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Comprehensive evaluation of carbon capture and storage (CCS) in X field, Vietnam: A technical, economic, and sensitivity analysis

TA Quoc Dung[1,2*], BUI Trong Vinh[1,2]

[1] Faculty of Geology and Petroleum Engineering, Ho Chi Minh City University of Technology, Ho Chi Minh City, Vietnam.
[2] Vietnam National University Ho Chi Minh City, Ho Chi Minh City, Vietnam
Corresponding author: tqdung@hcmut.edu.vn

Abstract: *This paper explores the feasibility of deploying Carbon Capture and Storage (CCS) in X Field, located in Vietnam's Cuu Long Basin. Geological analysis reveals that Miocene sandstone formations with high porosity and secure shale caprock make X Field ideal for storing up to 39 million tonnes of CO2. Integrating CCS with Enhanced Oil Recovery (EOR) boosts economic viability by generating significant revenue from increased oil production, enhancing both financial returns and energy security.The project's success depends on effectively managing key factors like oil prices, CO2 capture costs, and storage efficiency. Strong regulatory frameworks and active public engagement are also essential. CCS in X Field presents a strategic opportunity for Vietnam to achieve its climate targets while driving economic growth and ensuring energy stability.*

Keywords: *Carbon Capture and Storage (CCS), Enhanced Oil Recovery (EOR), CO2 Storage Capacit, CO2 Capture Costs*

1 Introduction

1.1 Literature Review

Carbon Capture and Storage (CCS) is a crucial technology in global efforts to mitigate CO2 emissions, especially in high-emission sectors like power generation, steel manufacturing, and cement production. The fundamental process of CCS involves capturing CO2 at the source, transporting it via pipelines or other means, and injecting it into deep underground geological formations for long-term storage. This technology has the potential to capture up to 90% of CO2 emissions, making it a critical tool in the transition to a low-carbon economy [4,5,6]

Multiple studies, including the CO2 Sequestration work [2,3] emphasize that CCS not only reduces emissions from stationary industrial sources but also helps balance the energy transition by allowing the continued use of fossil fuels in a less harmful way. Additionally, integrating CCS with Enhanced Oil Recovery (EOR) can improve its economic feasibility by using injected CO2 to increase oil production, as shown in global CCS projects [8]. The literature also highlights the importance of site selection, infrastructure development, and regulatory frameworks in CCS deployment. For instance, the research results in Vietnam underlines the role of geological factors, such as reservoir depth, porosity, and caprock integrity, which are key to ensuring the long-term safety and effectiveness of CO2 storage[1,2,11]. Successful CCS implementation requires substantial investments in CO2 transport infrastructure, such as pipelines, and advanced monitoring technologies to ensure that CO2 remains securely stored [8,4,5].

Financial viability remains a significant challenge, as outlined in the Economic Value of CO2 for EOR Applications [4,8,10]. CCS projects tend to have high upfront costs, particularly for capture technology and storage infrastructure, but they can become more economically attractive when combined with policies like carbon pricing or through revenue from EOR In summary, the literature suggests that CCS is a viable and necessary technology for industries seeking to reduce their carbon footprint [6,9,12]. However, its success depends on favourable economics, strong regulatory frameworks, and technological advancements to reduce costs and ensure safe, long-term CO2 storage.

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1.2 Relevance of CCS in Vietnam

Vietnam's fast-growing economy and heavy reliance on coal for energy generation have positioned the country as a significant emitter of CO2. The country's commitment to reducing greenhouse gas emissions, as outlined in its Nationally Determined Contributions (NDCs) under the Paris Agreement, underscores the urgency of adopting technologies like Carbon Capture and Storage (CCS) to meet its climate objectives. CCS is particularly suited to industries such as power generation and cement production, which are major sources of emissions in the country [7]

Vietnam's geography offers several promising locations for CCS deployment, with the Cuu Long Basin standing out due to its favourable geological characteristics. Studies on the basin indicate the presence of deep saline aquifers and oil reservoirs that could serve as effective CO2 storage sites [1], [11]. In particular, X Field in the Cuu Long Basin is ideally located near industrial CO2 emitters, reducing transport costs and enhancing the feasibility of CCS study.

