

# Potentials of carbon storage and enhanced oil recovery in Niger Delta Region

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**ABSTRACT:** The increasing concentration of atmospheric carbon dioxide resulting from fossil fuel exploitation and industrial activities has intensified the need for sustainable carbon management strategies. This study evaluated the potentials of carbon storage and enhanced oil recovery (CO<sub>2</sub>-EOR) in selected reservoirs within the Niger Delta region of Nigeria. Ten depleted oil reservoirs were screened using established geological and reservoir criteria for carbon dioxide sequestration and miscible CO<sub>2</sub>-enhanced oil recovery operations. Reservoir parameters evaluated included depth, pressure, temperature, porosity, permeability, reservoir thickness, caprock thickness, oil gravity, oil viscosity, and remaining oil saturation. Minimum miscibility pressure (MMP) values were also calculated and compared with reservoir pressures to determine the feasibility of miscible CO<sub>2</sub> flooding. The results showed that three reservoirs were classified as suitable for CO<sub>2</sub> storage, four reservoirs were fairly suitable, while three reservoirs were unsuitable mainly due to poor caprock thickness and containment concerns. Evaluation of CO<sub>2</sub>-EOR potential revealed that eight reservoirs were good candidates for miscible CO<sub>2</sub> flooding, while two reservoirs showed average prospects because of low remaining oil fractions. Reservoir pressure values were greater than the calculated MMP values in all reservoirs, indicating favourable conditions for miscible CO<sub>2</sub> injection and enhanced oil recovery. Economic assessment further suggested that revenue generated from incremental oil production could offset operational and storage costs, thereby improving project feasibility. However, technical challenges such as reservoir heterogeneity, early CO<sub>2</sub> breakthrough, gravity segregation, and corrosion risks were identified as important considerations for implementation. The study demonstrates that depleted reservoirs in the Niger Delta possess significant potential for integrated carbon storage and enhanced oil recovery operations, which could contribute to greenhouse gas mitigation, improved hydrocarbon recovery, and sustainable energy development in Nigeria.

**Keywords:** Carbon storage, oil recovery, Minimum Miscibility Pressure, Niger Delta Region, reservoirs.

## INTRODUCTION

Global climate change and environmental degradation caused by greenhouse gas emissions have become major global concerns in recent decades. Carbon dioxide (CO<sub>2</sub>), largely generated from fossil fuel combustion, gas flaring, industrial activities, and energy production, is recognized as one of the principal contributors to global warming and atmospheric pollution. In oil-producing nations such as Nigeria, continuous hydrocarbon exploration and production activities, particularly gas flaring in the Niger Delta region, have significantly increased atmospheric CO<sub>2</sub> concentrations and associated environmental risks. These emissions contribute to rising global temperatures, ocean acidification, ecological imbalance, and adverse health

impacts on humans and ecosystems (IPCC, 2005; Nwankwo *et al.*, 2023).

Carbon Capture and Storage (CCS) has emerged as one of the most promising technologies for mitigating anthropogenic CO<sub>2</sub> emissions. CCS involves the capture of carbon dioxide from industrial and energy-related sources, followed by transportation and injection into suitable geological formations for long-term storage. Geological storage options include deep saline aquifers, depleted oil and gas reservoirs, coal seams, and formations utilized for enhanced hydrocarbon recovery operations (Hill *et al.*, 2013; Dai *et al.*, 2014). Among these options, depleted oil and gas reservoirs are considered particularly attractive

because of their proven trapping mechanisms, existing infrastructure, and extensive geological characterization acquired during hydrocarbon exploration and production activities (Ojo and Tse, 2016).

The Niger Delta Basin is one of the largest hydrocarbon-producing provinces in Africa and contains numerous mature and depleted reservoirs that may serve as suitable sites for geological CO<sub>2</sub> sequestration and enhanced oil recovery (EOR). Several studies have shown that many reservoirs within the basin possess favourable petrophysical and structural characteristics for CO<sub>2</sub> storage, including adequate porosity, permeability, reservoir thickness, sealing integrity, and injectivity potential (Umar *et al.*, 2020; Davies *et al.*, 2020; Maduwesi *et al.*, 2024). Recent investigations in the Niger Delta have further demonstrated the viability of depleted reservoirs for sustainable carbon storage and CO<sub>2</sub>-EOR applications (Eigbe *et al.*, 2024; Ajidahun *et al.*, 2026).

Enhanced Oil Recovery using CO<sub>2</sub> injection is a well-established tertiary recovery technique that improves hydrocarbon recovery while simultaneously providing an opportunity for long-term carbon storage. During CO<sub>2</sub>-EOR operations, injected carbon dioxide reduces oil viscosity, improves oil mobility, and increases reservoir pressure, thereby enabling the production of additional hydrocarbons that would otherwise remain unrecovered (Kovscek and Cakici, 2005). A significant proportion of the injected CO<sub>2</sub> remains trapped within the reservoir through structural, residual, solubility, and mineral trapping mechanisms, making CO<sub>2</sub>-EOR a dual-benefit technology for both energy production and greenhouse gas mitigation (Ampomah *et al.*, 2016; Azzolina *et al.*, 2015).

