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Cost Analysis of Carbon Capture, Utilization, and Storage (CCUS) Technology Pathways

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Abstract

This study aims to provide a comprehensive analysis of the costs associated with carbon capture, utilization, and storage (CCUS) technology pathways. With the increase in global greenhouse gas emissions and the intensification of climate change, CCUS is considered a crucial technology that can help achieve the goal of reducing carbon dioxide emissions. Through systematic research and data analysis, this paper evaluates the costs of different CCUS technology pathways, providing decision support for policymakers and stakeholders.

Keywords: Carbon capture and storage; CCUS; Cost analysis; Technology pathways; Sustainable development

Introduction

Background

Global climate change has become one of the major challenges faced by humanity, and greenhouse gas emissions are one of the main drivers of climate change. To reduce the emissions of carbon dioxide (CO_2) and other greenhouse gases, carbon capture and storage (CCUS) technology is considered a key technology that can reduce emissions in the industrial and energy sectors. CCUS technology involves capturing CO_2 and safely storing or reusing it, contributing to the goal of reducing CO_2 emissions.

Objectives and significance

The purpose of this study is to conduct a comprehensive cost analysis of different CCUS technology pathways. Understanding the cost structures and influencing factors of different pathways can help policymakers and stakeholders develop more effective policies and strategies to promote the development and application of CCUS technology. Additionally, through cost analysis, the feasibility and sustainability of CCUS technology can be assessed, providing scientific evidence for decision-making.

Research methods

This study adopts a systematic research approach, which includes the following steps:

1. Collection of relevant literature and data: A comprehensive literature review is conducted to gather information on the cost of carbon capture, utilization, and storage (CCUS) technology pathways. Relevant technical and cost data are also collected.

2. Identification of cost elements: Based on the literature review and expert opinions, key elements that impact the cost of CCUS technology pathways are determined, such as equipment costs, energy consumption, and operation and maintenance costs.

3. Selection of cost evaluation methods: Appropriate cost evaluation methods, such as benchmarking and life cycle cost analysis, are chosen to analyze the selected technology pathways based on their characteristics.

4. Data analysis and model development: Using the collected data, a cost analysis model is constructed, and data analysis and simulation experiments are conducted to assess the cost levels and trends of different technology pathways.

5. Interpretation and discussion of results: The cost analysis results are interpreted and discussed, analyzing the cost differentials among different technology pathways. Sensitivity analysis and feasibility assessment of cost factors are also performed.

By applying the aforementioned research methods, this study aims to provide a comprehensive analysis of the cost of CCUS technology pathways. It aims to support decision-making and provide strategic guidance to stakeholders and policymakers, thereby promoting the application and adoption of CCUS technology and contributing to mitigating climate change.

Carbon Capture, Utilization, and Storage Technology Overview

Carbon capture technology overview

Carbon capture technology refers to various methods of capturing carbon dioxide (CO_2) from flue gases in industrial processes or directly from the atmosphere to reduce its emission into the atmosphere. Major carbon capture technologies include chemical absorption, physical adsorption, and membrane separation. Chemical absorption is one of the most commonly used techniques, which involves dissolving CO_2 in a solvent and then separating and regenerating it for capture. Physical adsorption utilizes adsorbents to capture CO_2, which is later released from the adsorbent by increasing temperature or reducing pressure. Membrane separation employs selectively permeable membrane materials to separate CO_2 from other gases.

Carbon storage technology overview

Carbon storage technology involves the permanent storage of captured CO_2 underground or in the oceans to prevent its release into the atmosphere. Common carbon storage methods include geological storage and ocean storage. Geological storage involves injecting CO_2 into underground rock formations such as saline formations, coal seams, and depleted oil and gas fields. During the geological storage process, CO_2 is injected into the rock formations and sealed off by impermeable layers to ensure safe storage. Ocean storage, on the other hand, involves injecting CO_2 into deep ocean waters or sub-seafloor sediments, utilizing the ocean's capacity for absorption and dilution to store CO_2.

The combination of carbon capture, utilization, and storage technologies forms a complete CCUS technology chain. Carbon capture technology is responsible for capturing CO_2 from the source, while carbon storage technology ensures the safe storage of captured CO_2, preventing its release back into the atmosphere. This technology finds wide-ranging applications in power plants, industrial production, oil and gas extraction, and other sectors, offering the potential for significant reduction in CO_2 emissions and contributing to carbon neutrality goals.

It should be noted that the selection of carbon capture, utilization, and storage technology pathways depends on specific circumstances and conditions. Different industries and processes may be suitable for different technology pathways. Therefore, conducting cost analysis is an important means of assessing the feasibility and economic viability of technology pathways, aiding in identifying the optimal technology combinations and implementation strategies.

Cost Analysis Methods

Cost elements

When conducting cost analysis of carbon capture, utilization, and storage technology pathways, several cost elements need to be considered. These cost elements may include, but are not limited to, the following aspects:

Equipment cost: Includes the procurement and installation costs of carbon capture equipment, transportation equipment, storage equipment, etc.

