frontiers | Frontiers in Energy Research

TYPE Opinion
PUBLISHED 20 January 2023
DOI 10.3389/fenrg.2023.1073402

OPEN ACCESS

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SPECIALTY SECTION
This article was submitted to Carbon Capture, Utilization and Storage, a section of the journal Frontiers in Energy Research

RECEIVED 18 October 2022
ACCEPTED 06 January 2023
PUBLISHED 20 January 2023

CITATION
Kang H, Li G, Zhou X, Gao J and Gong W (2023), Challenge and strategy for the successful application of CCUS-EOR in China.
Front. Energy Res. 11:1073402.
doi: 10.3389/fenrg.2023.1073402

Challenge and strategy for the successful application of CCUS-EOR in China

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KEYWORDS

sustainable development goal, carbon utilization, carbon storage, carbon dioxide emission, carbon neutrality

1 Introduction

The ultimate goal of sustainable development is to deal with the problems of population, resources, environment, and development, ensuring equal opportunities for development for all countries, regions, and individuals in the world, ensuring the same conditions and opportunities for development for our future generations, and achieving harmonious coexistence between humanity and nature. Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their needs. Specifically, it includes three core aspects: economic sustainable development, social sustainable development, and environmental sustainable development (Raworth, 2017). In fact, these three aspects are interrelated and inseparable as a whole. On basis of the Millennium Development Goals (MDGs), the Sustainable Development Goals (SDGs) are new targets set by the United Nations to guide global development efforts from 2015 to 2030. Compared with the Millennium Development Goals, the Sustainable Development Goals address the universal need to achieve development and ensure that the benefits of progress are shared by all and therefore have a broader scope and longer-term objectives. Many scholars have conducted a lot of useful research on SDG. Based on the complicated relations among the United Nations Sustainable Development Goals (SDGs) by 2030, by reviewing the existing literature, Wang and Li (2021) point out that synergy and trade-off are the main concepts to analyze the relationship between goals. They analyze from the epistemological level, define the relationship types between goals accurately, and perfect the analytical framework of sustainability science, which is conducive to successfully implementing the sustainable development strategy. Starting from the evolution of sustainable development goals, design principles, and concepts to challenges and opportunities, Xian et al. (2021) analyze the implementation of sustainable development goals in China by combing the relationship between sustainable development goals and China's existing development strategies and find out the shortcomings. At the same time, they put forward corresponding policy recommendations for China to further implement the sustainable development goals. Zhang et al. (2019) briefly review the transition from the Millennium Development Goals to the Sustainable Development Goals. Then, based on the comprehensive analysis of the existing literature, they summarize the research progress of the relationship among the 17 sustainable development goals and outline the shortcomings and future challenges of the current research. Finally, three implications of the current research for the implementation of China's future sustainable development goals are analyzed. Feng et al. (2021) carry out research on how to promote the implementation of global SDGs in the post-epidemic era. By extracting information from policy documents such as the Sustainable Development Assessment Report (2019) and the Accelerated Action on Sustainable Development Goals, an index model is established, and countries are divided into nine categories according to 17 sustainable development goals, which provides support for accelerating action on global sustainable development goals. Research is conducive to achieving the 17 sustainable development goals by 2030.