Globally, several successful CCS and CO<sub>2</sub>-EOR projects have demonstrated the technical feasibility and environmental benefits of geological carbon storage. Projects such as the Weyburn Field in Canada, the Sleipner Project in Norway, and the In Salah Project in Algeria have shown that CO<sub>2</sub> can be safely injected and stored in subsurface formations over long periods with minimal leakage risk (Hill *et al.*, 2013). These projects have also established that depleted hydrocarbon reservoirs can serve as effective storage sites while supporting enhanced hydrocarbon recovery operations.

In Nigeria, interest in CCS and CO<sub>2</sub>-EOR has continued to increase because of the country's dependence on fossil fuels and the environmental challenges associated with gas flaring and industrial emissions. Studies by Odesa and Adewale (2011), Effiom *et al.* (2024), and Ogbeiwi and Stephen (2023) emphasized the enormous potential for integrating carbon capture technologies with enhanced oil recovery operations in the Niger Delta. The region possesses vast depleted reservoirs and mature oil fields that could be repurposed for carbon storage while extending field productivity and improving national revenue generation.

Despite these opportunities, the implementation of CCS and CO<sub>2</sub>-EOR in Nigeria remains limited due to several technical, economic, regulatory, and infrastructural

challenges. Concerns relating to reservoir integrity, caprock competence, leakage risks, monitoring systems, transportation infrastructure, and high operational costs continue to hinder large-scale deployment of CCS technologies in the country (Galadima and Garba, 2008). Furthermore, comprehensive evaluation and screening of depleted reservoirs for carbon storage suitability are still inadequate in many parts of the Niger Delta Basin.

Therefore, this study evaluates the potentials of carbon storage and enhanced oil recovery in selected reservoirs within the Niger Delta region. The study focuses on assessing reservoir characteristics and comparing them with established screening criteria for geological CO<sub>2</sub> storage and miscible CO<sub>2</sub>-EOR operations. The outcome of this research is expected to provide useful insights into the viability of utilizing depleted Niger Delta reservoirs for sustainable carbon management and improved hydrocarbon recovery.

## METHODOLOGY

This study adopted a comparative analytical approach to evaluate the potentials of carbon storage and enhanced oil recovery (CO<sub>2</sub>-EOR) in selected depleted oil reservoirs within the Niger Delta region. The methodology involved the assessment of reservoir characteristics and comparison of the obtained parameters with established screening criteria for geological carbon sequestration and miscible CO<sub>2</sub>-EOR operations.

The research procedure was carried out in three major stages: (i) acquisition and assessment of reservoir data, (ii) screening of reservoirs for CO<sub>2</sub> storage suitability, and (iii) evaluation of reservoirs for CO<sub>2</sub>-enhanced oil recovery potential.

### Reservoir data acquisition

Reservoir and fluid properties of selected Niger Delta oil fields were obtained from available field records and published reservoir datasets. The acquired parameters included reservoir oil in place, reservoir depth, temperature, pressure, thickness, porosity, permeability, caprock thickness, well density, oil viscosity, oil gravity, and remaining oil fraction in the reservoir. The detailed reservoir characteristics used in this study are presented in Table 1.

### Screening for CO<sub>2</sub> storage potential

The suitability of the selected reservoirs for geological carbon storage was evaluated using internationally recognized site selection criteria proposed by Bachu *et al.* (2003). The screening process focused on determining the integrity, capacity, and safety of the reservoirs for long-term CO<sub>2</sub> sequestration.

Critical parameters considered during the screening

**Table 1.** Niger Delta oil field data.

Reservoirs	OP(STB)	Depth (ft)	Temp.	Pre. (Psi)	Thic. (ft)	Por.	Perm.	CT	WD (lb/ft <sup>3</sup> )	OV	OG	OG (°API)	°API + 131.5	BO (RB/STB)
A1	98428539	7851	133	3325	48	0.24	668	24	9975	0.8	0.77961	50	181.5	1.25
A2	93403217	7935	134	3498	48	0.25	1241	36	10494	1	0.79718	46	177.5	1.2
A3	86639358	8126	139	3500	48	0.29	1541	143	10500	1.5	0.84985	35	166.5	1.5
A4	92128174	8510	143	3728	48	0.27	3251	336	11184	1.2	0.81556	42	173.5	1.6
A5	92059531	8692	147	3838	48	0.18	458	134	11514	1.1	0.8017	45	176.5	1.2
A6	100571609	8751	147	3914	48	0.28	630	11	11742	1.8	0.83481	38	169.5	2
A7	115630552	9103	155	4034	48	0.23	932	304	12102	2.5	0.89274	27	158.5	1.26
A8	110988765	9201	158	4055	48	0.31	2545	50	12165	2.3	0.87616	30	161.5	1.3
A9	106705223	9271	159	4062	48	0.28	2448	22	12186	1.34	0.82507	40	171.5	1.45
A10	128930329	9602	162	4181	48	0.26	1421	283	12543	2	0.86544	32	163.5	1.22