Moreover, integrating CCS with Enhanced Oil Recovery (EOR) in these oil-rich regions could provide Vietnam with additional economic benefits by increasing oil production while simultaneously sequestering CO2. This dual benefit makes CCS a strategic tool not only for reducing emissions but also for supporting energy security and economic development [2,4,8]. Given the country's reliance on coal and other fossil fuels, CCS presents a key opportunity for Vietnam to transition toward a low-carbon economy while maintaining industrial growth.

1.3 Objectives of the Study

The objectives of this study are to:

- Evaluate the geological suitability of X Field in the Cuu Long Basin (figure 1) for long-term CO2 storage, focusing on critical factors such as reservoir depth, porosity, and caprock integrity.
- Analyze the technical feasibility of CO2 capture, transport, and injection in the context of X Field, considering the infrastructure required for effective CO2 management.
- Perform an economic evaluation, with particular emphasis on the integration of Enhanced Oil Recovery (EOR) to offset the costs of CCS deployment, enhancing the financial viability of the study.
- Conduct a sensitivity analysis to assess the impact of key variables such as oil prices and CO2 capture costs on the overall profitability and sustainability of the study.
- Draw lessons from international CCS projects and adapt these insights to the development of CCS in Vietnam, ensuring that the country can implement best practices and avoid common challenges faced in global CCS efforts.

2 Geological and Technical Analysis

2.1 Geological Overview of X Field

X Field, situated within the Cuu Long Basin offshore southern Vietnam, presents highly favorable geological conditions for CO2 storage, making it a prime candidate for Carbon Capture and Storage (CCS) initiatives. The Cuu Long Basin, shaped by a complex history of transtensional and compressional tectonic events during the Tertiary period, is characterized by Miocene sandstone formations that serve as the primary reservoir. These formations exhibit exceptional porosity ranging from 15% to 25% and high permeability, as documented in multiple studies ([1], [15], [16]). Such properties facilitate efficient CO2 injection and storage, enhancing the field's capacity to accommodate large volumes of supercritical CO2.

A critical feature of X Field is its robust caprock integrity, provided by thick shale layers overlying the reservoir, as illustrated in the regional seismic section (Figure 2). This shale caprock acts as an impermeable barrier, effectively trapping injected CO2 and preventing its upward migration. Research on the basin's tectonic evolution underscores its structural stability, with minimal faulting in the storage zone, further reinforcing the reliability of X Field for long-term CO2 containment ([15]). The combination of a high-porosity sandstone reservoir and a thick, sealing shale caprock ensures both storage efficiency and security, aligning with the geological requirements for successful CCS deployment ([1], [15]).

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To expand on the geological context, the reservoir in X Field is estimated to lie at a depth of approximately 2750 meters, based on typical depths of clastic structures in the Cuu Long Basin ([16]). The oil within the reservoir is classified as light crude, with an 35^0API, consistent with the paraffinic oils commonly found in the region.

