Carbon Capture in Developing Economies: The Role of AI in Addressing Infrastructure and Cost Challenges

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Abstract*- *Adopting carbon capture, utilization, and storage (CCUS) technologies in developing economies faces challenges limiting their contribution to global climate goals. These nations often face significant obstacles such as inadequate infrastructure, high costs, limited technical expertise, and weak policy frameworks. Compounding these issues are competing priorities, where immediate economic development, poverty alleviation, and energy access are prioritized over climate-focused initiatives. This article examines these barriers and explores how artificial intelligence (AI) can serve as a transformative tool to address them effectively. AI technologies offer innovative solutions to optimize CCUS adoption in resource-constrained environments. From infrastructure mapping and cost reduction to skills development and scalable deployment, AI-driven models provide actionable pathways for overcoming critical barriers. AI facilitates efficient decision-making by leveraging data analytics, predictive modeling, and process optimization, thereby enabling CCUS technologies to become more accessible and sustainable. To contextualize these opportunities, Nigeria is presented as a case study. The country's significant emissions profile, policy environment, and industrial activities are analyzed in light of the challenges and opportunities associated with CCUS implementation. These examples show how AI can enable developing economies to transition toward sustainable development while aligning with global climate targets. This article emphasizes the critical need for strategic collaborations, policy reforms, and capacity-building efforts to maximize the potential of AI-enhanced CCUS in developing economies. By addressing infrastructure gaps, reducing costs, and supporting skills development, AI technologies offer a promising pathway for these nations to position themselves as leaders in innovative climate solutions.

Indexed Terms*- *Carbon Capture, Utilization, and Storage (CCUS), Artificial Intelligence (AI), Developing Economies, Sustainable Development, Nigeria, Emissions Reduction, Infrastructure Optimization, Cost Efficiency.

I. INTRODUCTION

Carbon Capture, Utilization, and Storage (CCUS) technologies are a fundamental element in the global strategy to address climate change. These technologies aim to capture carbon dioxide (CO_2) emissions from industrial and energy-related sources, preventing their release into the atmosphere, and subsequently either store or repurpose the CO_2 for practical applications. In 2023, global energy-related CO2 emissions rose by 1.1%, totaling 410 million tonnes (Mt) and reaching a record 37.4 billion tonnes (Gt), with coal emissions responsible for over 65% of the increase, compared to a 1.3% rise of 490 Mt in 2022 (International Energy Agency, 2023). CCUS has become a cornerstone in the transition to net-zero emissions, especially since oil and gas operations contribute approximately 15% of global energy-related emissions, equivalent to 5.1 billion tonnes of greenhouse gases (OECD, 2023; International Energy Agency, 2023). Despite its transformative potential, widespread adoption of CCUS is hindered by significant challenges, particularly in resource-constrained regions.

Developing economies, which account for nearly two-thirds of global CO_2 emissions, face unique hurdles in implementing CCUS technologies. These include inadequate infrastructure, financial constraints, and competing socio-economic priorities, such as addressing poverty and expanding access to essential services (McLaughlin et al., 2023). The COP29 report estimated that developing nations will require an additional $1 trillion annually to meet their decarbonization goals (World Economic Forum, 2024). Additionally, the high costs associated with CCUS—averaging $15 –$130 per ton of CO_2 captured—pose substantial financial burdens, especially in regions with limited technological capacity and policy support (Statista, 2023).

In this context, artificial intelligence (AI) emerges as a game-changing tool capable of managing these challenges. AI can optimize cost-efficiency, enhance system design, and improve the monitoring and management of carbon storage sites. Leveraging advanced machine learning algorithms, AI enables precise predictions of CO_2 storage performance and facilitates real-time monitoring, reducing risks associated with leakage and inefficiencies (Mumtaz & Nadeem, 2024). Such capabilities make AI an indispensable ally in scaling CCUS deployment, particularly in regions where resource limitations are most pronounced.