**Keys:** Op = Oil in Place, Temp. = Temperature, Pre. = Pressure, Thic. = Thickness, Por. = Porosity, Perm. = Permeability, CT = Caprock Thickness, WD = Well Density lb/ft<sup>3</sup>, OV = Oil Viscosity.

**Table 2.** Site selection criteria for ensuring the safety and security of CO<sub>2</sub> storage (Bachu *et al.*, 2003).

Criterion level	No	Criterion	Eliminatory or unfavourable	Preferred or favourable
Critical	1	Reservoir-seal pairs; Extensive and competent barrier to vertical flow	Poor, discontinuous, faulted and/or breached	Intermediate and excellent; many pairs (multi-layered system)
	2	Pressure regime	Overpressured: pressure gradients greater than 14 kPa/m	Pressure gradients less than 12 kPa/m
	3	Monitoring potential	Absent	Present
Desirable	8	Depth	< 750-800 m	>800 m
	11	Geothermal regime	Gradients $\geq 35$ °C/km and/or high surface temperature	Gradients < 35 °C/km and low surface temperature
	12	Temperature	< 35 °C	$\geq 35$ °C
	13	Pressure	< 7.5 MPa	$\geq 7.5$ MPa
	14	Thickness	< 20 m	$\geq 20$ m
	15	Porosity	< 10%	$\geq 10\%$
	16	Permeability	< 20 mD	$\geq 20$ mD
	17	Caprock thickness	< 10 m	$\geq 10$ m
	18	Well density	High	Low to moderate

and monitoring potential. Additional desirable criteria such as reservoir depth, geothermal gradient, temperature, pressure, thickness,

porosity, permeability, caprock thickness, and well density were also evaluated. Reservoirs that satisfied the favourable conditions specified in the

screening framework were considered suitable for carbon storage applications. The adopted screening criteria are summarized in Table 2.

**Table 3.** Suggested characteristics of oil reservoirs suitable for miscible CO<sub>2</sub>-EOR (metric values are given in brackets) (IPCC 2005)

Reservoir Parameter	Miscible CO <sub>2</sub> -EOR
Size (ROIP in MMstb; or MtCO <sub>2</sub> )	≥1 (whichever condition is met first)
Depth (ft/m)	>1500 (>450)
Temperature (°F/°C)	82 to 250 (28 to 121)
Pressure	> MMP and < P <sub>f</sub>
Porosity (%)	≥3
Permeability (Md)	≥5
Oil Gravity (API)	27 to 45
Oil Viscosity (cP/mPa·s)	≤6
Remaining Oil Fraction in the Reservoir	≥0.30

**Screening for CO<sub>2</sub>-enhanced oil recovery potential**

The selected reservoirs were further evaluated for their applicability to miscible CO<sub>2</sub>-enhanced oil recovery using the screening guidelines recommended by the Intergovernmental Panel on Climate Change (IPCC, 2005). Reservoir properties including reservoir size, depth, temperature, pressure, porosity, permeability, oil gravity, oil process included reservoir-seal integrity, pressure regime, viscosity, and remaining oil saturation were compared with the recommended criteria for successful miscible CO<sub>2</sub> flooding. The screening standards used for this assessment are presented in Table 3.

**Determination of minimum miscibility pressure (MMP)**

The minimum miscibility pressure (MMP) of the reservoir oils was calculated to determine the pressure condition required for achieving miscibility between injected CO<sub>2</sub> and reservoir oil. The calculated MMP values were subsequently compared with reservoir pressures to identify reservoirs favourable for miscible CO<sub>2</sub>-EOR operations.

The determination of MMP was based on empirical correlations involving reservoir temperature, oil API gravity, molecular weight of the heavier hydrocarbon fraction (C<sub>5</sub>+), and oil relative density. Equations 1 to 3 were employed in the calculation procedure.

$$MMP = -329.558 + (7.727MW * 1.005^T) - (4.377 * MW) \dots\dots\dots 1$$

$$MW = \left(\frac{8864.9}{G}\right) * \frac{1}{1.0386} \dots\dots\dots 2$$

$$G = \frac{141.5}{\gamma_o} - 131.5 \dots\dots\dots 3$$

Where: MMP = Minimum miscibility pressure (psia), MW = Molecular weight of C<sub>5</sub>+ fraction, G = API gravity of oil, ρ = Relative density of oil, T = Reservoir temperature (°F)

Reservoirs with operating pressures greater than the calculated MMP and within fracture pressure limits were

considered favourable candidates for miscible CO<sub>2</sub>-enhanced oil recovery.

