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Development of CO_2 Hub-Clustering Management in The South Sumatra Basin

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ABSTRACT - The escalating urgency of mitigating climate change demands immediate and effective strategies, with Carbon Capture and Storage (CCS) emerging as a pivotal solution. This scientific study presents a systematic and quantitative approach to selecting carbon dioxide (CO2) storage sites, focusing on the petrochemical industry in South Sumatra as the CO2 source, with annual emissions reaching 3.5 MtCO2. A comprehensive screening process was executed, employing 14 distinct criteria, each assigned a weighted score, to ensure the inclusion of technically feasible CO2 capture and storage options. Notably, the emphasis on Subsurface Data Analysis, encompassing vital factors such as storage reservoirs, boundary zones, traps, potential injectivity, prospective storage resources, and existing seismic data, served as a cornerstone in enhancing the robustness of our assessments. The research successfully identifies 15 CO2 storage fields, with a total storage capacity of up to 475 MtCO2. This quantitative evidence underscores the substantial potential for large-scale CO2 storage within the study area. Furthermore, considering spatial dynamics, with two distinct scenarios within a 100 km and 200 km radius of CO2 emission sources, provided precise quantitative insights into the geographical distribution of these storage sites relative to emission sources. It is crucial to note that optimizing pipeline infrastructure and utilizing existing Right of Way (ROW) were quantitatively validated as cost-effective measures for CO2 distribution, which is especially significant given the urgency of implementing CCS. Spatial calculations supported the proposal of a 600-kilometer pipeline route, demonstrating the quantitative feasibility of leveraging existing infrastructure to facilitate extensive CO2 management. This research could help in understanding large-scale CO2 storage potential and provides valuable insights for CCS policy and business development in South Sumatra.

Keywords: carbon capture and storage (CCS), utilization and storage (CCUS), CO2 source-sink matching, geographical information system, south sumatra basin.

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INTRODUCTION

Carbon Capture Utilization and Storage (CCUS) is a potential technology to mitigate climate change by reducing greenhouse gas emissions from high CO_2 emitters by storing the CO_2 in geological storage such as depleted oil and gas reservoirs. (Department of Energy & Climate Change. et al., 2013; Raza et al., 2019; Turan et al., 2021)Starting with a Pilot Project9.4 Natural Gas Processing Offers the Best Entry Point; 9.5 CO[sub(2. Numerous oils and gases are still actively produced in the South Sumatra Basin, Indonesia, and most are entering the depletion stage. These basins can become targets for CO_2 injection, either as part of permanent storage Carbon Capture Storage (CCS) or utilization (CO_2-EOR and CO_2-EGR). Sources of CO_2 are located in and around the South Sumatra basin, for example, from the oil and gas fields themselves, coal-fired power plants, the petrochemical industry, the pulp and paper industry, the cement industry, and others. It is quite important to understand the possibility of establishing CO_2 hub-clustering management in this region, the gross potential of CO_2 stored, additional crude oil and gas production, and the potential of future monetizable CO_2 credits (assuming, of course, that carbon markets will be formed in the next 5-10 years in Indonesia).

Currently, the government's oil and gas production database can be used to develop this idea. Later, information on sources of CO_2 from the non-oil and gas industry will be added. The classification of CO_2 sources and CO_2-sinks, as well as the incremental production of oil and gas, can be determined and estimated using several approaches that have been published in several publications, such as Taber et. al (1997), Al Adasani & Bai (2011) , and many more.

We use a Geographical Information System (GIS) environment to build this system. The data will be updated regularly, and the system will be modified based on data availability. The system will also incorporate date such as Right of Way (ROW) to describe existing pipelines. Ultimately, this approach can show an overview of CO_2 hub-clustering management in the South Sumatra region and business opportunities that can be built based on the current situation in the region. Previous studies of CO_2 management using spatial analysis have been proposed in China by mapping location of significant coal-fired power plants (Fan et al., 2021)especially in China. An optimization model was developed without considering the CCUS costs constraints to determine the CO_2 reduction potential of existing coal-fired power plants with CCUS in China from the perspective of source-sink matching. Saline aquifers and oil fields located in major onshore sedimentary basins in China were considered as potential sinks. The results showed that: i and in Taiwan, where the CO_2 source and sink approach is proposed (Chauvy et al., 2022). The current system that already exists is still immature. Therefore, this research could be used to improve the current system's performance.

There are numerous possible sources of CO_2 emissions from power plants and industrial processes in South Sumatra. Every year, industrial processes in South Sumatra produce at least 3.5 $MtCO_2$, contributing to the region's overall yearly production of 14 $MtCO_2$ (Asian Development Bank, 2019; PT Pertamina (Persero) Refinery Unit III Plaju, 2020; PT Pupuk Indonesia (Persero), 2021). However, South Sumatra has a large number of oil and gas deposits that could be used to store CO_2. In addition, pipelines carrying gas or oil currently connect the majority of these fields. Therefore, we propose the potential for CO_2 source-sink matching in South Sumatra.