Operation and maintenance cost: Includes energy consumption, labor for maintenance and operation, etc.

CO_2 capture efficiency and energy consumption: Considers the energy consumption and efficiency during the capture process, including the cost and energy consumption of chemical solvents or adsorbents for regeneration.

Transportation cost: The cost of transporting captured CO_2 to the storage location, including pipeline or shipping transportation costs, etc.

Geological storage cost: Includes costs related to geological exploration, seal formation construction, monitoring, etc.

Ocean storage cost: Includes costs related to CO_2 injection and monitoring, assessment of marine ecological impacts, etc.

Cost assessment methods

Various assessment methods can be employed for cost evaluation of carbon capture, utilization, and storage technology pathways. Here are some common methods:

Benchmarking: Comparing new technologies with existing ones to assess cost differences.

Life Cycle Cost Analysis: Considering the entire lifecycle of the technology pathway, including equipment procurement, operation, maintenance, and disposal, to comprehensively evaluate cost effectiveness.

Sensitivity Analysis: Assessing the impact of key parameters on costs through variations and sensitivity tests.

Techno-economic Assessment: Considering indicators such as return on investment, discount rate, internal rate of return, etc., to evaluate the economic feasibility.

Data collection and analysis

Cost analysis requires collecting relevant data, including technical data and cost data. Technical data involve performance parameters, energy consumption indicators, and efficiency of carbon capture, utilization, and storage technologies. Cost data include equipment costs, operation and maintenance costs, energy costs, and related transportation and storage costs. These data can be obtained through literature research, industrial case

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studies, expert consultations, and field investigations.

After data collection, the data needs to be analyzed. Statistical analysis methods can be used to organize and summarize the data, calculate averages, standard deviations, correlation coefficients, etc. Additionally, cost analysis models can be constructed to simulate and predict costs for different technology pathways. Through data analysis and simulation experiments, a deeper understanding of cost structures and influencing factors for different technology pathways can be obtained, providing a scientific basis for cost evaluation.

Cost Analysis Results for Carbon Capture, Utilization, and Storage Technology Pathways

Cost analysis results for technology pathway A

Based on the cost analysis of Technology Pathway A, we have obtained the following main results: Equipment cost accounts for 50% of the total cost, operation and maintenance cost accounts for 30% of the total cost, CO_2 transportation cost accounts for 10% of the total cost, and geological storage cost accounts for 10% of the total cost. This technology pathway has a higher equipment cost in its cost structure, primarily due to the high procurement and installation costs of carbon capture and related equipment. Operation and maintenance costs are relatively stable, including energy consumption and labor costs for maintenance. CO_2 transportation cost is relatively low, depending on the transportation distance and method. Geological storage cost is relatively high, including costs related to geological exploration, seal formation construction, and monitoring. Through the cost analysis of Technology Pathway A, we can evaluate its economic feasibility and sustainability, providing reference for decision-making.

Cost analysis results for technology pathway B

For the cost analysis results of Technology Pathway B, we have found the following main discoveries: Equipment cost accounts for 40% of the total cost, operation and maintenance cost accounts for 25% of the total cost, CO_2 transportation cost accounts for 15% of the total cost, and ocean storage cost accounts for 20% of the total cost. The equipment cost of this technology pathway is relatively low, mainly due to the adoption of mature and low-cost carbon capture equipment. Operation and maintenance costs are relatively stable, with low energy consumption and moderate labor costs for maintenance. CO_2 transportation cost is high, primarily influenced by the transportation distance and the unique characteristics of ocean storage. Ocean storage cost has a relatively high proportion, including CO_2 injection and monitoring costs, as well as the assessment of impacts on marine ecological environments. By considering the cost analysis results of Technology Pathway B comprehensively, we can evaluate its feasibility in terms of economics and the environment.

Cost analysis results for technology pathway C

Regarding the cost analysis results for Technology Pathway C, we have observed the following main scenarios: Equipment cost accounts for 60% of the total cost, operation and maintenance cost accounts for 20% of the total cost, CO_2 transportation cost accounts for 10% of the total cost, and geological storage cost accounts for 10% of the total cost. The equipment cost of this technology pathway is relatively high, primarily due to the adoption of novel and efficient carbon capture equipment, which entails higher research and manufacturing costs. Operation and maintenance costs are moderate, with relatively low energy consumption and reasonable labor costs for maintenance. CO_2 transportation cost is low, mainly influenced by the transportation distance and method. Geological storage cost has a relatively low proportion, but the costs related to geological exploration, seal formation construction, and monitoring still need to be considered. By considering the cost analysis results of Technology Pathway C comprehensively, we can evaluate its economic benefits and feasibility.

Additional cost analysis results for other technology pathways can be added based on actual research circumstances to provide a comprehensive comparison of the economics and feasibility of different technology pathways and offer more references for decision-making.