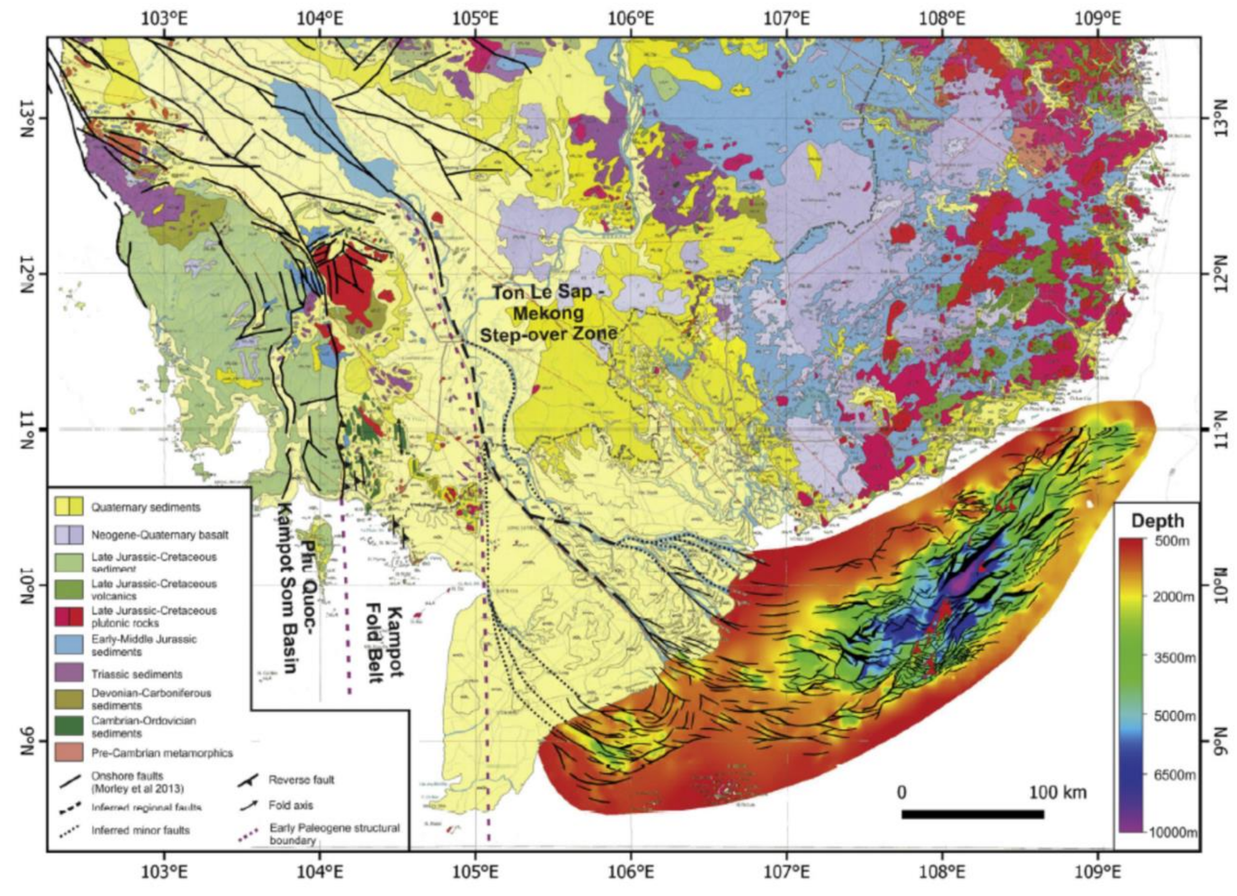

Fig. 1. Geologic map (15)