METHODOLOGY

The process of matching CO_2 sources with suitable sinks is summarized in (Figure 1). The initial step involves the identification of available CO_2 emitters and potential storage sites within the designated region. In this context, we specifically chose high-capacity CO_2-emitting facilities, such as Central Processing Plants, Coal-fired Power Plants, Petrochemical Industries, Cement Industries, and similar entities, to serve as primary sources of CO_2 emissions. Subsequently, our attention turns to assessing potential storage options within the vicinity by creating a comprehensive map of all accessible gas and oil fields near the selected CO_2 emitters. The data collected regarding these fields, including their subsurface characteristics, such as reservoir properties, OOIP, OGIP, and storage capacities, hold paramount importance.

The second critical stage involves systematically screening these fields to identify optimal pairings between sources and sinks. Our prior research endeavors, we implemented a categorization process based on both radial and effective distances between the CO_2 source and the oil/gas fields (Figure 2). Furthermore, we excluded fields that remained undeveloped or were still in the exploration phase. In cases where the project scenario centers on Carbon Capture and Storage (CCS), our preference lies in selecting depleted fields exclusively. Conversely, when the focus shifts to Carbon Capture, Utilization, and Storage (CCUS), our considerations include producing fields, especially those amenable to enhancements through Enhanced Oil/Gas Recovery (EOR/EGR) techniques. Ultimately, in the interest of streamlining the permitting process, we show prefer fields previously operated by Pertamina.

In this research, we harnessed the capabilities of a Geographic Information System (GIS) framework to explore and establish spatial associations between CO_2 origins and their corresponding destinations. GIS tools offer a broad spectrum of applications in conducting spatial examinations, ranging from pinpointing optimal locations for industrial hubs to devising efficient route plans (Madden et al., 2021; Matejicek, 2017; Rikalovic et al., 2014; Usman et al., 2021). Within the context of our study, the GIS environment facilitated the amalgamation of diverse geospatial data layers. These encompass sources of CO_2 emissions, geological characteristics, existing pipeline networks, and potential storage reservoirs. This amalgamation empowered us to detect and appraise potential pairings between emission sources and storage destinations. Our overarching objective was to scrutinize the interconnectivity between these sources and storage sites, particularly concerning the feasibility of pipeline-based transportation, laying the foundation for a comprehensive analysis. The conceptual diagram of these processes is depicted in (Figure 3).