Among the 17 sustainable development goals, Goal 7 aims to ensure access to affordable, reliable, and sustainable modern energy for all (Zhang et al., 2022). Carbon capture, utilization, and storage (CCUS) refers to the separation of carbon dioxide from industrial processes, energy utilization, or the atmosphere, and it also refers to the use of carbon dioxide or the direct injection of carbon dioxide into the formation for storage. The target of CCUS-EOR is carbon sequestration. Carbon sequestration refers to efforts to capture excess carbon dioxide from the atmosphere and process and store it in non-malignant manners. According to the technical process, CCUS projects can be divided into capture, transportation, utilization, and storage. At present, the situation of global carbon emissions is more serious, and the implementation of CCUS will help promote the realization of sustainable development goals. Based on the systematic review of the development history of CCUS technology, Huang et al. (2022) comprehensively comb the development history of basic research, technology development, industrial demonstration, policy introduction, and international cooperation for CCUS in China and put forward suggestions accordingly to promote the sustainable development of CCUS technology. Xiang et al. (2022) analyze the situation of coal consumption and CO_2 emissions from the coal chemical industry and the role of the coal chemical industry in the national economy and point out that the coupling of carbon emission reduction technology and coal chemical process is the key to realize carbon emission reduction and sustainable development of the coal chemical industry. In order to achieve large-scale carbon emission reduction in the coal chemical industry, resource utilization technologies such as green electricity, green hydrogen, and carbon capture and storage/carbon capture utilization and storage (CCS/CCUS and CO_2) must be adopted. Afterward, the main progress in the application of green electricity, green hydrogen, CCS/CCUS, and CO_2 resource utilization technologies in recent years is summarized, and it is predicted that the popularization and application of hydrogen metallurgy and green ammonia synthesis demonstration technologies may lead to significant changes in the pattern of the coal chemical industry. Finally, in view of the possible zero-carbon chemical system in the future, the reasonable prediction is launched. Cao (2022) analyzes and summarizes the upstream and downstream system layout of the process and the supporting surface technology route on the basis of combing the implementation process of carbon capture, utilization, and storage-enhanced oil recovery (CCUS-EOR) with the actual situation of Daqing Oilfield and puts forward a new understanding of promoting the construction of the CCUS-EOR project.

Based on long-term CCUS research and practical experience, Qin et al. (2020) focus on the analysis of global oil displacement CCUS (CCUS-EOR). The main influencing factors of the successful implementation of CCUS-EOR are systematically analyzed. Finally, specific suggestions for the sustainable development of China's CCUS-EOR industry are put forward from the aspects of development basis, main tasks, project operation, policies and regulations, and so on. According to the research of Yuan et al. (2022), it is expected that in 2030, the annual CO_2 injection scale of China's CCUS-EOR industry will reach 30 million tonnes, and the annual oil increase scale will reach 10 million tonnes. Joppa et al. (Lucas et al., 2021) from Microsoft introduce the valuable experiences of their company and prove that underground sequestration is the best way to store CO_2. Therefore, the implementation of CCUS-EOR is of good prospect in China and in the world. Based on the statistics of BP (BP plc, which refers to British Petroleum in United Kingdom), this paper analyzes the trend of CO_2 emissions in the past 30 years. From the point of view of energy exploitation and sustainable development, the positive significance of studying CCUS is confirmed. Then, combined with the literature, the challenges faced by CCUS in the specific implementation process in the oil and gas industry are summarized. Finally, according to the challenges, the direction of further development for CCUS-EOR is proposed.

2 CO_2 emission analysis

Based on the studies of Vitillo et al. (2022), CO_2 emissions are closely related to climate change and pose great threat to the sustainable development of humankind. In order to clearly analyze the changing trend of CO_2 emissions, the statistical data of BP Company on world CO_2 emissions are quoted, and the statistical data are plotted as follows. The abscissa in Figure 1 represents the year, which is about 30 years from 1990 to 2021. The ordinate represents global CO_2 emissions in million tonnes emitted per year. As can be seen from Figure 1, CO_2 emissions can be divided into three sources: CO_2 emissions from energy, CO_2 emissions from flaring, and CO_2 equivalent emissions from methane and process emissions. The total amount of CO_2 emissions from flaring is relatively small. In 1990, its value is about 221 million tonnes and then showed an overall increasing trend with the passage of time. By 2021, its value reaches about 308 million tonnes. The total amount of CO_2-equivalent emissions from methane and process emissions is larger than that of CO_2 emissions from flaring, and its value in 1990 is 2,325.63 million tonnes, which is about 10 times the total CO_2 emissions from flaring.

In the past 30 years, although CO_2-equivalent emissions from methane and process emissions have occasionally declined slightly, they have also shown an overall increasing trend until 2021. CO_2-equivalent emissions from methane and process emissions reach 4,784.24 million tonnes in 2021, which is about double its total value in 1990. The total CO_2 emissions from energy are much larger than the CO_2 emissions from flaring, with a value of 21,306.32 million tonnes in 1990, which is about 100 times the total CO_2 emissions from flaring. In the past 30 years, although the CO_2 emissions from energy have occasionally declined slightly, they have also shown an overall increasing trend. By 2021, the emissions from energy of CO_2 have reached a value of 33,884.06 million tonnes, which is about 59% higher than the total amount in 1990.