**RESULTS AND DISCUSSION**

**Screening of Niger Delta reservoirs for CO<sub>2</sub> storage potential**

The selected Niger Delta reservoirs were evaluated using established geological screening criteria for carbon dioxide storage proposed by Bachu (2000, 2003) and the IPCC (2005). The screening parameters included reservoir-seal integrity, reservoir depth, geothermal regime, temperature, pressure, porosity, permeability, reservoir thickness, caprock thickness, and well density. The detailed screening results are presented in Table 4, while the summary classification of the reservoirs is illustrated in Figure 1.

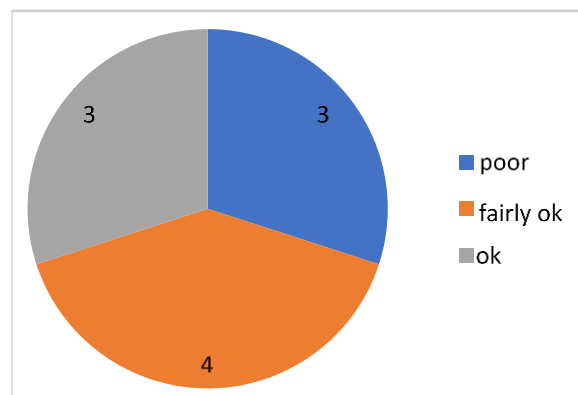
The screening results revealed that three reservoirs were classified as suitable (“OK”) for CO<sub>2</sub> storage, four reservoirs were categorized as fairly suitable, while three reservoirs were classified as poor candidates for geological carbon storage. The reservoirs identified as suitable exhibited favourable reservoir characteristics including adequate depth, high porosity, good permeability, sufficient caprock thickness, and acceptable pressure conditions. These characteristics are important because they enhance injectivity, storage capacity, and long-term containment of injected carbon dioxide (Bachu, 2000; Bradshaw *et al.*, 2007).

Reservoir depth is a critical factor in carbon sequestration because CO<sub>2</sub> must be injected at depths sufficient to maintain supercritical conditions, thereby maximizing storage efficiency and reducing buoyancy-driven leakage risks. All the reservoirs evaluated exceeded the minimum depth requirement recommended for geological storage operations. This observation agrees with the findings of Umar *et al.* (2020) and Davies *et al.* (2020), who reported that many Niger Delta reservoirs possess adequate burial depths favourable for carbon sequestration.

Porosity and permeability values recorded for the reservoirs also indicate favourable storage and injectivity

**Table 4.** Selected Niger Delta screened against suggested reservoir properties for CO<sub>2</sub> storage.

Criterion	A 1	A2	A3	A4	A5	A6	A7	A8	A9	A10
Reservoir-seal pairs	Poor	Intermediate	Excellent	Excellent	Intermediate	Poor	Excellent	Intermediate	Intermediate	Excellent
Pressure regime	9.580	9.971	9.742	9.909	10.185	10.427	10.076	9.969	9.910	9.849
Depth (m)	2392.924	2418.563	2476.831	2593.857	2649.330	2667.313	2774.603	2804.473	2825.809	2926.699
Geothermal regime°C/km	23.448	23.430026	24.000014	23.774247	24.11511	23.952561	24.62802	24.96012	24.96842	24.67695
Temperature (°C)	56.111	56.667	59.444	61.667	63.888	63.889	68.333	70.000	70.556	72.222
Pressure (Mpa)	22925068	24117861	24131651	25703655	26986080	27813451	27958241	27958241	28006504	28826980
Porosity (%)	24	25	29	27	18	28	23	31	28	26
Permeability (Md)	668	1241	1541	3251	458	630	932	2545	2448	1421
Thickness (m)	14.6304	15.849	73.456	12.496	6.0960	25.603	18.288	12.496	68.275	49.072
Caprock thickness	7.3152	11.008766	43.638	102.394	40.843	3.352	92.659	15.240	6.705	86.258
Well density	9975	9686.77	2091.29	13093.5	27633.6	6709.71	9681.6	14242	9681.6	6709.71
Field screening remark based on CO <sub>2</sub> storage capacity	poor	Fairly ok	Ok	Fairly ok	Fairly ok	Poor	Ok	poor	Fairly ok	Ok

**Figure 1.** Oil field screening for CO<sub>2</sub> storage.

characteristics. High porosity enhances storage capacity, while permeability controls the ease of CO<sub>2</sub> injection and migration within the reservoir. Most of the evaluated reservoirs exhibited porosity and permeability values significantly above the minimum thresholds recommended for CO<sub>2</sub> sequestration projects. Similar observations were reported by Ojo and Tse (2016), Agunbiade *et al.*

(2023), and Eigbe *et al.* (2024), who demonstrated that depleted reservoirs within the Niger Delta possess suitable petrophysical characteristics for carbon storage applications.

