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A Critical Review of the Regulatory and Policy Landscape Governing Carbon Capture, Utilization, and Storage (CCUS) Technologies in the United States: Challenges, Opportunities, and Future Directions

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Abstract

This critical review examines the regulatory and policy landscape governing Carbon Capture, Utilization, and Storage (CCUS) technologies in the United States, highlighting the challenges, opportunities, and future directions for effective implementation. CCUS technologies are pivotal in mitigating CO_2 emissions, particularly in hard-to-decarbonize sectors such as energy and industry. Despite the significant potential of CCUS, the current regulatory framework is fragmented, leading to inconsistencies in implementation across federal, state, and local jurisdictions. Key challenges include high costs, public opposition, and the underdeveloped infrastructure for CO_2 pipelines. This review synthesizes insights from various studies, emphasizing the need for robust regulatory frameworks that can facilitate the expansion of CCUS technologies. It also discusses the importance of improving capture efficiency, developing monitoring technologies, and enhancing public acceptance. The review concludes with recommendations for policymakers to create a cohesive regulatory environment that supports innovation and investment in CCUS technologies.

Keywords: Carbon Capture; Regulatory Framework; Public Acceptance; Policy Recommendations

1. Introduction

Carbon Capture, Utilization, and Storage (CCUS) technologies are essential for reducing CO_2 emissions, particularly in hard-to-decarbonize sectors like energy and industry [1, 2]. Various capture methods, including pre-combustion and post-combustion, have been developed, each with distinct efficiencies and limitations [1,3]. While CCUS presents significant potential for mitigating pollution from industrial emissions, the regulatory and policy landscape must evolve to address existing barriers and harness opportunities for innovation and investment. Utilization options range from enhanced oil recovery to mineral carbonation, showcasing the versatility of captured CO_2 [3, 4]. The regulatory landscape is fragmented, with federal, state, and local jurisdictions creating inconsistencies in CCUS implementation [5]. Key challenges include high costs, public opposition, and the need for extensive CO_2 pipeline infrastructure, which is currently underdeveloped [2, 5]. There is a pressing need for robust regulatory frameworks that can facilitate the expansion of CCUS technologies [2, 5]. Research priorities include improving capture efficiency, developing monitoring technologies, and enhancing public acceptance [3, 4]. Successful case studies and international examples can provide valuable lessons for U.S. policy development [4]. This paper reviews the regulatory and policy landscape governing Carbon Capture, Utilization, and Storage (CCUS) technologies in the United States and seeks to reveal the complex interplay of challenges and opportunities. It also synthesizes insights from various studies, highlighting the current state of CCUS technologies, regulatory frameworks, and future directions for effective implementation.

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2. The Evolution of CCUS Regulations and Policies in the U.S.

The evolution of Carbon Capture, Utilization, and Storage (CCUS) regulations and policies in the U.S. has been marked by strategic advancements aimed at reducing carbon emissions and promoting sustainable energy practices. The U.S. has been at the forefront of CCUS technology development, with significant emphasis on national-level technological guidance and macro-control. The introduction of the 45Q tax credit policy has been a pivotal regulatory measure, incentivizing investments in CCUS by offering tax credits for each ton of CO_2 captured and stored. This policy has attracted various types of capital investment, establishing a robust legal framework for CCUS deployment. The U.S. National Carbon Capture Center further supports this by providing a testing environment for CCUS technology research and development. The 45Q Tax Credit provides financial incentives for capturing and storing CO_2, significantly boosting CCUS projects' economic viability in the United States. Additionally, the National Carbon Capture Center serves as the U.S. Department of Energy's main research facility for carbon capture technology. Acting as a neutral testing ground, the center works to develop technologies that reduce greenhouse gas emissions from fossil fuel power plants. Furthermore, it supports research on carbon dioxide utilization and direct air capture (DAC) solutions [6]. Over the years, the U.S. has focused on improving capture methods, such as pre-combustion, post-combustion, and oxy-fuel combustion, to enhance efficiency and reduce costs [1, 3]. However, the integration of CCUS into broader environmental policies, such as carbon trading systems, has been crucial in aligning economic and environmental goals. In recent times, overcoming cost barriers and developing suitable storage sites have remained a challenge. Establishing comprehensive regulatory frameworks and addressing public concerns have also been discovered to be essential for widespread CCUS adoption [2]. There has also been a growing need for continued investment in R&D, which is necessary to improve capture efficiency and develop robust storage site assessments [3].

While the U.S. has made significant strides in CCUS policy and technology, challenges such as high costs and infrastructure needs persist. Addressing these issues through enhanced policy measures and technological innovation will be crucial for the future success of CCUS in achieving carbon neutrality goals.

3. Historical perspective on CCUS regulations

The historical perspective on Carbon Capture, Utilization, and Storage (CCUS) regulations reveals a complex evolution shaped by regional and international efforts to control emissions. CCUS technologies have been recognized as essential for reducing CO_2 emissions, prompting various regulatory frameworks to support their development and integration into climate policies. These regulations have evolved to address technological, safety, and economic challenges, with significant variations across different jurisdictions. The following sections provide a detailed examination of these regulatory developments.