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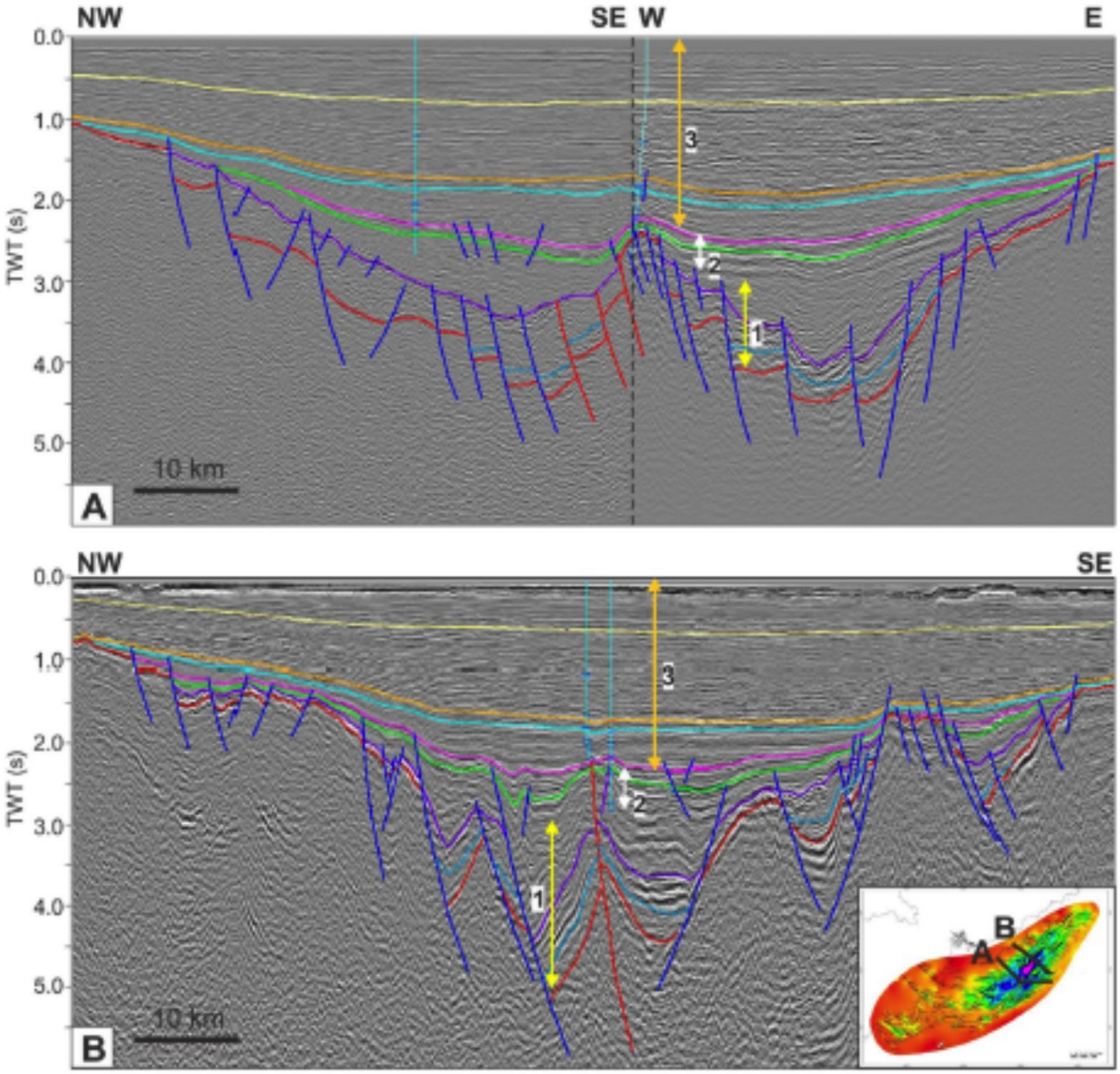

Fig. 2. Regional seismic section across the Cuu Long Basin (15)

2.2 CO2 Storage Capacity Calculation

Using the volumetric storage capacity method, the estimated CO2 storage capacity of X Field can be calculated as follows:

$$Capacity = A \times \Phi \times h \times \rho_{CO2} \times EF$$

Where:

- ✔ A = 25 km² (reservoir area),
- ✔ h = 100 meters (reservoir thickness),
- ✔ Φ = 15% (porosity),
- ✔ EF = 0.2 (efficiency factor)
- ✔ ρ_{CO2} = 650 kg/m³ (density of CO2 in a supercritical state).

By substituting these values:

$Capacity = (25\times10^{6})\times0.12\times100\times650\times0.2 = 39000\times10^{6} kg = 39$ million tonnes of CO2

Thus, X Field has an estimated CO2 storage capacity of 39 million tonnes, making it a highly promising site for intermediate -scale CCS deployment.

3 Economic Analysis

3.1 Capital Expenditures (CAPEX)

The estimated capital expenditures (CAPEX) for the CCS study in X Field include [10]:

- ✔ CO2 Capture Facility: $500 million for installing post-combustion capture technology at nearby industrial facilities [10]
- ✔ CO2 Transport Infrastructure: $100 million for constructing a 200-kilometer pipeline to transport CO2 from the capture site to X Field.
- ✔ Injection Wells: $75 million total for five Class VI injection wells, each costing approximately $15 million

3.2 Operational Expenditures (OPEX)

The ongoing operational costs include:

- ✔ CO2 Capture Costs: $65 per tonne of CO2 captured [10]
- ✔ Transport Costs: $10 per tonne for transporting CO2 via pipeline
- ✔ Storage and Monitoring Costs: $15 per tonne of CO2 for injection and continuous monitoring.