Caprock integrity remains one of the most important criteria for successful geological carbon storage because it determines the ability of the reservoir to prevent upward migration and leakage of injected carbon dioxide. The reservoirs classified as poor candidates generally exhibited inadequate caprock thickness, which may compromise long-term containment security. Thin or discontinuous caprocks increase the possibility of CO<sub>2</sub> leakage through fractures, faults, or abandoned well pathways (Lindeberg, 1997; Chadwick *et al.*, 2008). Consequently, reservoirs with poor caprock characteristics were considered unsuitable for long-term storage operations. This observation is consistent with the work of Ajidahun *et al.* (2026), which emphasized the importance of structural integrity and sealing efficiency in reservoir selection for CO<sub>2</sub> sequestration.

The pressure and geothermal conditions of the reservoirs also indicate favourable subsurface environments for carbon storage. Reservoir

pressures were sufficiently high to maintain injected CO<sub>2</sub> in dense phases, thereby improving storage efficiency and injectivity performance. Temperature gradients obtained from the reservoirs are within acceptable ranges for geological storage operations and compare favourably with values reported in previous Niger Delta sequestration studies (Maduwesi *et al.*, 2024; Mutadza *et al.*, 2025a).

Overall, the screening assessment indicates that a significant proportion of the selected Niger Delta reservoirs possess favourable geological and petrophysical conditions for carbon dioxide storage. The results support earlier studies by Momodu *et al.* (2022) and Effiom *et al.* (2024), which identified depleted hydrocarbon reservoirs in the Niger Delta as viable candidates for large-scale CCS implementation.

#### Minimum miscibility pressure (MMP) evaluation for CO<sub>2</sub>-EOR

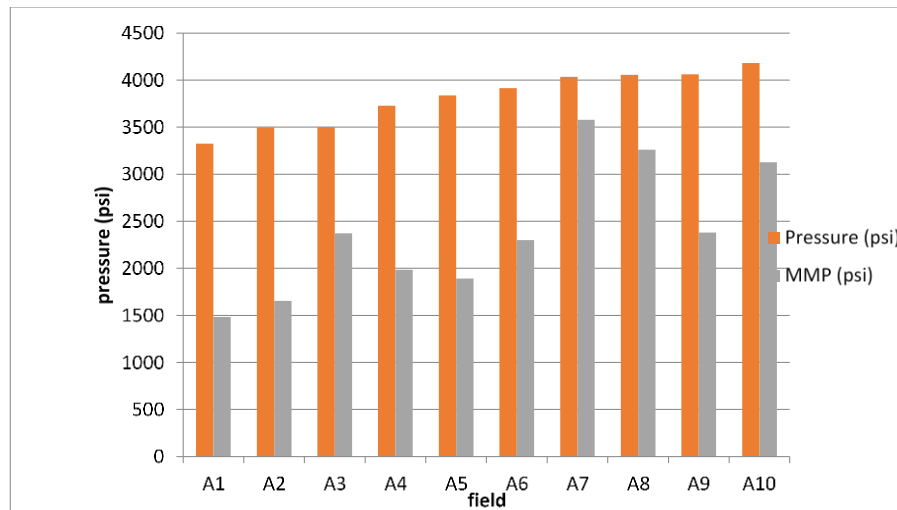
The minimum miscibility pressure (MMP) values calculated for the selected reservoirs are presented

**Table 5.** Parameter for calculating minimum miscibility pressure

G (Oil gravity °API)	MW	MMP (psi)
50	170.7086	1483.915
46	185.5529	1655.524
35	243.8695	2372.241
42	203.2246	1985.234
45	189.6763	1891.178
38	224.6166	2300.261
27	316.1271	3578.661
30	284.5144	3259.638
40	213.3858	2380.468
32	266.7323	3126.642

**Table 6.** Comparison of reservoir pressure with minimum miscibility pressure.

Reservoir	Pressure (psi)	MMP (psi)	P/MMP	Remark
A1	3325	1483.915	2.240695073	Good prospect
A2	3498	1655.524	2.112925594	Good prospect
A3	3500	2372.241	1.475398296	Good prospect
A4	3728	1985.234	1.877864306	Good prospect
A5	3838	1891.178	2.029422597	Good prospect
A6	3914	2300.261	1.701545808	Good prospect
A7	4034	3578.661	1.127237233	Good prospect
A8	4055	3259.638	1.244003279	Good prospect
A9	4062	2380.468	1.706386993	Good prospect
A10	4181	3126.642	1.33721726	Good prospect

**Figure 2.** Comparison between reservoir pressure and MMP.

in Table 5, while the comparison between reservoir pressure and MMP is shown in Table 6 and Figures 2 and 3. MMP is one of the most important parameters in evaluating the feasibility of miscible CO<sub>2</sub>-enhanced oil recovery because it defines the minimum pressure required for injected CO<sub>2</sub> to achieve miscibility with reservoir oil.

