Carbon Capture and Storage (CCS) in Nigeria: A Review of Challenges and Opportunities

Ojiako Godfrey Ogbo (Corresponding Author)
Dept of Environmental Management, Nnamdi Azikiwe University, Awka
og.ogbo@unizik.edu.ng

David Chijioke Onuoha
Dept of Environmental Management, Nnamdi Azikiwe University, Awka
chidave2k3@yahoo.com

Christian Chijioke Odoh
Dept of Environmental Management, Nnamdi Azikiwe University, Awka
odoh@unizik.edu.ng

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Abstract: *Carbon Capture and Storage (CCS) is crucial for mitigating climate change by capturing and storing CO_2 emissions from industrial processes and power generation. This paper reviews the challenges and opportunities of implementing CCS in Nigeria, based on literature from 2014 to 2024. Key challenges include technical barriers like inadequate infrastructure and limited expertise, economic constraints due to high costs, and regulatory issues from the lack of a comprehensive legal framework. Public perception and awareness also pose significant social challenges. However, Nigeria has substantial opportunities for CCS due to its geological potential for CO_2 storage in depleted oil and gas fields and saline aquifers. Economically, CCS can create jobs, stimulate technological innovation, and position Nigeria as a CCS leader in Africa. Environmentally, CCS can significantly reduce greenhouse gas emissions. The paper concludes with policy recommendations, including subsidies, tax incentives, and a robust regulatory framework, to promote CCS in Nigeria. It emphasizes the need for investments in research and development, public-private partnerships, and effective public engagement strategies to address challenges and harness opportunities, contributing to global climate change mitigation and sustainable development.*

Keywords: carbon capture and storage, climate change mitigation, CCS technology, carbon sequestration

INTRODUCTION

Carbon Capture and Storage (CCS) is a critical technology in the global effort to mitigate climate change. CCS involves capturing carbon dioxide (CO_2) emissions from industrial sources and power plants and subsequently storing it underground in geological formations, preventing it from entering the atmosphere. This technology is essential for reducing greenhouse gas emissions and achieving the climate targets set by international agreements such as the Paris Agreement (Bui et al., 2018; Boot-Handford et al., 2014).

The relevance of CCS to climate change mitigation cannot be overstated. As the world continues to rely on fossil fuels for energy, CCS provides a viable pathway to reduce the carbon footprint of these energy sources. It is particularly crucial for industries that are difficult to decarbonize, such as cement, steel, and chemicals, which collectively contribute significantly to global CO_2 emissions (Paltsev et al., 2021). Furthermore, CCS is a key component in achieving net-zero emissions, as it can be combined with bioenergy (BECCS) and direct air capture technologies to remove CO_2 from the atmosphere (Bui et al., 2018).

For countries like Nigeria, which is a significant producer of fossil fuels, CCS is particularly important. Nigeria's economy is heavily dependent on oil and gas exports, making it a major emitter of CO_2. Implementing CCS can help Nigeria meet its climate commitments while continuing to exploit its fossil fuel resources. This dual benefit makes CCS an attractive option for the country, as it balances economic development with environmental sustainability (Faure, 2016; Rosa et al., 2020).

The deployment of CCS in Nigeria can also spur economic growth by creating new industries and jobs related to CO_2 capture, transport, and storage. Additionally, it can attract foreign investment and technological expertise, further boosting the country's economic prospects. By positioning itself as a leader in CCS technology, Nigeria can enhance its global standing in climate negotiations and contribute to global climate goals (Xenias & Whitmarsh, 2018; Feldpausch-Parker et al., 2015).

CCS is a vital tool for global climate change mitigation efforts, and its implementation is especially important for fossil fuel-rich countries like Nigeria. By adopting CCS, Nigeria can reduce its carbon emissions, meet international climate commitments, and drive economic growth through technological innovation and foreign investment.

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METHODOLOGY

This literature review aims to systematically explore the challenges and opportunities associated with the implementation of Carbon Capture and Storage (CCS) in Nigeria. The primary research questions guiding this review are:

- What is the current state of CCS in Nigeria?
- What are the main challenges of CCS and its implementation in Nigeria?
- What opportunities exist for the successful deployment of CCS in Nigeria?

The literature search was conducted using academic databases viz a viz Google Scholar, JSTOR, PubMed, Scopus, and Web of Science, supplemented by government reports, industry publications, and conference proceedings. Search terms included "carbon capture and storage Nigeria," "CCS challenges Nigeria," "CCS opportunities Nigeria," "carbon credits Nigeria," and "climate change mitigation Nigeria." Studies were selected based on predefined inclusion and exclusion criteria: peer-reviewed articles, reports published in the last 10 years, and studies specifically focused on Nigeria and CCS case studies internationally were included, while non-peer-reviewed articles, older studies, or those not directly relevant to CCS were excluded. An initial review of titles and abstracts was followed by a full-text review to ensure relevance and quality. In all, 30 articles were selected for review.

Data were extracted from the selected studies, summarizing key findings and noting the methodologies used in the original research. A thematic analysis was conducted to identify and categorize the main themes, such as technical challenges, economic barriers, policy issues, and potential opportunities for CCS in Nigeria. The quality and relevance of the studies were critically evaluated based on the methodologies employed, the robustness of the findings, and their applicability to the Nigerian context.

The findings are organized and presented according to the identified themes, with detailed discussions supported by evidence from the reviewed literature.