The EU has been proactive, enacting the CCS Directive in 2009 and integrating CCUS into the Emissions Trading System (ETS), which incentivizes carbon capture by considering stored CO_2 as "not released" [7, 8]. The EU's regulatory framework supports innovation in low-carbon technologies through allowances and auctions [7]. USA and Australia have shown commitment to safety and environmental protection in CCUS operations, but their regulations have been criticized for not fully addressing offshore CCUS challenges, such as CO_2 impurities [9]. China and the Middle East are developing regulatory systems to support CCUS supply chains, focusing on integrating CCUS into climate change mitigation portfolios and ensuring consistency with international law [10]. Offshore CCUS projects face unique safety challenges, particularly in CO_2 pipeline transportation. Regulatory frameworks in the USA, Europe, and other regions have been compared, revealing gaps in addressing specific hazards associated with CO_2 streams [9]. Recommendations include international harmonization and the adoption of Safety Case legislation [9]. The integration of CCUS into emissions trading systems, as seen in the EU, provides economic incentives for carbon capture and storage. This approach is being considered by other countries, such as Korea, which is revising its CCUS legislation to align with emissions trading systems [7].

While significant progress has been made in developing CCUS regulations, challenges remain in harmonizing international standards and addressing specific regional needs. The evolution of these regulations reflects a growing recognition of CCUS as a critical component of global emissions regulation strategies, yet further efforts are needed to ensure comprehensive and effective regulatory frameworks.

4. Current Regulatory and Policy Frameworks

The current regulatory and policy frameworks for Carbon Capture, Utilization, and Storage (CCUS) are diverse and evolving, reflecting the varying stages of technological adoption and policy development across different regions. These

frameworks are crucial for the commercial viability and scalability of CCUS projects, as they provide the necessary legal and economic incentives to support investment and development. The effectiveness of these frameworks can significantly impact the deployment and success of CCUS technologies globally. The EPA's Geologic Sequestration Rule governs the injection of CO_2 into underground formations, addressing site selection, monitoring, and post-closure management to prevent leakage and environmental harm [11]. The rule is part of a broader strategy to reduce greenhouse gas emissions, particularly from the power sector, which accounted for 25% of U.S. emissions in 2021 [12]. While the EPA's regulations aim to promote CO_2 storage as a viable climate solution, the complexities of legal frameworks and environmental risks present significant challenges that may hinder the effective implementation of these technologies.

Sullivan et al. [13] provide an overview of the Department of Energy's CarbonSAFE Initiative, which aims to identify and characterize geologic storage sites capable of storing 50+ million metric tons of CO_2 from industrial and power sources, building upon earlier efforts by Regional Carbon Sequestration Partnerships that have already safely stored over 10.5 million metric tons of CO_2. The DOE's Carbon Storage Program aims to develop technologies for CO_2 capture, separation, and storage to reduce greenhouse gas emissions without hindering economic growth. The program has three main elements: Core Research and Development (R&D), Infrastructure, and Global Collaborations [14]. The Bureau of Land Management's Instruction Memorandum (IM 2022-041) establishes the policy for authorizing rights-of-way on public lands for carbon sequestration projects, including site characterization, transportation, injection, capture, and geologic sequestration of CO_2. This policy is part of a comprehensive strategy to combat climate change and reduce CO_2 levels in the atmosphere, applying only to BLM-administered lands.

5. Challenges in the Current Regulatory and Policy Landscape

The widespread adoption of Carbon Capture, Utilization, and Storage (CCUS) technology faces several regulatory hurdles that impede its implementation. These challenges stem from complex legal frameworks, economic viability concerns, and public acceptance issues, which collectively hinder the progress of CCUS initiatives.

The regulatory landscape for CCUS is intricate, with varying requirements across regions and countries, complicating project approvals [15, 16]. In Europe, gaps in regulation still exist, necessitating a robust legal regime to address specialized risks and ensure environmental safety [16]. Also, the high costs associated with CCUS technology remain a significant barrier. Policies that could incentivize cost reductions, such as carbon taxes and grants, are often insufficient or poorly implemented [17]. The economic feasibility of CCUS is contingent on strong policy interventions, which are currently lacking in many regions [17]. Public concerns regarding the safety and environmental impact of CCUS technologies can lead to resistance against project development [2]. Addressing these social impacts is crucial for gaining public support and facilitating smoother regulatory processes. While these regulatory hurdles present significant challenges, some argue that with the right policy frameworks and public engagement strategies, CCUS could still play a pivotal role in achieving global climate goals.

There are also long-term liability risks associated with CO_2 storage, which create uncertainty for investors and operators, deterring investment in CCUS projects [18]. The absence of clear legal frameworks regarding liability for potential leaks or environmental impacts further complicates project viability [19].

