Introduction

The energy transition in Southeast Asia faces a significant challenge in balancing energy security, affordability, and environmental sustainability. As the region undergoes economic development, natural gas is considered a transitional fuel to reach net zero emissions due to its lesser environmental effect and the region's abundant resources. However, many upstream projects are extracting from high-acid gas fields, which are anticipated to become the primary source of hydrocarbon production in the coming years, as shown in Figure 1. This shift is expected to increase the region's greenhouse gas (GHG) emissions from upstream oil and gas production, projected to reach 128 million metric tons of CO_2 equivalent by 2050. Notably, approximately 94% of these emissions will result from reservoir CO_2 venting. To mitigate the rise in emissions from high-acid gas monetization, it is crucial to integrate carbon capture and storage (CCS) into development plans, especially as jurisdictions commit to achieving climate targets.

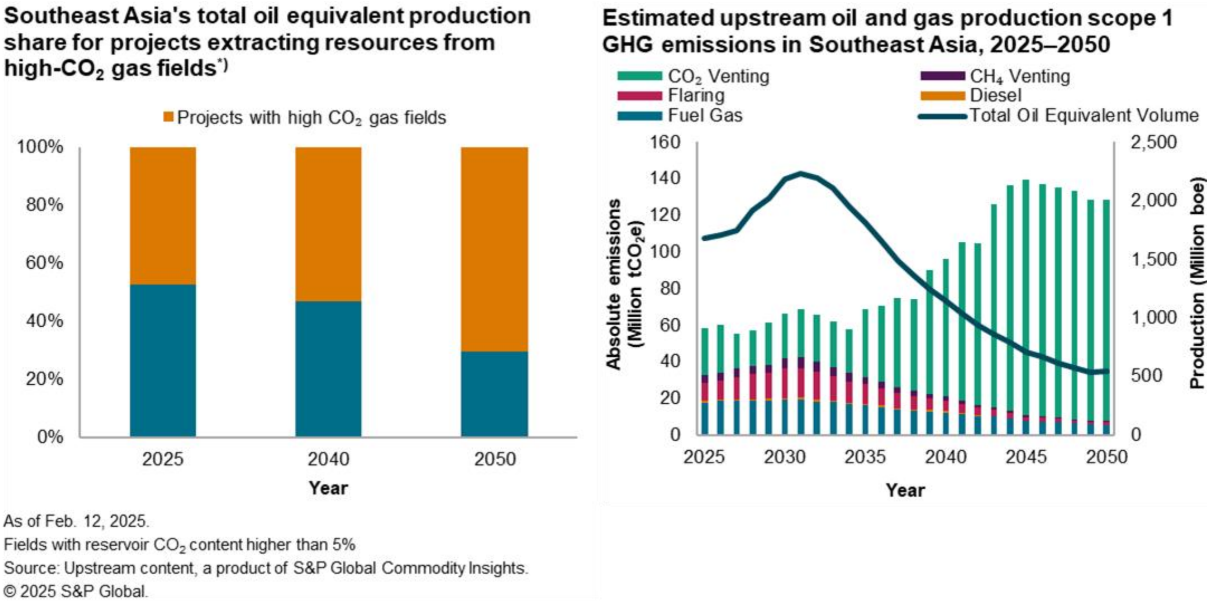

Figure 1 *Forecast of Southeast Asia's production volume shares of upstream projects extracting from high-CO_2 fields and the overall estimated upstream production emissions impact from 2025 to 2050*

To maximize the benefits of acid gas monetization and minimize environmental effect, it is important to consider matching CO_2 venting emissions with geological CO_2 storage potential. As operators have more available data for decision making on explored area, this study examines depleted/depleting fields and dry structures in Southeast Asia. The aim is to align these geological potentials with estimated CO_2 venting emissions from upstream oil and gas production, therefore identifying possible CO_2 emissions abatement opportunities. Moreover, cost analysis of select matched upstream projects and storage potential are explored.

Method

The primary objective of this study is to conduct source-to-sink analysis and matching of CO_2 venting emissions from upstream projects expected to be onstream between 2025 and 2050 in Southeast Asia. The overall workflow of our methodology is presented in Figure 2.

The forecast upstream oil and gas projects' production curve and the time-series annual GHG emissions profile for the projects are obtained from Vantage®, from S&P Global Commodity Insights, which estimates the production and emissions based on project and field characteristics. Specific for the CO_2 venting emissions, the estimated average CO_2 content of the gas and typical sales gas specification for each jurisdiction is used to estimate the Scope 1 GHG emissions arising from CO_2 removal in upstream production.