LITERATURE REVIEW

Background

Carbon Capture and Storage (CCS) is a technology designed to reduce carbon dioxide (CO_2) emissions from industrial processes and power plants. CCS involves three primary components: capture, transport, and storage of CO_2.

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Capture: This involves separating CO_2 from other gases produced in industrial processes or power generation. Several technologies can be used for this purpose, including post-combustion, pre-combustion, and oxy-fuel combustion. Post-combustion capture involves removing CO_2 from the flue gases after combustion using chemical solvents like amines. Pre-combustion capture separates CO_2 from fuel before combustion by converting the fuel into a mixture of hydrogen and CO_2, with the latter being captured. Oxy-fuel combustion burns fuel in oxygen instead of air, producing a flue gas that is primarily water vapor and CO_2, making it easier to capture the CO_2 (Boot-Handford et al., 2014; Zhang et al., 2020).

Transport: Once captured, the CO_2 must be transported to a storage site. This is typically done using pipelines, which are considered the most efficient and cost-effective method for transporting large volumes of CO_2 over long distances. In some cases, CO_2 can also be transported by ship, especially if the storage sites are located offshore (Bui et al., 2018; Roussanaly et al., 2023).

Storage: The final step involves injecting the captured CO_2 into deep underground geological formations, such as depleted oil and gas fields, saline aquifers, or unmineable coal seams. Ensuring the long-term containment of CO_2 is critical, and extensive monitoring and verification processes are employed to prevent leaks and ensure environmental safety (Boot-Handford et al., 2014; Moretta & Craig, 2022).

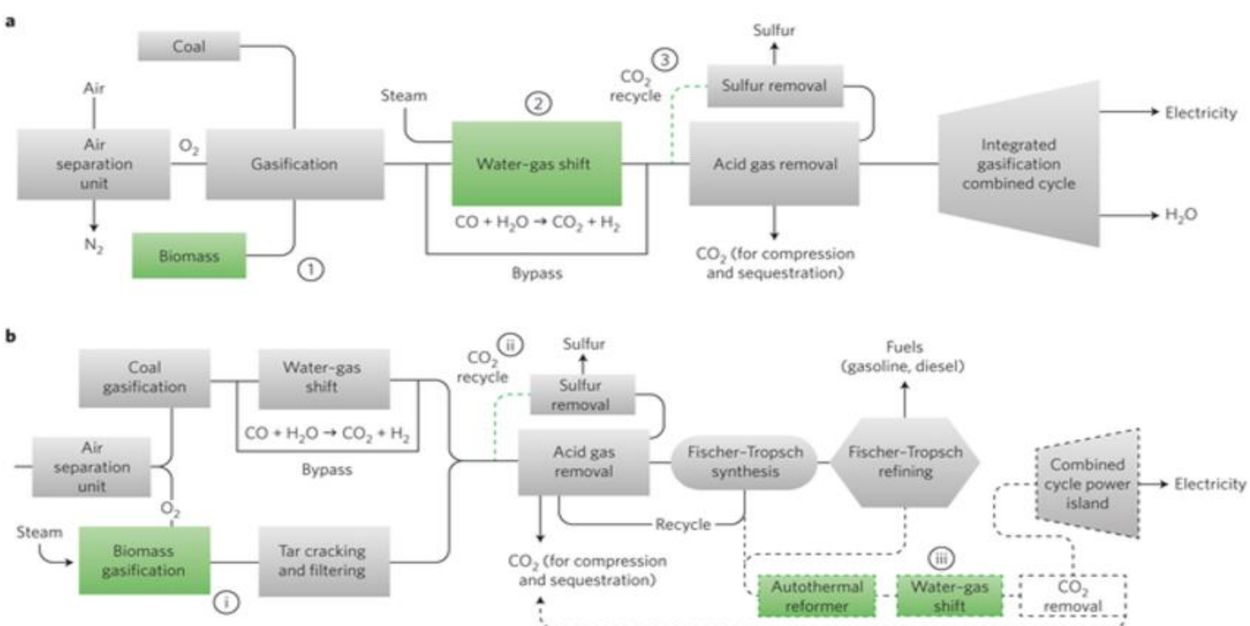

Figure 1: Flow diagrams for carbon capture and storage processes by Sanchez and Kammen (2016).

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Global Overview

Globally, CCS has been identified as a crucial technology for achieving climate change mitigation targets. Several successful case studies and ongoing projects demonstrate its potential:

Sleipner Project, Norway: The Sleipner Project, operational since 1996, is one of the world's first commercial CCS projects. It captures approximately 1 million tonnes of CO_2 annually from natural gas processing and stores it in the Utsira saline aquifer beneath the North Sea. The project has been a pioneer in demonstrating the feasibility of large-scale CO_2 storage and has provided valuable data for monitoring and verification techniques (Bui et al., 2018; Watson et al., 2014).

Boundary Dam, Canada: The Boundary Dam Carbon Capture Project in Saskatchewan, Canada, is another landmark project. Operational since 2014, it captures about 1 million tonnes of CO_2 per year from a coal-fired power plant. The captured CO_2 is used for enhanced oil recovery (EOR) and is stored in geological formations. This project has showcased the integration of CCS with existing industrial infrastructure (Paltsev et al., 2021; Seigo et al., 2014).