The calculated MMP values varied across the reservoirs due to differences in oil gravity, reservoir temperature, and molecular weight of heavier hydrocarbon fractions. Reservoirs with lighter oils generally recorded lower MMP values, while reservoirs containing relatively heavier oils exhibited higher MMP values. This trend agrees with the

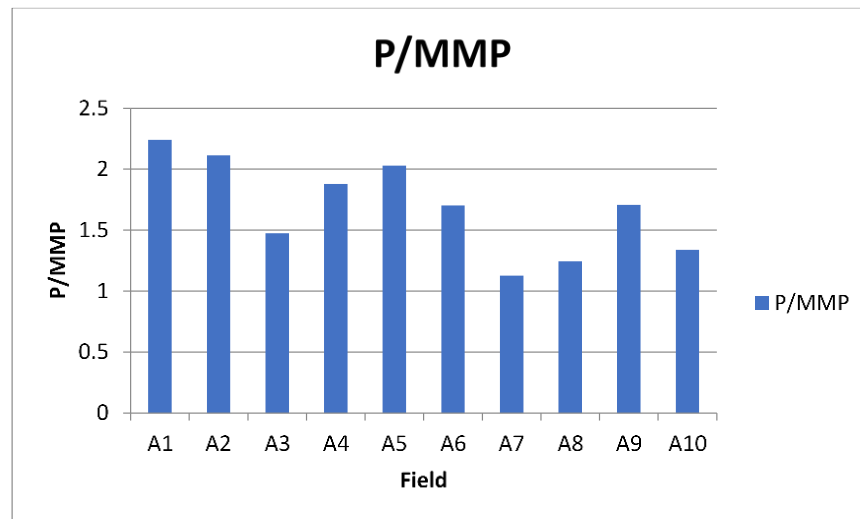


Figure 3. Ratio of P/MMP.

observations of Kovscek and Cakici (2005) and Salehpour *et al.* (2020), who reported that oil composition and reservoir temperature significantly influence miscibility behaviour during CO<sub>2</sub> flooding.

Comparison of reservoir pressure with MMP indicates that all evaluated reservoirs possessed pressure values greater than their corresponding MMP values. The pressure-to-MMP ratios shown in Figure 3 were all greater than unity, indicating favourable conditions for miscible CO<sub>2</sub> flooding. Reservoirs with pressure conditions above MMP are expected to achieve efficient oil displacement, improved sweep efficiency, and enhanced recovery performance during CO<sub>2</sub> injection operations (Tzimas *et al.*, 2005).

The favourable miscibility conditions obtained in this study suggest that injected CO<sub>2</sub> would effectively interact with reservoir oil through mechanisms such as oil swelling, viscosity reduction, and interfacial tension reduction. These mechanisms improve oil mobility and increase hydrocarbon recovery efficiency. Similar results were reported by Odesa and Adewale (2011), who demonstrated that several offshore Niger Delta reservoirs possess favourable miscibility conditions for CO<sub>2</sub>-EOR implementation.

Although all reservoirs met the miscibility requirement, reservoirs with higher pressure-to-MMP ratios are expected to exhibit better displacement efficiency and more stable miscible flooding behaviour. Reservoirs with ratios closer to unity may still experience partial miscibility under certain operating conditions, which could reduce sweep efficiency and incremental oil recovery. Nevertheless, the results generally indicate strong prospects for miscible CO<sub>2</sub>-EOR operations within the evaluated fields.

### Screening of reservoirs for CO<sub>2</sub>-enhanced oil recovery potential

The selected reservoirs were further screened using

standard CO<sub>2</sub>-EOR screening criteria, including reservoir size, depth, temperature, pressure, porosity, permeability, oil gravity, oil viscosity, and remaining oil fraction. The screening results are presented in Table 7, while the overall assessment summary is illustrated in Figure 4.

The results show that eight reservoirs were classified as good candidates for CO<sub>2</sub>-EOR, while two reservoirs were categorized as average candidates. The reservoirs classified as good prospects satisfied most of the recommended screening criteria for miscible CO<sub>2</sub> flooding, including adequate reservoir size, favourable pressure conditions, acceptable oil gravity, low oil viscosity, and sufficient remaining oil saturation.