This paper explores the intersection of AI and CCUS technologies, focusing on their potential to address the infrastructural and cost-related barriers that impede large-scale adoption in developing economies. By examining how AI-driven solutions can make CCUS technologies more accessible, scalable, and cost-effective, this discussion emphasizes the importance of adopting innovative strategies to meet global climate targets. Addressing these challenges is critical for achieving net-zero emissions and ensuring a sustainable and equitable future for all.

II. LITERATURE REVIEW

Overview of CCUS Technologies

Carbon Capture, Utilization, and Storage (CCUS) is a multi-faceted process involving three main components: the capture of CO_2 from industrial or energy-related sources, the utilization of captured CO_2 in applications such as enhanced oil recovery or chemical production, and the permanent storage of CO_2 in geological formations. The International Energy Agency (2024) notes that about 45 commercial facilities capturing more than 50Mt CO_2 are already implementing carbon capture, utilization, and storage (CCUS) in industrial processes, fuel transformation, and power generation. Hanson et al. (2025) evaluate the integration and optimization of CCUS systems, highlighting the synergies between capture, utilization, and storage, and include techno-economic analyses of integrated systems along with case studies of successful projects. Emphasizing the importance of CCUS in managing climate change, pointing out the need for continued innovation, policy support, and cost reductions for its widespread deployment and effectiveness. Although CCUS deployment had previously fallen short of expectations, it has gained significant momentum recently, with over 700 projects at various stages of development within the CCUS value chain (International Energy Agency, 2024). While adoption is concentrated in developed nations such as the United States and Norway, developing economies are largely underrepresented in the CCUS. Studies like Cabrera et al. (2022), highlight the role of policy incentives and technological advancements in driving adoption but point to a substantial gap in deployment across resource-constrained regions.

Challenges in Developing Economies

Developing nations face significant barriers to implementing CCUS technologies. A review by Ojiako et al. (2024) identifies infrastructural deficits, financial constraints, and limited technical expertise as primary obstacles affecting the adoption and progress of CCUS in developing nations like Nigeria. While recommending policies to promote CCS in Nigeria, the emphasis is on subsidies, tax incentives, and a productive regulatory framework, alongside the importance of investments in research and development, public-private partnerships, and effective public engagement strategies. Ajao (2024) points out that high upfront costs are significant obstacles due to financial constraints, insufficient expertise, and inadequate regulations. Additionally, the study highlights effective strategies and models for enhancing CCS capabilities in these countries. Eze (2024) highlights several challenges, including inadequate financing, insufficient infrastructure, poor investment and incentive allocation, low public awareness and acceptance, and the need to adapt policy frameworks. Adedola & Bassey (2022) argue that the scalability of CCUS technologies is hindered by a lack of skilled labor, insufficient institutional capacity, inadequate investment capital, and inconsistent policies by successive governments.

AI in Energy and Climate Solutions

The role of artificial intelligence (AI) in addressing global energy and climate challenges has been documented in some cases. A study by Onwusinkwue et al. (2024) highlights how renewable energy technologies address operational challenges and support the global shift towards clean energy. The study also explores AI's role in optimizing energy generation, monitoring emissions, and predictive maintenance in industrial settings, showcasing techniques like deep learning and neural networks for enhancing efficiency in solar, wind, and hydropower systems. In CCUS, AI can greatly improve the efficiency of data capture, storage security, and cost management. Combining deep reinforcement learning (DRL) with process simulations speeds up the optimization of process design and operation, while generative deep learning (GDL) is crucial for designing and discovering optimal materials for capture and utilization (Al- et al., 2024). Studies by Nassef (2023) & Priya et al. (2023) both demonstrated through models the transformative potential of integrating AI-driven machine learning algorithms into CCUS systems by optimizing CO_2 capture in real-time and significantly reducing costs in pilot projects.