Gorgon Project, Australia: The Gorgon CO_2 Injection Project in Western Australia, which started in 2019, aims to capture and store up to 4 million tonnes of CO_2 per year from a natural gas processing facility. The CO_2 is injected into a deep into giant sandstone formation beneath Barrow Island. This project is one of the largest CCS initiatives globally and is expected to make a significant contribution to Australia's emission reduction efforts (Reiner, 2016; Moretta & Craig, 2022).

Despite these successes, the deployment of CCS globally faces challenges, including high costs, regulatory hurdles, and public acceptance issues. However, the continuous advancement in CCS technology and increasing policy support highlight its critical role in the transition to a low-carbon future (Smit, 2016; Zhang et al., 2020).

Current State of CCS in Nigeria

Existing Research and Projects

Carbon Capture and Storage (CCS) is a pivotal technology in the fight against climate change, aimed at reducing greenhouse gas emissions from industrial and power generation processes by capturing and storing CO_2 emissions. Despite its global relevance, Nigeria's progress in CCS implementation remains nascent. The country has primarily focused on utilizing CO_2 for enhanced oil recovery (EOR) rather than large-scale geological storage. Existing research and pilot projects in Nigeria highlight both the potential and the challenges associated with CCS deployment in the region.

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Dike and Akani (2020) state that there are currently no large-scale CCS projects in Nigeria. Instead, existing efforts are limited to technologies that capture CO_2 from associated gas for EOR. This limited focus means that the country lacks comprehensive studies and implementations of CCS that address the full spectrum of carbon capture, storage, transportation, and utilization. The research primarily emphasizes trapping CO_2 in depleted oil wells for EOR, with insufficient attention to the broader implications for climate change mitigation and sustainable energy transitions.

Another significant contribution to the field comes from Yahaya-Shiru et al. (2023), who conducted a numerical geo-modelling study to assess the storage capacity and injectivity of CO_2 in the 'X-Field' of the Niger Delta. Their research employed advanced geomodelling techniques and the ECLIPSE compositional reservoir simulator (E300) to evaluate the efficiency of CO_2 sequestration over a 50-year simulation period. The study revealed that the cumulative storage capacity of the target reservoir (Reservoir J) was estimated at 7.01 billion standard cubic meters (Bsm^3), demonstrating the reservoir's suitability for geological storage of CO_2. This research underscores the need for performance-based storage capacity estimations and well-planned injection strategies for effective CCS projects in the region.

Further research by Ojo and Tse (2016) evaluated the geological characteristics of depleted oil and gas reservoirs in the Coastal Swamp depobelt of the Niger Delta. Their study focused on the injectivity, containment, and storage capacity of sandstone reservoirs, which were found to have ideal conditions for CO_2 storage, including sufficient depth, porosity, permeability, and caprock thickness. The total theoretical storage capacity was estimated at 147 million tons, indicating significant potential for CCS in Nigeria. The research highlights the importance of selecting suitable geological formations to ensure the efficacy and safety of CO_2 sequestration.

While these studies provide valuable insights into the potential for CCS in Nigeria, there are still significant gaps in the country's CCS research landscape. Dioha et al. (2019) emphasize the need for more comprehensive studies that explore technically feasible pathways for reducing GHG emissions within Nigeria. Their research using the Nigerian Energy Calculator 2050 (NECAL2050) indicates that despite the potential for alternative low-carbon pathways, fossil fuels will continue to dominate Nigeria's energy system by 2050. This underscores the necessity for strategies that decouple economic development from GHG emissions, highlighting the role of bioenergy and energy efficiency in Nigeria's low-carbon transition.

Ekemezie and Digitemie (2024) provide a broader review of Carbon Capture and Utilization (CCU) technologies, exploring their emerging applications and challenges. Their review highlights advancements in carbon capture methods, such as chemical absorption, membrane separation, and adsorption, as well as various pathways for CO_2 utilization, including the production of fuels and carbon-based materials. This comprehensive overview underscores the transformative potential of

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CCU technologies in contributing to sustainable development, despite the technical and regulatory challenges that hinder widespread adoption.

Legal and Regulatory Framework

The legal and regulatory framework for CCS in Nigeria is currently underdeveloped, with significant gaps and limitations that need to be addressed to facilitate the deployment of CCS technologies. Dike and Akani (2020) highlight that there are no specific laws or regulations for the widespread application of CCS in Nigeria. The existing policies focus primarily on the utilization of CO_2 for EOR, with little emphasis on comprehensive carbon capture, storage, transportation, and utilization.

Mohammed (2020) discusses the role of the Clean Development Mechanism (CDM) under the Kyoto Protocol in reducing carbon emissions in Nigeria's oil and gas industry. The CDM projects have shown effectiveness in reducing CO_2 emissions through gas flaring reductions. However, the overall impact on national CCS policy remains limited. The success of CDM projects suggests that similar international market-based mechanisms could be beneficial for promoting CCS in Nigeria, provided there is adequate facilitation and support from the government.

Onwuka and Adu (2024) emphasize the need for sustainable strategies in onshore gas exploration, incorporating carbon capture technologies to ensure environmental compliance. They argue that integrating CCS into onshore gas exploration processes can significantly reduce the environmental impact of traditional practices. However, this requires robust regulatory frameworks and policies that support the implementation of carbon capture technologies.