Carbon capture technologies, particularly CCS, involve significant capital and operational costs, making them economically unviable without substantial financial backing [20]. The lack of effective cost recovery mechanisms further exacerbates this issue, as companies are hesitant to invest in technologies that do not guarantee returns [18]. More importantly, national policy uncertainty creates an unstable environment for CCS development, as fluctuating regulations can impact project feasibility [21].

While these barriers present substantial challenges, some argue that advancements in technology and increasing public awareness of climate change may drive more robust regulatory frameworks and financial incentives in the future, potentially facilitating CCUS adoption.

6. Opportunities for Policy Enhancement and Regulatory Reform

The enhancement of policies and regulatory frameworks surrounding carbon capture and storage (CCS) presents significant opportunities for improving its implementation and effectiveness. Current legislation often hinders rapid project deployment, necessitating reforms that can streamline processes and foster innovation. Key areas for policy enhancement include:

The existing approval timeline for CCS projects can extend up to 8-10 years, limiting the number of projects that can be initiated to meet emission reduction targets. Proposals for legislative changes could facilitate quicker approvals, such as allowing the use of depleted petroleum fields for CO_2 storage and redefining containment concepts to focus on risk assessment rather than rigid permit constraints [22]. A stable international regulatory framework is essential for the broader adoption of CCS, as current policy uncertainties at national levels pose significant barriers. Enhanced cooperation and harmonization of regulations across countries can promote investment and innovation in CCS technologies [21]. The U.S. has a well-established infrastructure for CO_2 transport and storage, which can be leveraged to support CCS initiatives. This includes over 13,000 permitted injection wells and extensive pipeline networks. Regulatory reforms could encourage the integration of CCS with existing oil and gas operations, optimizing resource use and reducing costs [23].

While these opportunities for regulatory reform are promising, there remains skepticism regarding CCS as a long-term solution to climate change. Critics argue that it may divert attention and resources from renewable energy investments, potentially undermining broader sustainability goals [24].

7. Future Directions and Policy Recommendations

Future directions and policy recommendations for carbon capture focus on enhancing the effectiveness and scalability of carbon capture and storage (CCS) technologies, addressing governance and regulatory challenges, and integrating these technologies with renewable energy sources. The development of Direct Air Capture with Carbon Storage (DACCS) is particularly emphasized as a critical tool for achieving net-zero emissions. Key recommendations include establishing governance principles, incentivizing long-term carbon storage, and integrating CCS with renewable energy systems. These strategies are essential for managing the transition to a low-carbon future and ensuring the social acceptance of these technologies [25, 26].

7.1. Governance and Policy Frameworks

- Implement governance principles that ensure negative emissions and prioritize long-term carbon storage [25]
- Develop policies that phase in carbon pricing to incentivize carbon capture and storage efforts [25].
- Address pore space ownership issues to facilitate the commercialization of CCS, with federal ownership suggested as the most efficient structure [27].

7.2. Technological Integration and Innovation

- Co-develop capture, transport, and storage technologies to enhance the scalability and efficiency of CCS systems [25].
- Couple CCS technologies with renewable energy sources to maximize environmental benefits and reduce reliance on fossil fuels [25].
- Focus on hybrid and modified systems for carbon capture, which hold significant potential but require further research and development.

7.3. Social and Environmental Considerations

- Embrace certification and compliance measures to ensure the safety and effectiveness of CCS projects [25].
- Recognize and address social acceptance issues by engaging with communities and stakeholders in the development and deployment of CCS technologies [25].
- While these recommendations provide a comprehensive framework for advancing carbon capture technologies, challenges remain. The integration of CCS with existing energy systems and the resolution of regulatory and ownership issues are complex and require coordinated efforts at national and international levels. Additionally, the economic viability and public acceptance of these technologies will be critical to their successful implementation [27].

8. Conclusion

The conclusions drawn from the critical review of the regulatory and policy landscape governing Carbon Capture, Utilization, and Storage (CCUS) technologies in the United States highlight several key findings: The review emphasizes the necessity of an adaptive regulatory framework that can evolve alongside technological advancements and market dynamics. This flexibility is crucial for the successful expansion of CCUS technologies, allowing for timely responses to emerging challenges and opportunities in the field. A cohesive regulatory approach is essential to address the

fragmented nature of the current landscape, which includes varying regulations at the federal, state, and local levels. This fragmentation can lead to inconsistencies in CCUS implementation, hindering progress and investment. The paper identifies significant challenges that must be overcome for CCUS to thrive, including high capital costs, public opposition, and the need for extensive CO_2 pipeline infrastructure. These barriers can deter investment and slow down the deployment of CCUS technologies. Engaging with communities and stakeholders is critical for addressing social acceptance issues. Public concerns regarding the safety and environmental impact of CCUS technologies can lead to resistance against project development. Therefore, effective communication and transparency are vital for gaining public support.

The review calls for a focus on research priorities that include improving capture efficiency, developing monitoring technologies, and enhancing public acceptance. Successful case studies and international examples can provide valuable lessons for U.S. policy development, guiding future regulatory frameworks.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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