Gaps in Current Research

Despite significant advancements in Carbon Capture, Utilization, and Storage (CCUS) technologies and the emerging role of artificial intelligence (AI) in addressing climate challenges, notable research gaps remain, particularly concerning the integration of AI into CCUS systems in developing economies. While studies like those by Hanson et al. (2025) and the International Energy Agency (2024) extensively explore the global deployment and optimization of CCUS systems, they predominantly focus on developed nations. This leaves a critical gap in understanding the unique challenges faced by developing economies, where infrastructure deficits, financial constraints, and limited technical expertise pose significant barriers. Existing research, such as Adedola & Bassey (2022) provides an overview of these barriers but lacks detailed, localized strategies designed for resource-constrained regions. Conversely, Ojiako et al. (2024) and Adedola & Bassey (2022) highlight the importance of policy frameworks, public-private partnerships, and investments in research and development for CCUS adoption in developing economies. However, these studies primarily address policy and economic dimensions without sufficiently exploring the potential of AI as a tool to mitigate these challenges. There is limited analysis of how AI could specifically address issues such as cost reductions, infrastructure optimization, and technical capacity building in these regions. Research on AI applications in energy and climate solutions is growing, but its integration into CCUS systems remains underexplored. Studies by Onwusinkwue et al. (2024) and Al-Sakkariet al. (2024) demonstrate the transformative potential of AI in renewable energy and industrial processes but provide only limited insights into its scalability and effectiveness in CCUS technologies, especially in developing economies. Furthermore, existing AI models focus on pilot projects, leaving a gap in understanding how these innovations can be applied at scale. Finally, the intersection of AI and CCUS in developing economies remains an under-researched area. While studies by Priya et al. (2023) and Nassef (2023) highlight the cost and efficiency benefits of AI-driven solutions in CCUS, they fail to address the socio-economic, regulatory, and institutional barriers that could impede their implementation in resource-constrained settings. There is also a lack of empirical studies examining the long-term economic and environmental impacts of AI-CCUS integration in these regions. These gaps show the need for interdisciplinary research that combines technological, economic, and policy perspectives to explore the feasibility of AI-driven CCUS adoption in developing economies. Focused studies are required to evaluate localized AI-CCUS strategies, assess their scalability, and provide actionable recommendations for overcoming infrastructure and cost-related challenges.

III. CHALLENGES OF CCUS ADOPTION IN DEVELOPING ECONOMIES

Infrastructure Deficits

One of the most significant challenges to CCUS adoption in developing economies is the lack of adequate infrastructure. Unlike developed nations with established pipelines, storage facilities, and capture plants, developing countries often lack the foundational systems required for efficient carbon capture, transportation, and storage. A 2024 report by the International Energy Agency (IEA) highlights that the current CO2 transport and storage infrastructure is inadequate to achieve the approximately 1,000 Mt CO2 per year by 2030 target outlined in the Net Zero Emissions (NZE) Scenario (International Energy Agency, 2024). Geological assessments needed to identify suitable CO2 storage sites are often incomplete in many developing economies, which delays project initiation. Rahmanian et al. (2024) highlight that CO2 storage sites must meet criteria such as capacity, safety, regulatory compliance, public acceptance, and financial feasibility, refined by factors like geology, pressure, and accessibility. Eze et al. (2024) identified logistical challenges, like insufficient pipeline infrastructure and storage sites, as well as economic factors and alternative energy sources, as obstacles to implementing large-scale CCUS projects in Africa.

High Costs

The financial barriers associated with CCUS deployment are pronounced in resource-constrained settings. According to Cabrera et al. (2022), the average cost of capital for energy projects in African countries is at least 2-3 times higher than in advanced economies and China, making investments less attractive by increasing project expenses (IEA, 2023). When evaluating Carbon Capture, Utilization, and Storage (CCUS), it's crucial to prioritize cost-effective sources and compare abated systems with and without CCUS, instead of using the unabated fossil system as a baseline. With traditional approaches being unsustainable, developing countries like Nigeria could benefit significantly from carbon trading, particularly in light of the EU carbon border adjustment tariff and California's low carbon fuel standard (International Energy Agency, 2021). Hanson et al. (2025) also discuss the importance of cost reductions for the economic feasibility and scalability of deploying effective energy solutions. High operational costs hinder the deployment of CCUS systems due to the significant energy requirements for capture, transportation, and storage. Additionally, the high expenses of obtaining suitable chemical feedstocks make certain synthesis pathways, such as green fuels and mineral carbonation, economically unviable (Lynne et al., 2023). Additionally, the high capital expenditure for building capture facilities and pipelines often competes with pressing economic priorities such as healthcare, education, and infrastructure development. Without substantial external funding or subsidies, the financial burden of CCUS projects remains insurmountable for many nations.