The absence of a dedicated CCS regulatory framework presents a significant barrier to the adoption of CCS technologies in Nigeria. To address this, it is essential to develop comprehensive policies that cover all aspects of CCS, from capture to storage. This includes setting standards for site selection, monitoring and verification, liability management, and incentives for private sector investment.

Moreover, aligning Nigeria's CCS policies with international standards and best practices can facilitate the development of a robust legal framework. Learning from the experiences of countries like the UK, which has advanced in CCS policy and regulation, can provide valuable insights for Nigeria. The development of a national CCS strategy that includes clear legal and regulatory guidelines will be crucial for the successful deployment of CCS technologies in Nigeria.

While Nigeria has made some progress in CCS research and even dabbled in what resembles a CCS projects, there are significant gaps in both the research landscape and the legal and regulatory framework. Addressing these gaps through comprehensive studies, performance-based storage capacity estimations, and robust policies will be essential for the successful deployment of CCS technologies in Nigeria. This will not only contribute to the country's climate change mitigation efforts but also promote sustainable economic development by creating new industries and jobs related to CCS.

Challenges of CCS Implementation in Nigeria

The implementation of Carbon Capture and Storage (CCS) in Nigeria faces numerous challenges spanning technical, economic, regulatory, and social domains. These challenges must be addressed to harness the full potential of CCS for mitigating climate change and supporting sustainable development in the country.

Technical Challenges

The technical barriers to CCS implementation in Nigeria are significant and multifaceted. One of the primary challenges is the lack of infrastructure necessary for capturing, transporting, and storing carbon dioxide (CO_2). Nigeria's current infrastructure is predominantly geared towards the oil and gas industry, with limited facilities specifically designed for CCS activities (Dike & Akani, 2020). This infrastructural deficit is a critical impediment to the deployment of CCS technology.

Moreover, there is a notable deficiency in technological expertise within the country. CCS technology is complex and requires specialized knowledge and skills that are currently lacking in Nigeria. The technical know-how for designing, operating, and maintaining CCS systems is not widely available, which hampers the ability to develop and manage CCS projects effectively (Betiku & Bassey, 2022). This gap in expertise necessitates substantial investment in education and training programs to build a skilled workforce capable of supporting CCS initiatives.

Substantial investment in research and development (R&D) is also crucial. While there have been some studies, such as those by Yahaya-Shiru et al. (2023) and Ojo & Tse (2016), that explore the feasibility of CCS in specific geological formations, comprehensive research covering the entire CCS value chain is still lacking. Investment in R&D can facilitate the development of innovative solutions tailored to Nigeria's unique geological and industrial context, enhancing the effectiveness and efficiency of CCS technologies.

Economic and Financial Barriers

The financial challenges associated with CCS implementation in Nigeria are considerable. CCS technology is inherently expensive, involving high upfront capital costs for capturing, transporting, and storing CO_2. These costs can be prohibitive, particularly in a developing economy like Nigeria, where financial resources are limited and often allocated to more immediate development needs (Dioha et al., 2019).

Funding constraints further exacerbate the economic challenges. There is a scarcity of both public and private financing for CCS projects in Nigeria. The government has limited budgetary allocations for CCS, and private sector investment is deterred by the high risks and uncertain returns associated with the technology (Betiku & Bassey, 2022). This financial environment makes it difficult to secure the necessary funding for large-scale CCS projects.

Economic feasibility is another critical issue. The cost-benefit analysis of CCS projects often shows that the economic returns do not justify the high investments required. For instance, the cost of capturing CO_2 from industrial sources or power plants and transporting it to storage sites can outweigh the potential economic benefits, especially in the absence of significant carbon pricing mechanisms or financial incentives (Mohammed, 2020).

Policy and Regulatory Issues

Regulatory and policy challenges are also significant barriers to CCS implementation in Nigeria. Currently, there is no comprehensive legal framework specifically designed to govern CCS activities. Existing regulations are fragmented and often do not address the full spectrum of CCS processes, from capture to storage (Dike & Akani, 2020). This regulatory gap creates uncertainty and increases the risks associated with CCS investments.

Supportive government policies are essential to foster the development of CCS. These policies should include clear regulations that define the roles and responsibilities of different stakeholders, establish standards for site selection and monitoring, and provide guidelines for environmental protection and liability management (Onwuka & Adu, 2024). Additionally, policies that offer financial incentives, such as tax credits, subsidies, and grants, can help reduce the financial burden on CCS projects and encourage private sector participation.

The experience of other countries, like the UK, which has advanced in CCS policy and regulation, can offer valuable lessons for Nigeria. Adopting best practices from these countries can help Nigeria develop a robust regulatory framework that supports the safe and effective deployment of CCS technologies (Betiku & Bassey, 2022).

Public Perception and Awareness

Public perception and awareness present significant social and cultural challenges to CCS implementation in Nigeria. There is a general lack of awareness about CCS technology among the public, which can lead to misunderstandings and opposition to CCS projects. Many people are not familiar with the concept of CCS or its potential benefits for climate change mitigation and sustainable development (Ekemezie & Digitemie, 2024).

Acceptance of CCS projects is further complicated by concerns about safety and environmental impact. Public fears about the risks associated with CO_2 storage, such as potential leaks and their consequences, can lead to resistance against CCS initiatives. Addressing these concerns through effective communication and education is critical to gaining public support (Onwuka & Adu, 2024).