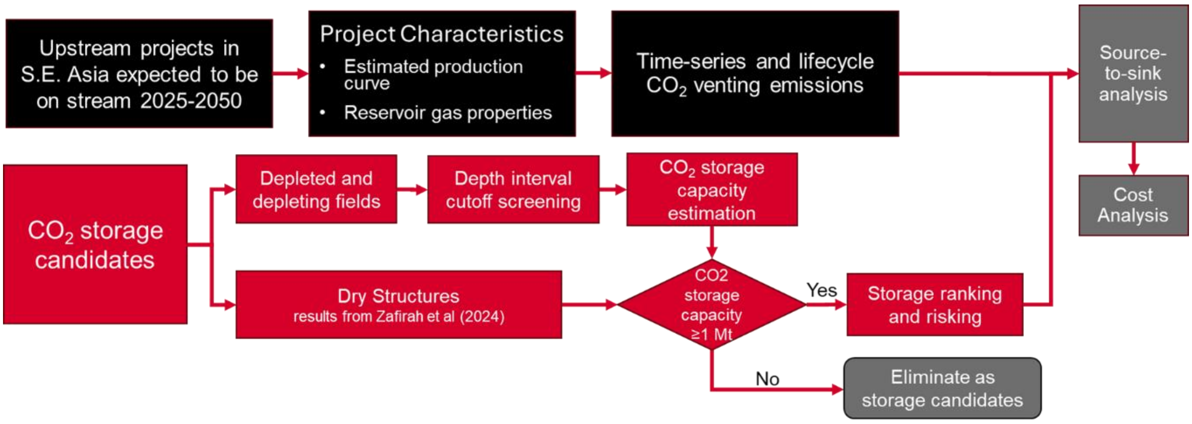

Figure 2. *Workflow of methodology for CO_2 storage estimation and source-to-sink analysis*

As the geological CO_2 storage candidates, depleted/depleting oil and gas fields are defined as fields with Np/Ult ≥55% filtered from fields within the region that is located at a depth of 800-2500 m, which is the interval between CO_2 supercritical depth and overpressure cutoff depth (Zhu, 2024). The CO_2 storage capacity for screened oil and gas fields is estimated by the USGS (Brennan, 2010) oil and gas reservoirs capacity replacement storage methodology below

$$KRR_{SR} = [((KR_{OIL} + KR_{NGL}) \times FVF_{OIL} \times E_{OIL}) + (KR_{GAS} \times FVF_{GAS} \times E_{GAS})] \times \rho_{CO_2}$$

KRR_{SR} represents the known recovery replacement storage resource, while KR is the known recovery at standard conditions. FVF is the formation volume factor, converting surface volumes to volumes at reservoir conditions. E is the buoyant storage efficiency, and ρCO_2 is the density of CO_2 at reservoir conditions. The index of *OIL*, *NGL*, and *GAS* represent the hydrocarbon type. For dry structures storage candidates and volume, the methodology and result from Razali et al (2024) is used. The storage candidates that have capacity above 1 million metric tons of CO_2 are risked and ranked based on the framework adapted from Zhu et al (2024) that evaluates storage based on two categories: capacity and injectivity, and containment.

Table 1 *Risking and ranking framework for depleted oil and gas reservoirs, adapted from Zhu (2024)*

Category	Criteria	Ranking		
		1	2	3 (Best)
Capacity and injectivity	Static CO_2 storage capacity	< 5 Mt	5-20 Mt	> 20 Mt
	Depth	800-1000 m	2000 - 2500 m	1000 - 2000 m
	Resource type	Oil only	Oil & Gas	Gas Only
	Porosity	10-20%	20-30%	>30%
	Permeability	10-200 mD	200-1000 mD	>1000 mD
	Depositional Environment	Shelf shallow carbonate, marine shelf/delta carbonate, delta plain, distal delta front, coastal plain	Deep marine clastic, alluvial fan, strandplain, fluvial, peritidal, lacustrine, estuarine	Fluvial deltaic, deltaic, shallow shelf clastic, eolian, peritidal
	Reservoir Gross Thickness	< 100 ft	100-800 ft	>800 ft
	Reservoir Net Thickness	< 50 ft	50-200 ft	>200 ft
Containment	Fault	Reservoir compartmentalization	Reservoir-bounding fault	No fault
	Trap Forms	Normal fault (fault dependent)	Rollover anticline into growth fault, faulted anticline, pinch-out	Dome
	Seal Type	Local seal	Regional seal	Stacked regional seals
	Seal Thickness	<20 ft	20-100 ft	>100 ft
	Well Density	> 8 wells/km^2	4-7 wells/km^2	< 3 wells/km^2
	Well Integrity	Completed/Abandoned Prior to 1974	Completed/Abandoned Post 1974	Completed/Abandoned Post 1990

With the estimated upstream production CO_2 venting emissions and potential storage capacity, we identify potential CO_2 storage sites within a 275 km radius using the methodology presented in the flowchart in Figure 3.