Technical Expertise

To maximize the clean energy sector's ability to combat climate change and boost economic growth, it's essential to tackle the talent gap. We can develop a skilled, diverse workforce capable of driving a sustainable energy transition by implementing educational reforms, ensuring industry collaborations, and raising awareness (O'Rourke, 2024). Developing economies face a critical shortage of skilled professionals capable of designing, implementing, and managing CCUS projects. Ojiako et al. (2024) reveal that less expertise in developing regions like Nigeria is a major challenge of carbon capture technologies. Training programs and technical workshops are rare, leaving industries reliant on foreign expertise, which adds to operational costs. Betiku & Bassey (2024) highlighted that Nigeria's weaknesses include a lack of expertise in Carbon Capture, Utilization, and Storage (CCUS) technology. This skill gap delays project timelines but also limits the ability to maintain and optimize CCUS systems over the long term.

Policy and Regulatory Barriers

Weak climate policies and inconsistent regulatory frameworks further hinder CCUS adoption in developing economies. According to Ojiako et al. (2024), fragmented policies and a lack of a comprehensive legal framework often cause failure to provide clear guidelines for CO_2 capture, transportation, and storage, leading to delays in project approvals. Also, Unclear and complex regulatory frameworks for Carbon Capture, Utilization, and Storage (CCUS) can lead to delays and increased costs for project development. Establishing comprehensive regulations that cover safety, monitoring, and liability is essential for creating a predictable and supportive environment for CCUS projects (CECO Enviro, 2024). The absence of firm carbon pricing mechanisms reduces the financial incentives for industries to adopt CCUS technologies (Cabrera et al., 2022). In countries with unstable governance, regulatory inconsistencies between successive administrations influenced uncertainty for investors and project developers, further stalling progress (Maghdid et al., 2024).

Competing Priorities

Balancing economic development with climate goals presents a persistent challenge for developing nations. Many countries prioritize industrial growth, poverty alleviation, and energy access over environmental initiatives. Yeboah (2023) highlighted that in developing economies, balancing economic growth and environmental conservation involves navigating trade-offs, as economic expansion is crucial for social progress but can harm the environment if not managed well. Policymakers need to adopt sustainable practices, enforce strict environmental regulations, promote eco-friendly technologies, and integrate environmental impact assessments into development projects to maintain a balance between economic development and ecological preservation. This trade-off is particularly evident in fossil fuel-dependent economies, where the focus remains on maximizing resource extraction and revenue generation, even at the expense of long-term environmental sustainability. A Reuters report by Dixon (2024) highlights that the global effort to decarbonize faces multiple challenges, with fossil fuel demand continuing to rise, especially in countries that are increasing coal use. Political factors and technological inefficiencies in renewable energy storage further hinder progress, making it difficult for developing nations to balance economic development with climate goals. According to Spath & Xia (2022), developing countries face the greatest risks from climate change and lack the resources for effective mitigation and adaptation, but overcoming these challenges while ensuring sustainable economic growth also presents numerous opportunities. Similarly, Adeoye (2024) discusses how Africa faces significant challenges due to climate change, including unreliable infrastructure and financial constraints. While some African leaders advocate for the continued use of fossil fuels for industrialization and development, others propose transitioning directly to renewable energies. However, this approach faces economic and financing barriers, making it challenging to balance economic development with environmental sustainability. The prioritization of short-term economic gains often leads to continued reliance on fossil fuels, thereby delaying the adoption of technologies like CCUS that could contribute to sustainable development.