In terms of the relative size of the total amount, CO_2 emissions from energy accounts for the largest proportion, which is also the main source contributing to the total CO_2 emissions. From this point of view, the ways to promote the application of CO_2 in the field of energy supply and combine CO_2 emission reduction with energy security supply have become inevitable to achieve sustainable development at this stage. CCUS-EOR has double benefits of greatly improving oil recovery and burying carbon emission and is the most realistic and feasible CCUS technology with the largest application scale at present, with broad application prospects.

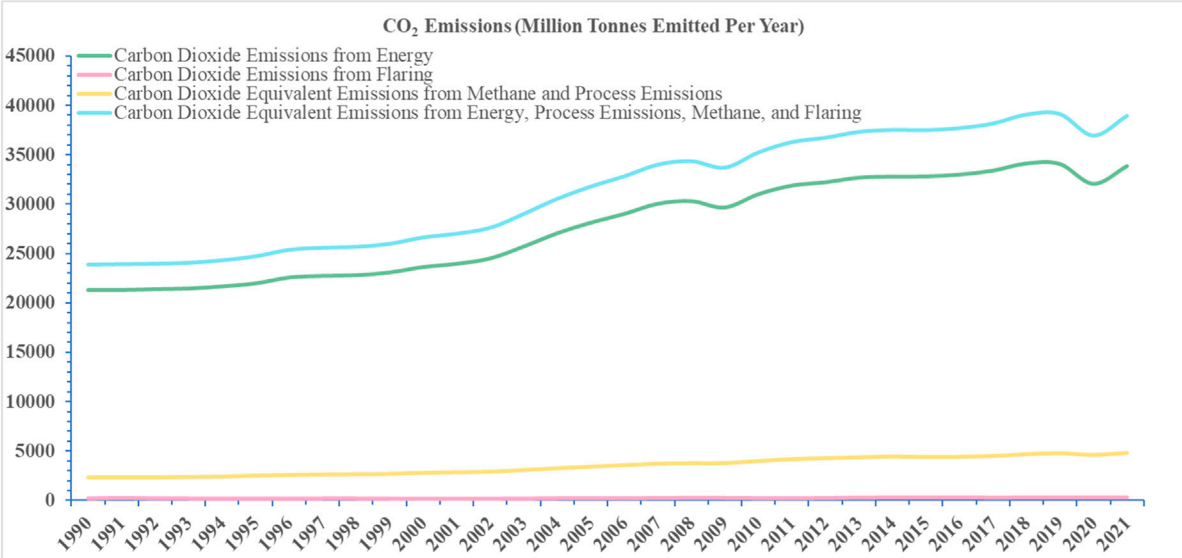

FIGURE 1
CO_2 emissions emitted all over the world from year 1990 to 2021.