Moreover, social and cultural factors can influence public acceptance of CCS. In regions where there is strong attachment to land and natural resources, people may be reluctant to support projects that involve significant alterations to the landscape. Engaging with local communities and involving them in decision-making processes can help address these concerns and build trust (Akinyemi et al., 2021).

The successful implementation of CCS in Nigeria requires addressing a range of technical, economic, regulatory, and social challenges. Building the necessary infrastructure, developing technological expertise, securing adequate funding, creating supportive policies, and enhancing public awareness are all critical steps towards realizing the potential of CCS in mitigating climate change and promoting sustainable development in Nigeria.

Opportunities for CCS in Nigeria

Carbon Capture and Storage (CCS) represents a significant opportunity for Nigeria to mitigate climate change impacts, promote sustainable development, and leverage its natural and economic resources.

Natural Resources and Geology

Nigeria is endowed with substantial geological formations that are conducive to CO_2 storage, including depleted oil and gas fields and saline aquifers. These geological structures offer significant storage capacity for captured CO_2, making them ideal for large-scale CCS projects. The Niger Delta region, in particular, has numerous depleted oil and gas reservoirs that can be repurposed for CO_2 storage. Research by Ojo and Tse (2016) highlights the geological suitability of sandstone reservoirs in the Coastal Swamp depobelt of the Niger Delta. Their study identified reservoirs with ideal characteristics for CO_2 storage, including sufficient depth, porosity, permeability, and caprock thickness. These reservoirs can potentially store up to 147 million tons of CO_2, providing a substantial storage solution for emissions from Nigeria's industrial and power sectors.

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Further research by Yahaya-Shiru et al. (2023) utilized advanced geomodeling techniques to evaluate the injectivity and storage capacity of the 'X-Field' in the Central Swamp II depobelt of the Niger Delta. Their findings demonstrated the reservoir's suitability for long-term CO_2 storage, with a cumulative storage capacity estimated at 7.01 billion standard cubic meters. These studies underscore Nigeria's geological potential for CO_2 storage and the viability of utilizing its existing oil and gas infrastructure for CCS projects.

Economic Incentives

The implementation of CCS in Nigeria presents numerous economic benefits, including job creation, technological innovation, and the potential to position Nigeria as a leader in CCS within Africa. CCS projects can stimulate economic growth by creating new industries and jobs related to CO_2 capture, transport, and storage. This is particularly relevant in the Niger Delta region, where transitioning to CCS can provide alternative employment opportunities for communities traditionally dependent on the oil and gas sector (Dioha et al., 2019).

Technological innovation is another significant economic incentive. The development and deployment of CCS technologies can drive technological advancements and build local expertise in cutting-edge environmental technologies. This can enhance Nigeria's technological capabilities and foster innovation across related sectors, such as renewable energy and sustainable industrial practices (Betiku & Bassey, 2022).

Moreover, Nigeria has the potential to become a leader in CCS within Africa, leveraging its extensive oil and gas infrastructure and geological resources. By investing in CCS, Nigeria can attract foreign investment and position itself as a hub for CCS technology and expertise in the region. This leadership can extend to regional cooperation and partnerships, enhancing Nigeria's influence in international climate change mitigation efforts (Ekemezie & Digitemie, 2024).

Environmental Benefits

The environmental benefits of CCS are profound, primarily in reducing greenhouse gas emissions and mitigating the impacts of climate change. CCS technology captures CO_2 emissions from industrial sources and power plants, preventing them from entering the atmosphere. This directly contributes to reducing Nigeria's carbon footprint and aligning with global climate targets (Bui et al., 2018).

By capturing and storing CO_2, CCS can help Nigeria meet its international climate commitments under agreements such as the Paris Agreement. This is particularly important given Nigeria's reliance on fossil fuels for energy production, which contributes significantly to its greenhouse gas emissions. Implementing CCS can enable Nigeria to continue utilizing its fossil fuel resources

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while mitigating their environmental impact, promoting a balanced approach to energy production and environmental sustainability (Dioha et al., 2019).

Additionally, CCS can play a critical role in addressing local environmental issues, such as air pollution and land degradation associated with oil and gas activities. By capturing emissions from these sources, CCS can improve air quality and reduce health risks for local communities, contributing to broader environmental and public health benefits (Mohammed, 2020).

Policy and International Cooperation

The development of supportive policies and regulations is essential for advancing CCS in Nigeria. A robust legal framework can provide the necessary guidance and incentives for CCS deployment, addressing regulatory gaps and creating a conducive environment for investment. Policies should include clear regulations for site selection, monitoring and verification, liability management, and environmental protection (Onwuka & Adu, 2024).

International cooperation and partnerships are also critical for the success of CCS in Nigeria. Engaging with global CCS initiatives can provide access to technical expertise, financial resources, and best practices. Nigeria can benefit from collaborative projects and knowledge sharing with countries that have advanced CCS programs, such as the United Kingdom and Norway (Betiku & Bassey, 2022).

Access to climate finance is another important aspect of international cooperation. Funding from international climate funds, such as the Green Climate Fund (GCF) and the Global Environment Facility (GEF), can support the development and implementation of CCS projects in Nigeria. These funds can help mitigate the high upfront costs associated with CCS and facilitate the scaling up of projects (Ekemezie & Digitemie, 2024).