IV. THE ROLE OF AI IN OVERCOMING CHALLENGES

Infrastructure Optimization

Artificial intelligence has a very important role in optimizing CCUS infrastructure by enabling precise mapping and modeling of ideal locations for capture and storage facilities. Through AI-powered geospatial analysis and machine learning algorithms, areas with optimal geological formations for CO_2 storage can be identified, significantly reducing the risk of leakage and maximizing storage capacity (Nassabeh et al., 2024). Jiao & Alavi. (2020) and Plevris (2024) have demonstrated how AI integrates data from seismic surveys, geological modeling, and real-time monitoring systems to enhance site selection and improve operational safety. According to the International Journal of Environmental Science and Technology (2024), these advancements could accelerate the deployment of CCUS projects by reducing the time and resources needed for site assessments (McKinsey, 2023).

Cost Reduction

AI-driven predictive analytics has emerged as a transformative tool for reducing the costs associated with CCUS deployment. AI can improve machine learning models that forecast emissions trends, allowing energy companies to make informed decisions and optimize their operations for better sustainability. Baber & Sadi (2024) pointed out that by combining AI with advanced data analytics, the energy sector can enhance sequestration techniques and reduce environmental risks, leading to a more sustainable energy future through effective carbon capture and storage. Research from Ukoba et al. (2024) indicates the effectiveness of AI in predictive maintenance, showing benefits such as increased output, better availability and quality, cost savings from automation, early failure detection, reduced downtime, and equipment life prediction. AI-based optimization techniques, including reinforcement learning and advanced process control, can enhance capture efficiency by 20-45%, leading to significant cost savings. Furthermore, Muhammad. (2024) opined that integrating AI with project management software is complex and resource-intensive, demanding significant investment in infrastructure, training, and change management. However, AI can revolutionize project management by improving resource allocation, risk mitigation, and decision-making, utilizing big data analysis and machine learning algorithms to enable more informed, data-driven decisions, optimize resources, and reduce risks in real-time.

Skills Development

AI-powered training platforms offer scalable solutions for addressing the shortage of skilled professionals in developing economies. These platforms use virtual reality (VR) and augmented reality (AR) to provide immersive training experiences for engineers and technicians (Bahroun et al.,2024). Al-Sakkari et al. (2024) explore both first principles-based and data-driven techniques, such as AI and machine learning (ML) methods, for assessing CCUS systems. They also emphasize the importance of life cycle assessment (LCA) and the integrated LCA-AI approach in equipping professionals with practical skills for designing, implementing, and managing CCUS projects. Integrating AI into emissions monitoring and reduction strategies significantly advances the oil and gas industry's efforts to meet global climate goals. These AI-driven solutions offer real-time, actionable insights that help operators make informed decisions, optimize processes, and reduce emissions, enabling the oil and gas sector to take proactive steps toward a more sustainable and environmentally responsible future (Bashir and Nadeem, 2024).

Scalable Deployment

The scalability of AI-enabled models for CCUS is a critical factor in ensuring widespread adoption. Successfully capturing, transporting, and utilizing or storing CO_2 as a mitigation strategy relies on having the necessary technologies available at each stage of the process, along with developing and expanding CO_2 transport and storage networks (International Energy Agency, 2020). Every step in the value chain must be technologically prepared and developed simultaneously for CCUS to scale up effectively. According to Noordt & Tangi. (2023), organizational AI capability components are essential for the successful development and utilization of AI, but they are often not readily accessible to public administrations. AI enables the creation and implementation of small-scale pilot projects, which can serve as models for larger deployments. By simulating various operational scenarios and assessing their feasibility, AI can help decision-makers understand the long-term impacts of scaling up CCUS technologies. This approach is particularly beneficial for developing economies, where limited resources necessitate the careful evaluation of pilot programs before large-scale investments. Enhancing the optimization of injection processes and minimizing CO2 emissions by applying AI algorithms to reservoir geology, production performance, and real-time data, ensuring maximum efficiency (Manikandan et al., 2024).