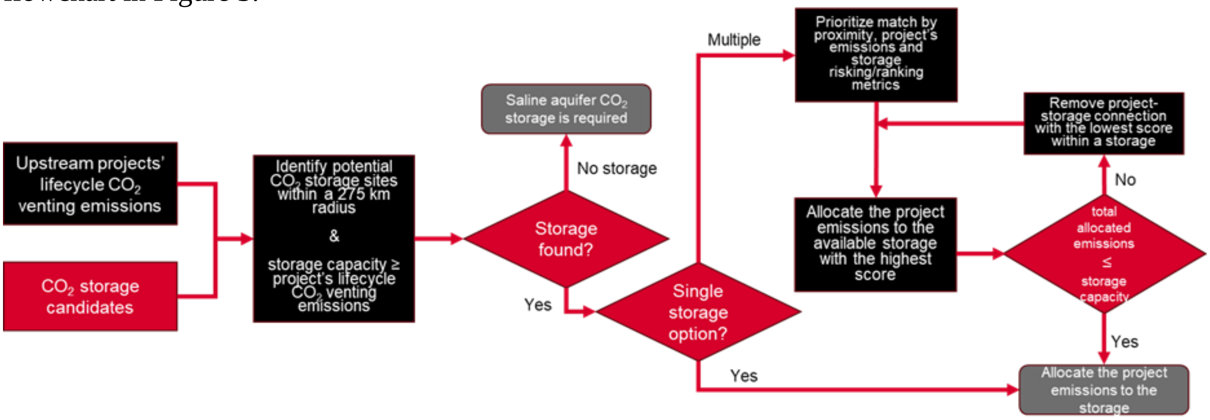

__Figure 3__ Source-to-sink flowchart of the allocation of CO_2 venting emissions from upstream projects to storage candidates

Results

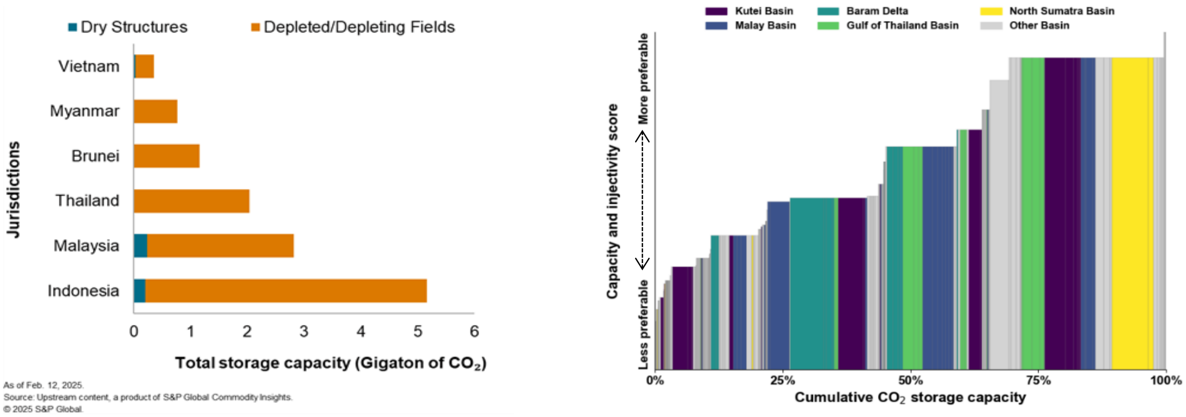

__Figure 4__ __(a)__ Estimated CO_2 storage capacity in depleted and depleting oil and gas fields and dry structures in selected jurisdictions in Southeast Asia; __(b)__ Capacity and injectivity risking and ranking of storage candidates colored by main basin