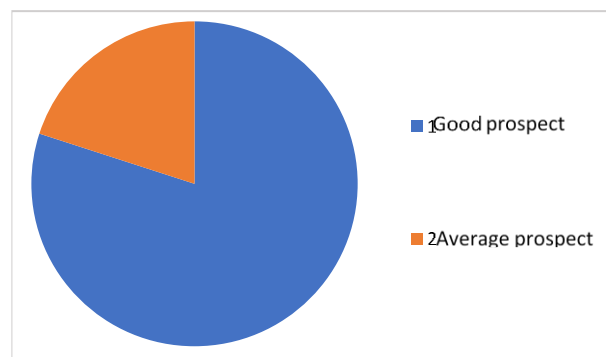
Reservoir size is an important economic consideration for CO<sub>2</sub>-EOR projects because larger reservoirs generally provide greater incremental oil recovery and improved economic returns. All evaluated reservoirs possessed substantial reserves of oil initially in place, indicating strong economic potential for tertiary recovery operations. This observation agrees with the findings of Godec *et al.* (2011) and Leach *et al.* (2011), who emphasized that reservoir size strongly influences the commercial viability of combined CO<sub>2</sub>-EOR and carbon storage projects.

Oil gravity and viscosity values obtained from the reservoirs also indicate favourable conditions for CO<sub>2</sub> flooding. Most reservoirs contained light to medium crude oils with relatively low viscosities, which enhance miscibility and improve oil displacement efficiency during CO<sub>2</sub> injection. Light oils generally require lower miscibility pressures and exhibit better recovery performance than heavier oils (Adu *et al.*, 2019; Yu *et al.*, 2024).

The two reservoirs classified as average candidates failed to fully satisfy the remaining oil fraction criterion. Remaining oil saturation is an important parameter because CO<sub>2</sub>-EOR becomes economically attractive only when sufficient residual oil remains within the reservoir after primary and secondary recovery operations. Reservoirs with low remaining oil fractions may not generate sufficient

**Table 7.** Selected Niger Delta screened against suggested reservoir properties for CO<sub>2</sub>-EOR.

Reservoir Parameter	Miscible CO <sub>2</sub> -EOR	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
Size (ROIP in MMstb)	≥1	98428539	101186818	435001776	78692815	38358138	176000315	144538190	94802903	497957706	432453812
Depth (ft)	>1500	7851	7935	8126	8510	8692	8751	9103	9201	9271	9602
Temperature (°F)	82 to 250	133	134	139	143	147		155	158	159	162
Pressure (psi)	> MMP and < P <sub>f</sub>	3325	3498	3500	3728	3838	3914	4034	4055	4062	4181
Porosity (%)	≥3	24	25	29	27	18	28	23	31	28	26
Permeability (Md)	≥5	668	1241	1541	3251	458	630	932	2545	2448	1421
Oil Gravity (API)	27 to 45	50	46	35	42	45	38	27	30	40	32
Oil Viscosity (cP/mPa·s)	≤6	0.8	1	1.5	1.2	1.1	1.8	2.5	2.3	1.34	2
Remaining Oil Fraction in the Reservoir	≥0.30	0.37	0.45	0.021	0.473	0.283	0.753	0.471	0.854	0.879	0.655
Remark		Good	Good	Average	Good	Average	Good	Good	Good	Good	Good

**Figure 4.** Summary of assessment for fields that have prospect of CO<sub>2</sub>-EOR.

incremental oil recovery to justify project costs. Similar conclusions were reported by Chen and Pawar (2019), who noted that residual oil saturation strongly influences CO<sub>2</sub>-EOR performance and storage efficiency.

The porosity and permeability characteristics of the reservoirs further support their suitability for CO<sub>2</sub> flooding operations. High permeability values promote injectivity and fluid movement, while adequate porosity improves reservoir storage

capacity for injected CO<sub>2</sub>. These favourable reservoir properties are consistent with studies by Mutadza *et al.* (2025b) and Davies *et al.* (2020), which identified the Niger Delta Basin as a promising region for combined CO<sub>2</sub> sequestration and enhanced oil recovery operations.

The overall screening results demonstrate that the majority of the selected Niger Delta reservoirs possess strong technical potential for integrated CO<sub>2</sub>-EOR and carbon storage projects. The findings support previous studies by Ogbeiwi and Stephen (2023) and Effiom *et al.* (2024), which concluded that CO<sub>2</sub>-EOR could serve as a viable strategy for reducing greenhouse gas emissions while simultaneously improving oil recovery and economic performance in Nigeria's petroleum sector.

#### Economic implications of CO<sub>2</sub>-EOR and carbon storage

The economic evaluation indicates that integrated CO<sub>2</sub>-EOR and storage projects could be economically feasible within the selected Niger Delta reservoirs. Economic assessment

considered major cost components including CO<sub>2</sub> capture and compression, transportation, storage, monitoring, and revenue generated from incremental oil production. Based on the estimated world oil price used in the analysis, projected revenues from additional oil recovery significantly exceeded the estimated operational costs.