Regulatory Assistance

Navigating complex regulatory frameworks is a significant challenge for CCUS adoption, especially in regions with fragmented policies. AI systems can streamline this process by automating compliance tracking, monitoring changes in regulations, and assisting in the preparation of necessary documentation (Nembe et al., 2024).Integrating AI into regulatory compliance can shift it towards a proactive and predictive model, enhancing the security and trustworthiness of the financial ecosystem. To solve the complexities of this integration, ensuring collaboration between regulatory authorities, financial institutions, and technology developers is crucial, as machine learning algorithms can analyze regulatory data, provide actionable insights, ensure adherence to international standards, and expedite approval processes (Varun et al., 2024). For example, a study by Hanson et al. (2025) demonstrates how AI-powered legal tech platforms have reduced regulatory approval times in pilot CCUS projects.

V. CASE STUDY: NIGERIA

Nigeria, Africa’s most populous nation and a leading oil producer, has a significant carbon emissions profile driven by industrial and energy-related activities. The country’s carbon footprint is characterized by emissions from gas flaring, transportation, and power generation. In 2023, Nigeria emitted 11.5 million tons of CO2 from natural gas flaring, a slight increase from 2022 but a significant reduction compared to the 19 million tons emitted in 2013. This decrease indicates progress in managing emissions, despite the recent uptick (Statista, 2024). In 2022, Nigeria's CO2 emissions from fuel combustion totaled 100.389 million tons, which accounted for 0.3% of global CO2 emissions from combustible fuels. Between 2000 and 2022, there was a 126% increase in these emissions (International Energy Agency, 2022). Industrial activities, particularly in the oil and gas sector, account for a substantial portion of Nigeria's greenhouse gas (GHG) emissions, making the country one of the top emitters in sub-Saharan Africa.

Challenges in Nigeria's CCUS Implementation

Infrastructure Gaps in the Oil and Gas Sector: Despite being an oil-rich nation, Nigeria's infrastructure for carbon capture, utilization, and storage (CCUS) is underdeveloped. The lack of pipelines, advanced processing plants, and secure storage facilities impedes efforts to deploy CCUS technologies (Ojiako et al., 2024). TheInternational Renewable Energy Agency (IRENA). (2023) emphasizes that Nigeria requires significant investment in infrastructure to support carbon capture and storage.

Economic and Policy Constraints: Economic constraints, including limited public and private sector funding, hinder the adoption of CCUS technologies in Nigeria (Guobadia & Belo-Osagie (2023). Weak policy frameworks further influence this issue, with inconsistent climate policies and limited incentives for industries to invest in CCUS. Studies by Betiku & Bassey (2024) highlight the absence of a firm regulatory framework as a significant barrier to implementing large-scale CCUS projects in the country.

AI-Driven Solutions for Nigeria

Optimizing Gas Flaring Reduction Efforts: AI offers transformative solutions to Nigeria's persistent gas flaring problem. Machine learning models can analyze real-time data from oil production sites to identify inefficiencies and suggest adjustments to minimize gas flaring.By leveraging AI-driven predictive analytics, companies can explore various scenarios to enhance resource allocation and operational efficiency, while simultaneously minimizing their environmental impact (Ameh, 2024).

Mapping Carbon Storage Sites: Nigeria's geological formations, including depleted oil and gas reservoirs, offer potential storage sites for CO_2. AI-driven geospatial mapping tools can analyze seismic, geological, and hydrological data to identify optimal storage locations. Research by Al-Sakkari et al. (2024) describes how AI-based modeling can reduce the time required for geological assessments, accelerating the feasibility studies for CCUS projects.

Cost-Effective Pilot Projects: AI can enable cost-effective pilot projects by optimizing design and operations. Collaborations between local industries and AI firms can focus on small-scale CCUS initiatives that serve as templates for broader deployments. Using AI to monitor and optimize capture processes in industrial plants can reduce operational costs and improve efficiency (Abraham et al., 2024).