3 Challenges for CCUS-EOR

Despite the good prospects, there are many challenges to successfully implementing CCUS for enhanced oil recovery (Xue, 2021; Zhao et al., 2021; Liu, 2022). First, the specific development scheme of CCUS-EOR is still not clear enough. At present, China has not formed a complete system of regulations and standards for the construction, operation, supervision, and evaluation of CCUS-EOR yet. China's CCUS-EOR potential should be fully evaluated to meet relevant international environmental and safety regulatory requirements and standards first. Moreover, the CO_2 capture of coal, power, and other industries and the EOR technology of oil companies have not been well integrated, and the complete industrial chain of CCUS-EOR has not formed yet. The second challenge is the cost control. There is no nearby ready CO_2 source for many oil fields, and CO_2 is mostly transported from far distance to the oil field site after special capture. The high cost of capturing and transporting CO_2 has resulted in an increase in the CO_2 cost in the oil field. In particular, the high cost of CO_2 capture poses a serious challenge to the implementation of these projects. In order to achieve higher oil recovery, it is necessary to increase the purity of CO_2 as much as possible, which further increases the cost of CO_2 capture. There is another category of costs that should also be carefully taken into consideration—environmental costs. During the whole implementation process of CCUS-EOR, additional energy consumption will be generated, resulting in the emission of pollutants, and it is also easy to have a certain impact on the nearby ecological environment and personal safety. Moreover, the investment payback period of CCUS-EOR is generally very long, and the project needs a large investment in the early stage, which is also a big burden for oil and gas enterprises, limiting the implementation scale of the project. The third challenge is the technical constraints. CCUS-EOR requires detailed demonstration of reservoir type, reservoir physical properties, CO_2 injection pressure, injection mode, and so on. In the process of CCUS-EOR, effective monitoring should be carried out to prevent CO_2 leakage and gas channeling in the formation, so that CO_2 can effectively play its role in the EOR process. Moreover, in the process of CO_2 transportation, injection, and recovery as associated gas, due to the complexity of medium composition, temperature, and pressure, it will usually cause a significant degree of corrosion to the string and pipeline, leading to string failure and fracture (Xue, 2021).

4 Strategies to promote CCUS-EOR

In view of the aforementioned challenges, corresponding strategies should be considered to promote the smooth development of CCUS-EOR (Xue, 2021; Zhao et al., 2021; Liu, 2022). First of all, the state should actively establish a win–win cooperation mechanism around carbon emission reduction targets at the national level, with the purpose to further sort out and clarify the responsibilities and obligations of different industries and enterprises in the process of project development. At the same time, it is necessary to establish an effective coordination mechanism and a fair cooperation mode for each link of CCUS-EOR. Only in this way, can the problems of gas supply, pipeline network transportation, and the relationship between local enterprises be solved, so as to achieve a good coordination for all aspects of the CCUS-EOR projects. Second, efforts should be made to improve economic policies such as tax, credit, land, carbon market trading, environmental protection, project approval, and other related regulatory requirements, as well as storage, monitoring, and carbon trading standards to promote the smooth implementation of CCUS-EOR projects.

Third, the implementation cost of the CCUS-EOR project should be reduced by strengthening technology research and development. By improving the corrosion of CO_2 transmission pipeline network and equipment, CO_2-EOR injection well, and production well string, the service life of string and equipment can be improved, and the operation cost can be reduced. At the same time, the research on the mechanism of CO_2-EOR should be strengthened. Related research studies should be conducted to deepen the understanding of reservoir geology, to screen appropriate reservoir applicability methods, select appropriate CO_2 injection mode and injection pressure, and study the combination with other EOR methods. Fourth, CO_2 emissions should be endowed with market attributes, and CO_2 suppliers should be encouraged to reduce the cost of CO_2 from both supply and demand through technological innovation and market innovation. At the same time, the government should improve the carbon market trading, verify the CO_2 emission reduction of oil enterprises, and allow the verification quota to be sold through the carbon trading market, so that oil enterprises can gain profits from sales, thus improving the enthusiasm of oil enterprises to carry out CCUS-EOR. By adopting the aforementioned strategies, the government will be very likely to further promote the progress of CCUS-EOR in China, make corresponding contributions to CO_2 emission reduction and energy supply, and ultimately help to achieve the world's Sustainable Development Goals (BP, 2022).

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

Funding

This work was supported by the Open Fund of State Key Laboratory of Enhanced Oil Recovery, PetroChina (Grant No. 2022-KFKT-29 and RIPED-2022-JS-2156), Science and Technology Project of Hebei Education Department (Grant No. QN2018158), and Science and Technology Fund of Hebei Normal University (Grant No. L2017B21).

Acknowledgments

The authors acknowledge the contributions of Hebei Normal University, State Key Laboratory of Enhanced Oil Recovery, and Research Institute of Petroleum Exploration and Development, PetroChina, that aided the efforts of the authors.

Conflict of interest

Authors GL, XZ, and JG were employed by PetroChina. The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest. The authors declare this study received funding from State Key Laboratory of Enhanced Oil Recovery, PetroChina. The funder had the following involvement with the study: study design, data analysis and preparation of the manuscript.

Publisher's note

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