Moreover, integrating CCS into Nigeria's Nationally Determined Contributions (NDCs) under the Paris Agreement can enhance its commitment to climate action and attract international support. By demonstrating a strong commitment to CCS, Nigeria can leverage international partnerships and funding opportunities to accelerate its transition to a low-carbon economy (Onwuka & Adu, 2024).

DISCUSSION

The review of the current state of Carbon Capture and Storage (CCS) in Nigeria reveals several critical insights and challenges. Despite Nigeria's substantial potential for CCS, as highlighted by the geological studies of the Niger Delta region (Ojo & Tse, 2016; Yahaya-Shiru et al., 2023), the country faces significant barriers that hinder the widespread implementation of this technology.

The primary challenges include technical, economic, regulatory, and social factors that must be addressed to harness the full potential of CCS in mitigating climate change.

Technically, Nigeria lacks the necessary infrastructure and expertise to develop and maintain CCS projects on a large scale (Dike & Akani, 2020). This infrastructural deficit, coupled with high initial capital costs, presents a formidable barrier. Advanced research and development (R&D) are essential to bridge this gap, as demonstrated by global advancements in CCS technologies (Bui et al., 2018). Unfortunately, both government and private sector are unwilling to venture into this area.

Economically, the high costs associated with CCS technology are a significant deterrent. Funding constraints and the economic feasibility of CCS projects need to be addressed through targeted financial incentives and investment in R&D (Dioha et al., 2019). Innovative financial mechanisms, such as carbon credits and international climate finance, can play a crucial role in making CCS economically viable (Mohammed, 2020).

Regulatory and policy challenges also pose substantial hurdles. Nigeria currently lacks a comprehensive legal framework for CCS, which creates uncertainty and increases investment risks (Onwuka & Adu, 2024). Developing a robust regulatory framework that aligns with international standards and best practices is crucial for the successful deployment of CCS technologies. This would also open up avenues for sustainable development in Nigeria.

Socially, public perception and awareness of CCS technology are critical factors. There is a general lack of understanding and acceptance of CCS among the public, which can lead to resistance against its implementation. Effective public engagement strategies are necessary to build trust and support for CCS projects (Akinyemi et al., 2021).

Recommendations

To promote Carbon Capture and Storage (CCS) in Nigeria, the Nigeria could implement a range of policy measures to create a conducive environment for CCS deployment. Offering subsidies and tax incentives is essential; these can reduce initial capital costs and encourage private sector investment by providing financial benefits such as tax credits or deductions (Dike & Akani, 2020).

A comprehensive regulatory framework would also be crucial. This could include guidelines for site selection, environmental impact assessments, monitoring protocols, and liability management. Regulations must ensure safe CO_2 storage, adhering to international best practices (Mohammed, 2020). Additionally, financial incentives and grants are necessary to support research and development (R&D) in CCS technologies. Establishing a dedicated CCS fund can drive technological advancements and reduce costs (Ekemezie & Digitemie, 2024).

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Public-private partnerships (PPPs) can leverage strengths from both sectors. By collaborating with private companies, the government can share risks and benefits, making CCS projects more attractive to investors. PPPs can also facilitate knowledge transfer from countries with advanced CCS technologies, enhancing local expertise (Onwuka & Adu, 2024). Integrating CCS into Nigeria's Nationally Determined Contributions (NDCs) under the Paris Agreement can demonstrate the country's commitment to climate action, attracting international funding and support for CCS projects (Dioha et al., 2019).

Investment in R&D is critical for advancing CCS technologies and overcoming technical barriers anywhere in the world and especially for Nigeria. Comprehensive geological assessments are needed to identify potential CO_2 storage sites, including depleted oil and gas fields and saline aquifers (Yahaya-Shiru et al., 2023). Research should focus on developing efficient and cost-effective CO_2 capture technologies, with innovations in chemical absorption, membrane separation, and adsorption reducing operational costs (Bui et al., 2018). Developing advanced monitoring technologies is essential for ensuring CO_2 storage safety and effectiveness (Ojo & Tse, 2016).

Fostering collaboration between government, industry, and academia can drive innovation in CCS technologies. Joint research initiatives can pool resources and expertise to address complex challenges (Betiku & Bassey, 2022). Implementing pilot projects can provide valuable data on practical challenges and solutions for CCS deployment, refining and optimizing processes (Ekemezie & Digitemie, 2024).

Public engagement is crucial for gaining support for CCS projects. Education and awareness campaigns should inform the public about CCS benefits and safety through various media channels (Onwuka & Adu, 2024). Engaging local communities in CCS project planning can build trust and support. Public consultations and workshops can provide platforms for community participation (Akinyemi et al., 2021).

Maintaining transparency about CCS projects is essential. Providing clear information about risks, benefits, and progress can address public concerns (Ekemezie & Digitemie, 2024). Collaborating with NGOs and civil society groups can enhance public engagement, facilitating dialogue and promoting stakeholder interests (Dike & Akani, 2020). Addressing safety and environmental concerns proactively is crucial for public acceptance. This includes showcasing successful CCS projects and demonstrating robust monitoring systems (Bui et al., 2018).

CONCLUSION

The implementation of Carbon Capture and Storage (CCS) in Nigeria presents both significant challenges and substantial opportunities. Key challenges include technical barriers such as

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inadequate infrastructure and limited technological expertise, economic and financial constraints due to high costs, and regulatory and policy issues stemming from the lack of a comprehensive legal framework. Additionally, public perception and awareness pose social challenges that need to be addressed to garner support for CCS projects.

