are mainly concentrated in the petrochemical field.

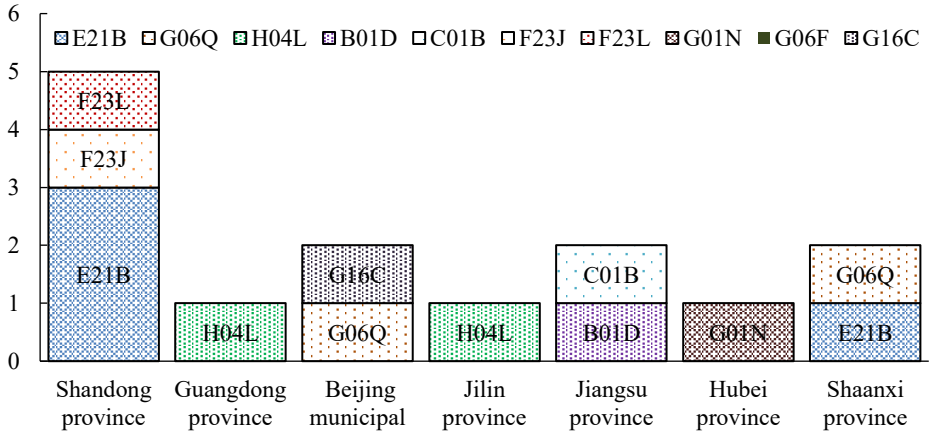

Fig. 3. CCUS technology distribution in China based on incopats retrieval (Top 10)

Research shows that carbon capture technology has matured and the cost of capture is gradually decreasing. In terms of carbon utilization, oil displacement is currently one of the most economical and scalable applications. In the United States, about 15 million tons of oil could be produced annually through CO_2 flooding. In terms of carbon sequestration, the Sleipner Gas Field Carbon Demonstration project, launched in 1996

by Statoil of Norway, is the world's largest saltwater sequestration project. Sequestration of 1 million tons of CARBON dioxide per year [7-11]. From the perspective of China, the 14th Five-year Plan is the "window period" to promote carbon peak, and also the critical period for the development of CCUS. Based on the requirements of the "dual carbon" target, China is formulating the CCUS technology development roadmap. Link the strategic positioning of CCUS with the carbon neutral scenario, improve the top-level design, business model and incentive policies of CCUS, and promote the research and demonstration projects of CCUS technology by large energy enterprises.

5 Conclusion

The results show that China's CCUS technology research was first involved in 2009, and the focus of CCUS technology research has continued to improve since 2006. However, at present, it is still in the exploratory stage, the core author has not yet formed, the research institutions are mainly scientific research institutes, and the patent applications are mainly enterprises. Oil displacement is one of the most effective ways of carbon utilization in China. According to the research results of existing scholars, on the premise of mature technology, CCUS is likely to achieve near zero emission, which is an important part of the global climate solution. From the perspective of development history, the United States and some European countries began to carry out the construction of CARBON dioxide capture and geological storage projects in the 1970s and 1980s, using EOR (enhanced oil recovery) technology to improve the output of oil fields and realize long-term geological storage of carbon dioxide under oil Wells. Effective treatment of carbon dioxide. The CCUS projects in China started relatively late and began to be implemented gradually after 2000, as well as the application of geological storage and carbon dioxide oil displacement (EOR).After 2010, China's CCUS project began to develop technical routes for carbon dioxide utilization as pre-combustion capture and cogeneration of power plants. Using catalytic hydrogenation and other means to upgrade carbon dioxide to formic acid and other chemical materials, carbon dioxide based plastics and other technical routes are also emerging, but CCUS technology is still facing high cost, economic feasibility and other problems, CCUS scale is still very small. There is no doubt that CCUS is an indispensable link in the whole carbon neutralization industry chain. In the future, it has become a major research hotspot in physical applications as oil displacement agents and supercritical CO_2 extraction, chemical applications as the synthesis of inorganic and organic fine chemicals and polymer materials with CO_2 as raw materials, and the conversion of CO_2 into biofuels, chemicals, biofertilizers, food and feed additives through biological applications, CCUS market has definite and huge development potential.

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