While large-scale CCUS adoption remains limited in Nigeria, there are emerging examples of AI applications in addressing emissions challenges. Partnerships between Nigerian National Petroleum Corporation (NNPC) and international tech firms have piloted AI-driven emission monitoring systems in oil fields with various preliminary site characterization studies have been conducted for CCUS project development; however, progress is being hindered by insufficient funding, inadequate policies, and low public awareness (Nwali et al., 2024). A case study by Nwali et al. (2024) described the reservoir units in the Niger Delta's extensional zone as being influenced by large growth faults associated with rollover anticlinal structures. The fault-sealing capability was assessed using the shale gouge ratio (SGR) method proposed by Yielding et al. (1999), which revealed that the fault exhibited leakage. Yahaya-Shiru et al. (2022) research on in-depth structural and stratigraphic analysis of the X field in the Niger Delta using 3D seismic data, focusing on CO_2 sequestration potential. They identified nine water-bearing sandstone reservoirs (A–J) within Central Swamp Depobelt II, each varying in quality. Key findings, including high SGR values, low permeability, significant fault throws, and reduced fault transmissibility in lower fault sections, indicate that the deeper structural traps in the field are low-risk areas suitable for CO_2 storage.

Proposed Scenarios for CCUS Advancement in Nigeria

- Establishing AI-powered CCUS hubs in collaboration with multinational energy firms.
- Leveraging AI tools for cross-sector partnerships that integrate CCUS with renewable energy solutions.
- Developing AI-assisted training programs to build local expertise in CCUS technologies.

VI. BENEFITS OF AI-ENHANCED CCUS FOR DEVELOPING ECONOMIES

Environmental Impact: AI-driven enhancements in CCUS systems contribute significantly to reducing greenhouse gas emissions by improving the precision and efficiency of carbon capture processes (Manikandan et al., 2024). This aligns developing economies with international climate agreements such as the Paris Accord, ensuring global collaboration in combating climate change. Also, AI algorithms optimize energy consumption in carbon capture plants, making operations more environmentally sustainable while lowering operational costs (Priya et al., 2023).

Economic Development: The integration of AI into CCUS technologies can stimulate economic growth by creating new jobs in technology and engineering sectors (Sharm, 2022). These roles range from software development for AI systems to on-the-ground implementation of CCUS technologies. Furthermore, such innovations make developing economies attractive destinations for foreign direct investment, as multinational corporations and climate funds often prioritize regions demonstrating commitment to advanced and sustainable practices (Li et al., 2024; World Bank, 2022).

Energy Transition: AI technologies facilitate a smoother transition from fossil fuels to renewable energy sources by enhancing the effectiveness of CCUS systems in managing emissions from traditional energy sources (Chatterjee & Dethlefs, 2022). This allows countries to maintain energy security while gradually diversifying their energy portfolios, ensuring that industrial and economic activities continue without significant disruptions during the transition period.

Global Competitiveness: Developing economies integrating AI-enhanced CCUS technologies can position themselves as leaders in addressing climate challenges and supporting sustainability in climate goals (Dziejarski et al., 2023; Hossin et al., 2024). Showing innovative approaches to carbon management, these nations can gain recognition in international forums and attract collaborations with global partners. Such advancements increased their reputation and provides a competitive edge in emerging green technology markets.

VII. CHALLENGES AND RISKS OF AI IN CCUS

Data Privacy and Security: The integration of AI into CCUS systems requires access to sensitive industrial data, including operational details, geological mappings, and emissions records (Manikanfan et al,. 2024). Safeguarding this data against breaches or unauthorized access is a major concern, as any compromise could lead to industrial espionage, data misuse, or regulatory penalties. According to Daniel (2020), developing economies often lack robust cybersecurity infrastructure. This may heighten the risk of data breaches and undermine the trust necessary for AI adoption in CCUS projects.

Cost of AI Implementation: While AI promises significant long-term cost savings, the initial investment in developing and deploying AI technologies for CCUS can be a limiting factor (Al-Sakkari et al., 2024). This includes the costs of acquiring advanced hardware, hiring skilled professionals, and conducting extensive training. For developing economies, these expenses are a major barrier, especially when competing priorities such as healthcare, education, and infrastructure demand immediate funding.