Despite these challenges, the opportunities for CCS in Nigeria are considerable. The country has substantial geological potential for CO_2 storage in its depleted oil and gas fields and saline aquifers. Economically, CCS can create jobs, stimulate technological innovation, and position Nigeria as a leader in CCS within Africa. Environmentally, CCS can significantly reduce greenhouse gas emissions, aiding in climate change mitigation efforts. Policy development and international cooperation offer further opportunities, with Nigeria poised to benefit from global CCS initiatives and access climate finance.

To meet future climate targets, it is estimated that the world needs to remove around 10 billion tons of CO_2 annually by 2050 (Tracker, 2021). This ambitious goal underscores the critical role of CCS and other negative emissions technologies in global climate mitigation strategies. Known investors in carbon capture, such as Shopify and Stripe, are leading the charge by funding innovative carbon capture projects and buy carbon dioxide removal credits, highlighting the growing interest and financial commitment to this field (Izikowitz, 2021; Honegger et. al., 2021). While tree planting and other natural sequestration methods are essential, they may not be sufficient to meet future carbon sequestration needs alone given our current projection. Industrial-scale CCS can complement these efforts, providing a more immediate and scalable solution to reduce atmospheric CO_2 levels.

The future of carbon credits is also promising, with projections indicating a significant peak as countries and companies strive to meet their emission reduction targets. By participating in the global carbon market, Nigeria can leverage its CCS potential to generate carbon credits, attracting international investments and contributing to global climate goals (Hu & Zheng, 2021).

Looking forward, the potential for CCS in Nigeria is promising, provided that the identified challenges are addressed. To harness the opportunities, Nigeria needs to develop a supportive policy framework that includes subsidies, tax incentives, and clear regulations. Investments in research and development are crucial to advance CCS technologies and build local expertise. Additionally, fostering public-private partnerships can help mitigate the financial burden and drive innovation.

Public engagement strategies are essential to increase awareness and acceptance of CCS technologies. Transparent communication, community involvement, and collaboration with NGOs can help build trust and support for CCS projects. Addressing these challenges through targeted policies, strategic investments, and effective public engagement can enable Nigeria to leverage its

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natural and economic resources for successful CCS implementation. This, in turn, will contribute significantly to the country's climate change mitigation efforts and promote sustainable development. By capitalizing on these opportunities, Nigeria can position itself as a key player in the global effort to reduce carbon emissions and combat climate change.

Future Research

Future research should focus on developing cost-effective CCS technologies tailored to Nigeria's specific geological and economic contexts. This includes exploring innovative methods for CO_2 capture and storage, enhancing the efficiency of existing infrastructure, and identifying new storage sites. Additionally, studies should investigate the socio-economic impacts of CCS on local communities, including job creation and public perception. Research into creating a comprehensive legal and regulatory framework to support CCS deployment is crucial. Collaboration with international partners to access global CCS advancements and climate finance will also be essential to drive progress and ensure the successful implementation of CCS in Nigeria.

References:

1. Betiku, A., & Bassey, B. O. (2022). Exploring the Barriers to Implementation of Carbon Capture, Utilisation and Storage in Nigeria. Day 1 Mon, February 21, 2022.
2. Boot-Handford, M. E., Abanades, J. C., Anthony, E., Blunt, M., Brandani, S., Mac Dowell, N., ... & Fennell, P. (2014). Carbon capture and storage update. Energy and Environmental Science, 7, 130-189.
3. Budinis, S., Krevor, S., Mac Dowell, N., Brandon, N., & Hawkes, A. (2018). An assessment of CCS costs, barriers and potential. *Energy strategy reviews*, *22*, 61-81.
4. Bui, M., Adjiman, C., Bardow, A., Anthony, E., Boston, A., Brown, S. F., ... & Dowell, N. M. (2018). Carbon capture and storage (CCS): the way forward. Energy and Environmental Science, 11, 1062-1176.
5. Dike, S. C., & Akani, N. K. (2020). Promoting Carbon, The Capture, Storage and Utilisation (CCSU) in Nigeria: Lessons from the UK. Journal of International Law and Jurisprudence, 6(2), 184-192.
6. Dioha, M. O., Emodi, N. V., & Dioha, E. C. (2019). Pathways for low carbon Nigeria in 2050 by using NECAL2050. Renewable Energy Focus, 29, 63-77.
7. Ekemezie, I. O., & Digitemie, W. N. (2024). Carbon Capture and Utilization (CCU): A Review of Emerging Applications and Challenges. Engineering Science & Technology Journal, 5(3), 949-961.
8. Falode, O. A., & Alawode, A. J. (2014). Potentials, prospects and challenges of geologic CO2 sequestration for enhanced coal-bed methane recovery in Nigeria. *Science and Technology*, *1*(4), 145-150.