This finding suggests that revenue generated from incremental hydrocarbon production could offset the cost of carbon storage operations while providing additional economic benefits. Similar conclusions were reached by Ogbeiwi and Stephen (2023) and Leach *et al.* (2011), who demonstrated that combined CO<sub>2</sub>-EOR and sequestration projects often become economically attractive when supported by favourable oil prices and existing infrastructure.

The availability of mature oil fields, existing production facilities, and transportation networks within the Niger Delta further improves the economic attractiveness of CCS and CO<sub>2</sub>-EOR implementation. Existing infrastructure reduces initial capital investment requirements and facilitates integration of carbon management technologies into ongoing petroleum operations.

## Technical challenges associated with CO<sub>2</sub>-EOR and carbon storage

Despite the favourable screening results, several technical challenges may affect the successful implementation of CO<sub>2</sub>-EOR and carbon storage operations within the Niger Delta reservoirs. One major challenge is poor sweep efficiency resulting from reservoir heterogeneity, gas override, mobility contrast, and early CO<sub>2</sub> breakthrough. Highly heterogeneous reservoirs may cause uneven CO<sub>2</sub> distribution and reduced displacement efficiency during flooding operations.

Reservoirs containing extensive vertical fractures may also experience out-of-zone CO<sub>2</sub> migration and early gas breakthrough, thereby reducing oil recovery performance and storage efficiency. Similarly, reservoirs with extremely high permeability and thickness may experience gravity segregation effects, causing inefficient sweep and reduced contact between injected CO<sub>2</sub> and reservoir oil.

Corrosion associated with CO<sub>2</sub> injection represents another major operational concern. Carbon dioxide can react with water to form carbonic acid, leading to severe corrosion of pipelines, well tubing, production facilities, and injection equipment. Offshore operations may experience additional challenges relating to platform modifications, equipment integrity, and increased operational complexity (Galadima and Garba, 2008).

Well spacing and reservoir management also influence the effectiveness of CO<sub>2</sub>-EOR projects. Large well spacing may reduce sweep efficiency and delay incremental oil production, while drilling additional wells increases project costs. Consequently, careful reservoir characterization, monitoring, and optimized injection strategies are necessary to improve project performance and ensure long-term storage security.

Overall, the study demonstrates that many depleted reservoirs within the Niger Delta possess significant potential for integrated carbon storage and enhanced oil recovery operations. However, successful implementation will require detailed reservoir characterization, effective monitoring systems, economic optimization, and appropriate regulatory frameworks to address the technical and environmental challenges associated with CO<sub>2</sub> injection and long-term geological storage.

## Conclusion

This study evaluated the potentials of carbon storage and enhanced oil recovery in selected depleted reservoirs within the Niger Delta region using established geological and CO<sub>2</sub>-EOR screening criteria. The results demonstrated that many of the evaluated reservoirs possess favourable geological and petrophysical characteristics suitable for carbon dioxide sequestration and miscible CO<sub>2</sub>-enhanced oil recovery operations.

The screening assessment showed that three reservoirs

were highly suitable for carbon storage, while four reservoirs were fairly suitable based on parameters such as reservoir depth, porosity, permeability, pressure conditions, and caprock integrity. Reservoirs classified as poor candidates were mainly limited by inadequate caprock thickness, which could compromise long-term containment of injected CO<sub>2</sub>.

Minimum miscibility pressure analysis indicated that reservoir pressures in all evaluated fields exceeded the calculated MMP values, confirming favourable conditions for miscible CO<sub>2</sub> flooding. Furthermore, eight reservoirs were identified as good candidates for CO<sub>2</sub>-enhanced oil recovery due to favourable oil gravity, low oil viscosity, adequate permeability, and sufficient remaining oil saturation. The economic evaluation also revealed that incremental oil production from CO<sub>2</sub>-EOR operations could potentially offset carbon storage costs and improve project profitability.

Despite the favourable prospects, the study identified several technical challenges including reservoir heterogeneity, poor sweep efficiency, gravity segregation, early CO<sub>2</sub> breakthrough, and corrosion-related operational concerns. Nevertheless, the findings confirm that the Niger Delta Basin possesses substantial potential for integrated carbon capture, storage, and enhanced oil recovery projects capable of supporting both environmental sustainability and improved hydrocarbon recovery.

## Recommendations

1. Detailed reservoir characterization and simulation studies should be conducted on the identified suitable reservoirs to improve understanding of CO<sub>2</sub> injection behaviour, storage capacity, and long-term containment performance.
2. Pilot-scale CO<sub>2</sub>-EOR and carbon storage projects should be implemented in selected Niger Delta reservoirs to evaluate operational feasibility and optimize injection strategies under field conditions.
3. Government and regulatory agencies should develop comprehensive policies, monitoring frameworks, and fiscal incentives to encourage investment in carbon capture, storage, and enhanced oil recovery technologies in Nigeria.

## CONFLICTS OF INTEREST

The authors declare that they have no conflict of interest.

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