Algorithm Bias: AI systems are only as effective as the data and algorithms driving them. In CCUS, the presence of biased or incomplete data can result in inaccurate predictions or suboptimal recommendations, potentially leading to operational inefficiencies or environmental risks. Geological models based on limited datasets might misrepresent the suitability of storage sites, increasing the likelihood of leakage or operational failures (Xiao et al., 2024).

Regulatory Hurdles: The dual integration of AI and CCUS technologies presents complex regulatory challenges. Developing economies must ensure compliance with international standards, including those governing environmental safety and data ethics (Ghulam & Sadi, 2024). Additionally, the lack of harmonized regulations for AI applications in industrial processes creates uncertainties, delaying project implementation (Ampomah et al., 2024). Resolving these regulations requires significant institutional capacity and collaboration between governments and industry stakeholders.

VIII. POLICY RECOMMENDATIONS

To address the financial and technical challenges associated with AI-driven CCUS projects, governments should encourage public-private partnerships (PPPs) to ensure strong collaborations with private-sector stakeholders. By pooling resources for research, development, and deployment of CCUS technologies (Ojiako et al., 2024), these partnerships can overcome existing barriers. Governments can provide tax incentives or subsidies to private companies investing in AI-enhanced CCUS systems, ensuring mutual benefits while addressing funding gaps (IEA, 2023). Building a skilled workforce is crucial for the successful implementation of AI and CCUS technologies (IEA, 2023). Governments and educational institutions should develop local training programs and certification courses tailored to these fields. By working with industry experts, these programs can address local knowledge gaps, enabling engineers, data scientists, and technicians to design, implement, and manage AI-enhanced CCUS solutions effectively. To encourage industries to adopt AI-driven CCUS technologies, policymakers should create incentives such as tax breaks, grants, or reduced permitting fees (UNDSA, 2024). These measures can lower the financial burden of transitioning to advanced carbon management systems, particularly for industries in developing economies where initial costs are a significant barrier. Governments could also establish green certification programs to reward companies prioritizing sustainable practices. Developing economies can benefit significantly from sharing technology, expertise, and best practices with advanced nations. Strengthening international collaboration through bilateral agreements, knowledge exchange programs, and participation in global initiatives can accelerate the adoption of AI-enhanced CCUS. Partnerships with organizations like the International Energy Agency (IEA) or United Nations Framework Convention on Climate Change (UNFCCC) can also provide access to funding and technical support (IEA, 2023).

CONCLUSION

The adoption of Carbon Capture, Utilization, and Storage (CCUS) in developing economies presents a unique set of challenges, including infrastructure deficits, financial constraints, limited technical expertise, and competing priorities. Despite these obstacles, the potential for CCUS to reduce greenhouse gas emissions and align with global climate targets remains undeniable. Addressing these challenges requires innovative solutions that go beyond traditional approaches. Artificial intelligence (AI) emerges as a transformative tool with the capability to bridge critical gaps in CCUS adoption. From optimizing infrastructure and reducing costs to enhancing skills development and regulatory compliance, AI provides scalable solutions that make the deployment of CCUS technologies more accessible and efficient. Its application extends to mapping optimal storage sites, improving operational efficiency, and designing replicable pilot projects designed to resource-constrained environments. Nigeria serves as a compelling case study for the integration of AI in CCUS strategies. As a nation grappling with significant emissions and structural challenges, integrating AI can facilitate sustainable development by optimizing resource use, driving cost-effective carbon management, and addressing policy and technical barriers. By embracing AI-driven solutions, Nigeria and other similar developing economies, can transition from fossil fuel dependency to a more sustainable and competitive future. The path forward requires efforts from governments, industries, and international stakeholders to ensure innovation, build local capacities, and implement supportive policies. With strategic collaboration and investment, the transformative potential of AI-enhanced CCUS can unlock sustainable development opportunities for developing economies, positioning them as key players in the global fight against climate change.

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