3.3 Economic Viability with Enhanced Oil Recovery (EOR)

By integrating EOR into the CCS study, the economic viability is significantly improved. For every tonne of CO2 injected into the reservoir, approximately 7 barrels of oil are recovered. With oil base priced at $70 per barrel, the revenue per tonne of CO2 injected can be calculated as 490 USD/tonne of CO_2

Given an annual injection rate of 5 million tonnes of CO2, the total annual revenue from EOR is 2.45 billion USD/year. This substantial revenue from oil production greatly offsets the cost of CO2 capture, transport, and storage, making the integration of CCS and EOR financially attractive for the X Field study.

4 Sensitivity Analysis

4.1 Sensitivity to Oil Prices

The financial viability of the study is closely tied to fluctuations in oil prices, which directly affect the revenue generated through EOR. The sensitivity analysis reveals the following impacts:

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- ✔ 10% increase in oil price: $77 per barrel → 15% increase in NPV.
- ✔ 10% decrease in oil price: $63 per barrel → 12% decrease in NPV.

The reliance on EOR means that changes in oil prices can have a significant impact on the profitability of the CCS study.

4.2 Sensitivity to CO2 Capture Costs

The cost of capturing CO2 represents a major portion of the study's operational expenditures. Variations in capture costs have the following effects:

- ✔ 10% increase in capture cost: $71.50 per tonne → 8% decrease in NPV.
- ✔ 10% decrease in capture cost: $58.50 per tonne → 9% increase in NPV.

Advancements in capture technology or economies of scale that reduce capture costs will have a positive impact on the overall economic viability.

4.3 Sensitivity to Storage Efficiency

Increasing the CO2 storage efficiency (the fraction of the reservoir effectively used for storage) leads to the following outcomes:

- ✔ 10% increase in storage efficiency results in a 10% increase in total storage capacity.

This improvement would allow for more CO2 to be stored without significant additional investment in new infrastructure, further enhancing the economic feasibility of the study.

4.4 Summary of Sensitivity Results

The table below summarizes the impacts of key variables on the study's Net Present Value (NPV):

Variable	Change	Impact on NPV
Oil Price	±10%	±12-15% change in NPV
Capture Cost	±10%	±8-9% change in NPV
Storage Efficiency	+10%	+10% increase in storage capacity

The study is most sensitive to oil prices, followed by capture costs, and finally storage efficiency. Optimizing these factors will further improve the financial feasibility of the CCS study in X Field.

5 Lessons Learned for Vietnam

Vietnam's CCS success requires strong regulatory oversight with legal frameworks and monitoring (seismic, pressure tests) to ensure safe CO2 storage, financial incentives like carbon pricing and subsidies to offset costs, and well-planned infrastructure, including pipelines and advanced tech, for efficient transport and containment; integrating CCS with EOR in oil-rich Cuu Long Basin boosts profitability while balancing environmental and economic goals, supported by public engagement campaigns to build trust and long-term monitoring with leak detection, funded to secure safety for decades.

6 Conclusion

The deployment of Carbon Capture and Storage (CCS) technology in X Field, located in Vietnam's Cuu Long Basin, shows strong potential for long-term carbon sequestration. The Miocene sandstone formations, with high porosity and reliable shale caprock, provide an estimated storage capacity of 39 million tonnes of CO_2, making X Field suitable for intermediate-scale CCS study.

Integrating CCS with Enhanced Oil Recovery (EOR) significantly improves economic viability. EOR enables the recovery of approximately 7 barrels of oil per tonne of CO_2 injected, generating about $2.45 billion in annual revenue, which offsets CCS costs and supports Vietnam's energy security.

The sensitivity analysis shows that oil prices, CO_2 capture costs, and storage efficiency are key factors affecting economic success. A 10% change in oil prices or capture costs has a substantial impact on Net Present Value (NPV), highlighting the importance of managing these variables. Improved storage efficiency can further enhance the study's feasibility.

Lessons from international CCS projects stress the importance of regulatory frameworks, financial incentives, and public engagement. Clear regulations, carbon pricing, and public awareness campaigns are essential for successful implementation.

In conclusion, CCS in X Field offers Vietnam a promising opportunity to meet climate goals and enhance energy security. Integrating EOR provides both emissions reduction and increased oil production. Addressing key economic factors and leveraging best practices will be crucial for the study's success and for setting a precedent for future CCS initiatives in the region.

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