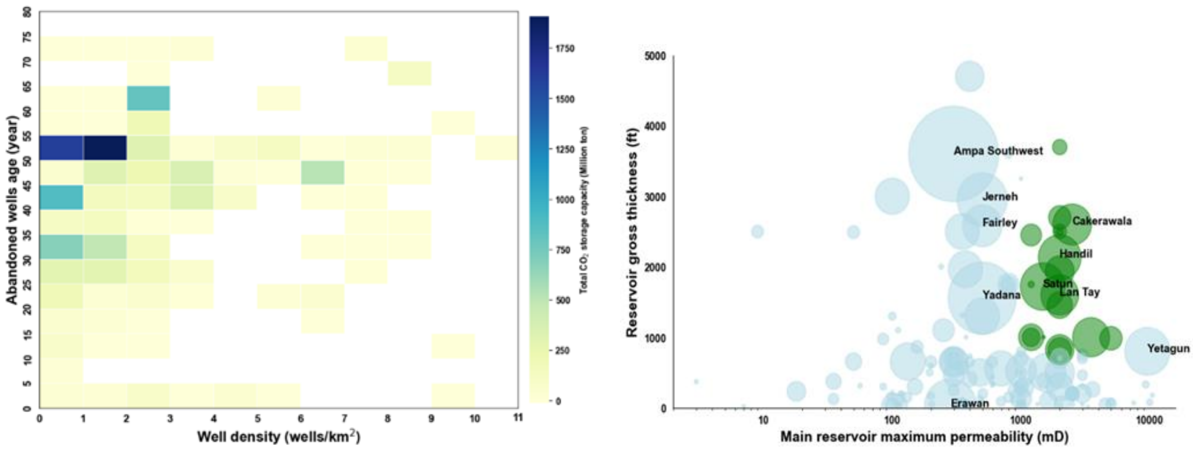

__Figure 5__ __(a)__ Cumulative storages' CO_2 capacity distribution by abandoned wells age and wells density;__(b)__ Injectivity risking and ranking of storage, where the bubble size represents the storage volume. The green bubbles indicate the highest-ranked storage options by reservoir gross thickness and maximum permeability

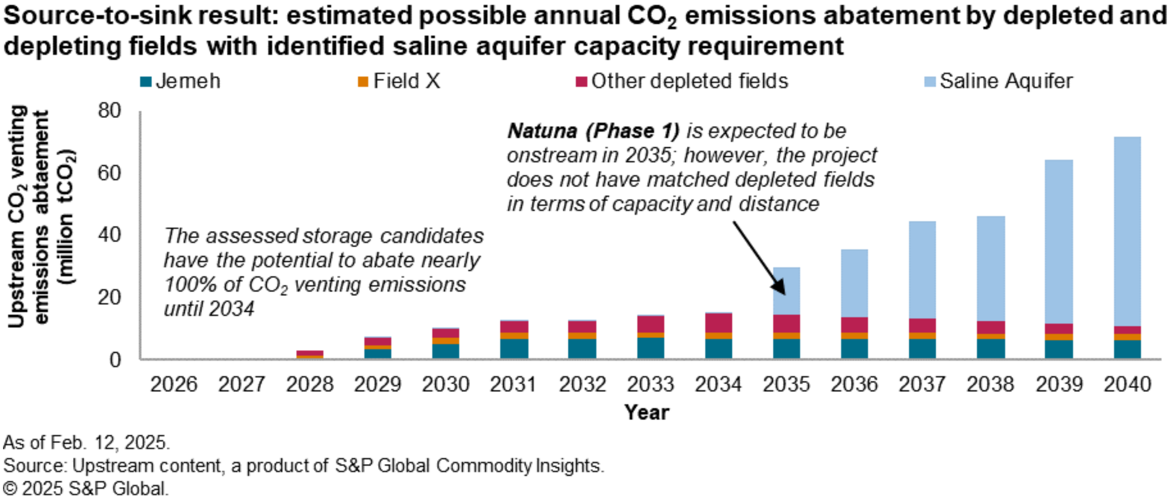

Figure 6. *Estimated possible annual CO_2 emissions abatement by depleted fields and identified requirement for additional storage capacity from saline aquifer to abate CO_2 venting emissions from Natuna*

Conclusions

With the described methodology, many depleted and depleting fields, along with the addition of dry structures in Southeast Asia, have been identified as potential storage site to store generated emissions from upcoming high-acid-gas monetization projects in the region. Potential connections and hubs between high-acid gas projects and CO_2 storage candidates have also been identified. It is also observed, although the region-wide storage potential exceeds the total CO_2 venting emissions expected from upstream projects coming online between 2025 and 2050, the source-to-sink analysis reveals that several upstream projects with high CO_2 venting emissions cannot be matched with the potential of depleting or depleted fields and dry structures. Consequently, this research recommends prioritizing the assessment of saline aquifers in specific projects and basins.

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