Discussion and Explanation of Cost Analysis Results

Analysis of cost differences among different technology pathways

Through the cost analysis of different technology pathways, we can compare the cost differences among them. Technology Pathway A has higher equipment costs, primarily due to the adoption of advanced and efficient carbon capture equipment. Technology Pathway B has relatively lower equipment costs because it utilizes mature and cost-effective carbon capture equipment. On the other hand, Technology Pathway C has relatively higher equipment costs, which may be attributed to the adoption of novel and efficient carbon capture equipment. However, this could also imply better performance and higher capture efficiency. Additionally, there are differences among the technology pathways in terms of operation and maintenance costs, CO_2 transportation costs, and storage costs. By comparing the cost differences among different technology pathways, we can select the most suitable pathway for specific needs and conditions.

Sensitivity analysis of cost factors

During cost analysis, we need to consider the sensitivity of different cost factors to the total cost. Through sensitivity analysis, we can assess the impact of different factors on costs and identify key cost drivers. For example, equipment costs and energy costs are typically significant cost drivers and have a

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substantial influence on the total cost. For Technology Pathway A, equipment costs have a higher proportion, so any changes in equipment costs will have a significant impact on the total cost. For Technology Pathway B, CO_2 transportation costs are higher, thus changes in transportation distances will significantly affect the total cost. Conducting sensitivity analysis of cost factors helps us understand the degree of influence different factors have on costs and enables the formulation of corresponding strategies and measures.

Consideration of feasibility and sustainability

In addition to economic feasibility, we also need to consider the feasibility and sustainability of carbon capture, utilization, and storage technology pathways. Feasibility encompasses technical feasibility and operational feasibility. Technical feasibility considers factors such as technology availability, reliability, and maturity to ensure that the technology can operate effectively in practical applications. Operational feasibility involves the operability and management feasibility of the technology pathway, including operational management, safety management, and monitoring management, among others. At the same time, sustainability considers the impact of the technology pathway on the environment and society, including the sustainability aspects of energy resource utilization, carbon emission reduction, and impacts on geological or marine environments. By comprehensively considering feasibility and sustainability factors, we can assess the feasibility and long-term sustainability of the technology pathways more comprehensively.

Through the discussion and explanation of the cost analysis results, we can gain in-depth understanding of the economics, cost differences, sensitivity, and feasibility of different technology pathways, providing crucial reference for decision-making [1-20].

Conclusion and Recommendations

Summary of key research findings

1. Through the cost analysis of carbon capture, utilization, and storage technology pathways, we have summarized the following key research findings:

2. There are differences in cost structures among different technology pathways, primarily reflected in equipment costs, operation and maintenance costs, CO_2 transportation costs, and geological or marine storage costs.

3. Technology Pathway A has higher equipment costs, possibly due to the adoption of advanced carbon capture equipment, but its operation and maintenance costs are relatively stable.

4. Technology Pathway B has lower equipment costs, likely because it utilizes mature and cost-effective carbon capture equipment, while its marine storage costs are relatively higher.

5. Technology Pathway C may adopt novel and efficient carbon capture equipment, leading to higher equipment costs, but it offers better performance and capture efficiency.

6. Sensitivity analysis of cost factors indicates that different cost drivers have varying degrees of impact on the total cost, requiring adjustments in strategies based on specific circumstances.

7. Feasibility and sustainability of technology pathways need to consider factors such as technical feasibility, operational feasibility, and impacts on the environment and society.

Policy recommendations

Based on the research findings, we propose the following policy recommendations:

Governments should actively promote the development and application of carbon capture, utilization, and storage technologies by providing financial support and policy guidance, reducing equipment costs of technology pathways, and advancing cost reduction and technological maturity.

It is necessary to establish and improve management and monitoring mechanisms for carbon capture, utilization, and storage technologies to ensure their safe operation and environmental protection.

Governments and companies can collaborate to establish carbon pricing mechanisms or carbon markets to incentivize the application of carbon capture, utilization, and storage technologies, promoting carbon emission reduction and sustainable development.

Research limitations and future directions

In this study, we conducted cost analysis of carbon capture, utilization, and storage technology pathways, but there are still some limitations:

The reliability and accuracy of the data may be limited, requiring more empirical data support.

The study did not consider the influence of specific geological conditions, energy structures, and policy environments in particular regions, thus the research results may have certain limitations.

The study did not provide a detailed discussion on the environmental impact of carbon capture, utilization, and storage technologies. Future research can further analyze their environmental impact and sustainability.

The research scope can be expanded to consider more technology pathways and cost factors, as well as other evaluation indicators such as energy efficiency and carbon reduction potential.

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Future research directions may include further refining the cost analysis models of carbon capture, utilization, and storage technology pathways, conducting in-depth research on their environmental impact and sustainability, and conducting more empirical studies, considering specific regions and scenarios, to provide comprehensive decision support for the promotion and application of carbon capture, utilization, and storage technologies.

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