9. Faure, M. (2016). Liability and Compensation for Damage Resulting from CO2 Storage Sites. William and Mary Environmental Law and Policy Review, 40, 387-476.
10. Feldpausch-Parker, A. M., Burnham, M., Melnik, M., Callaghan, M., & Selfa, T. (2015). News Media Analysis of Carbon Capture and Storage and Biomass: Perceptions and Possibilities. Energies, 8, 3058-3074.
11. Honegger, M., Poralla, M., Michaelowa, A., & Ahonen, H. M. (2021). Who is paying for carbon dioxide removal? Designing policy instruments for mobilizing negative emissions technologies. *Frontiers in climate*, *3*, 672996.
12. Hu, Y., & Zheng, J. (2021). Is green credit a good tool to achieve "double carbon" goal? Based on coupling coordination model and PVAR model. *Sustainability*, *13*(24), 14074.
13. Izikowitz, D. (2021). Carbon purchase agreements, dactories, and supply-chain innovation: what will it take to scale-up modular direct air capture technology to a gigatonne scale. *Frontiers in Climate*, *3*, 636657.
14. Markewitz, P., & Bongartz, R. (2015). Carbon capture technologies. *Carbon Capture, Storage and Use: Technical, Economic, Environmental and Societal Perspectives*, 13-45.
15. Mohammed, S. D. (2020). Clean Development Mechanism and Carbon Emissions in Nigeria. Sustainability Accounting, Management and Policy Journal, 11(3), 523-551.
16. Moretta, D. D., & Craig, J. (2022). Carbon capture and storage (CCS). EPJ Web of Conferences.
17. Nwali, O. I., Oladunjoye, M. A., & Alao, O. A. (2024). A review of atmospheric carbon dioxide sequestration pathways; processes and current status in Nigeria. *Carbon Capture Science & Technology*, *12*, 100208.
18. Ojo, A. C., & Tse, A. C. (2016). Geological Characterisation of Depleted Oil and Gas Reservoirs for Carbon Sequestration Potentials in a Field in the Niger Delta, Nigeria. Journal of Applied Sciences and Environmental Management, 20(1), 33-43.
19. Omoregbe, O., Mustapha, A. N., Steinberger-Wilckens, R., El-Kharouf, A., & Onyeaka, H. (2020). Carbon capture technologies for climate change mitigation: A bibliometric analysis of the scientific discourse during 1998–2018. *Energy reports*, *6*, 1200-1212.
20. Onarheim, K., Mathisen, A., & Arasto, A. (2015). Barriers and opportunities for application of CCS in Nordic industry—A sectorial approach. *International Journal of Greenhouse Gas Control*, *36*, 93-105.
21. Onwuka, O. U., & Adu, A. (2024). Sustainable strategies in onshore gas exploration: Incorporating carbon capture for environmental compliance. *Engineering Science & Technology Journal*, *5*(4), 1184-1202.
22. Osman, A. I., Hefny, M., Abdel Maksoud, M. I. A., Elgarahy, A. M., & Rooney, D. W. (2021). Recent advances in carbon capture storage and utilisation technologies: a review. *Environmental Chemistry Letters*, *19*(2), 797-849.
23. Paltsev, S., Morris, J., Kheshgi, H., & Herzog, H. (2021). Hard-to-Abate Sectors: The role of industrial carbon capture and storage (CCS) in emission mitigation. Applied Energy, 300, 117322.

24. Reiner, D. (2016). Advancing Carbon Capture and Storage in Australia. Climate Policy, 16(5), 586-610.
25. Rosa, L., Reimer, J., Went, M., & D'Odorico, P. (2020). Hydrological limits to carbon capture and storage. Nature Sustainability, 3, 1-9.
26. Roussanaly, S., Subraveti, S. G., Rodríguez Angel, E., & Ramírez, A. (2023). Is Carbon Capture and Storage (CCS) Really So Expensive?. PESA News.
27. Sanchez, Daniel & Kammen, Daniel. (2016). A commercialization strategy for carbon-negative energy. Nature Energy. 1. 15002. 10.1038/nenergy.2015.2.
28. Seigo, S. L., Dohle, S., & Siegrist, M. (2014). Public perception of carbon capture and storage (CCS): A review. Renewable & Sustainable Energy Reviews, 38, 848-863.
29. Smit, B. (2016). Carbon Capture and Storage: introductory lecture. Faraday discussions, 192, 9-25.
30. Tracker, C. A. (2021). Warming projections global update. *Climate Analytics and New Climate Institute: Berlin, Germany*.
31. Ugwuishiwu, B. O., Nwakaire, J. N., & Ohagwu, C. J. (2019). Cost analysis of carbon capture and storage for current gas-fired power plants in Nigeria. *Greenhouse Gases: Science and Technology*, *9*(2), 370-386.
32. Watson, J., Kern, F., & Markusson, N. (2014). Resolving or managing uncertainties for carbon capture and storage: lessons from historical analogues. Technological Forecasting and Social Change, 81, 192-204.
33. Xenias, D., & Whitmarsh, L. (2018). Carbon capture and storage (CCS) experts' attitudes to and experience with public engagement. International Journal of Greenhouse Gas Control.
34. Yahaya-Shiru, M., Igwe, O., Onwuama, C. N., et al. (2023). Numerical geo-modelling of 'X-Field', central swamp II Depobelt, Niger Delta, Nigeria: implications for carbon capture and sequestration. International Journal of Environmental Science and Technology, 20, 13673-13682.
35. Yelebe, Z. R., & Samuel, R. J. (2015). Benefits and challenges of implementing carbon capture and sequestration technology in Nigeria. *Int J Eng Sci*, *4*, 42-49.
36. Zhang, Z., Wang, T., Blunt, M., Anthony, E., Park, A., Hughes, R., ... & Yan, J. (2020). Advances in carbon capture, utilization and storage. Applied Energy, 278, 115627.