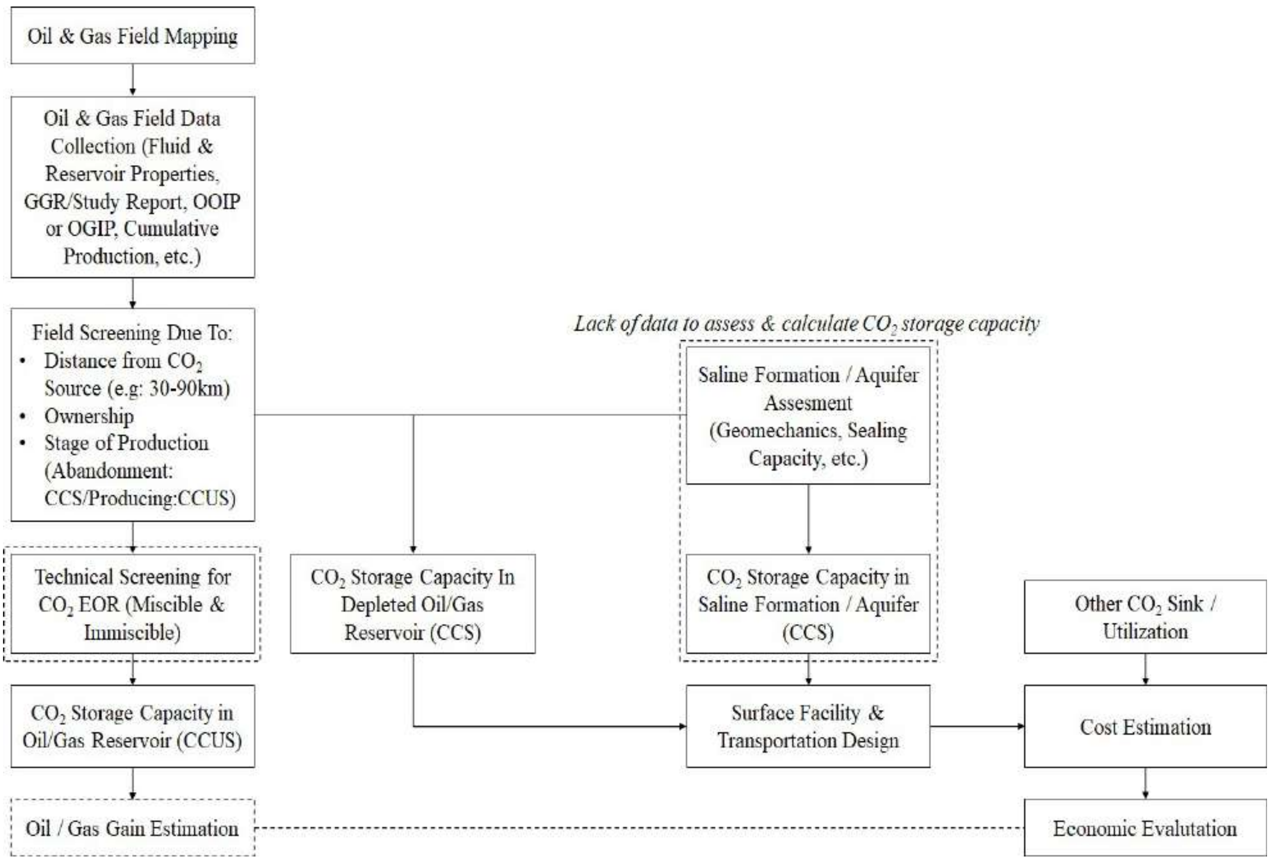
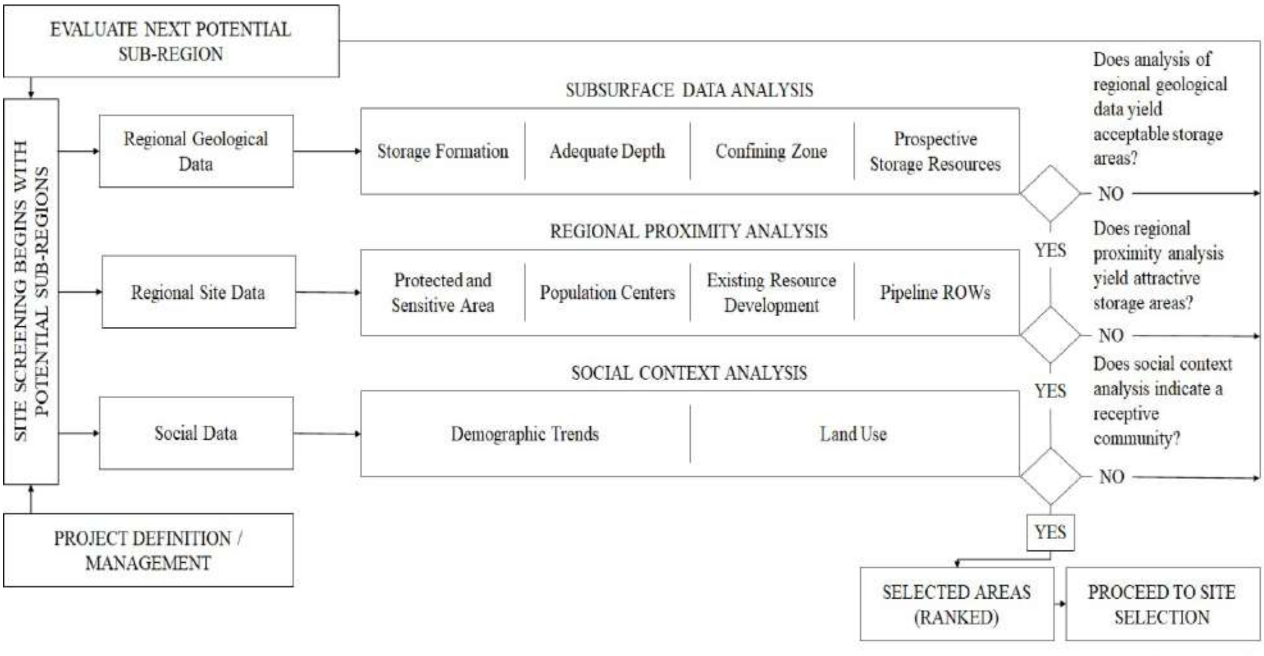


Figure 1
Flowchart oil and gas mapping



(NETL, 2017)

REGIONAL GEOLOGICAL DATA	Subsurface Data Analysis	Storage Formation	Identify potential storage formations using sub-regional or basin-scale geological and geophysical data. Candidate formations should have geologic characteristics-including porosity, permeability, thickness, salinity, and pore pressure-that make them suitable for storage.
		Adequate Depth	For Potential Sub-Regions, assess minimum depth of injection for achieving adequate protection of USDWs, and evaluate depths at which injected CO_2 will be in supercritical state for improved storage efficiency.
		Confining Zone	Identify confining zones in Potential Sub-Regions that will be effective for limiting vertical flow of injected CO_2 out of the storage formation.
		Prospective Storage Resources	Candidate storage formations should contain sufficient Prospective Storage Resources beneath a robust confining zone. Prospective Storage Resources for Potential Sub-Regions should be estimated utilizing existing data, including NATCARB and state geological survey data.

Complete Site Screening	Selected Areas	Review all Potential Sub-Regions, and create a list of Selected Areas based on geologic suitability, regional site suitability, and social context criteria.

Figure 2
Evaluation of potential region in this ccs study

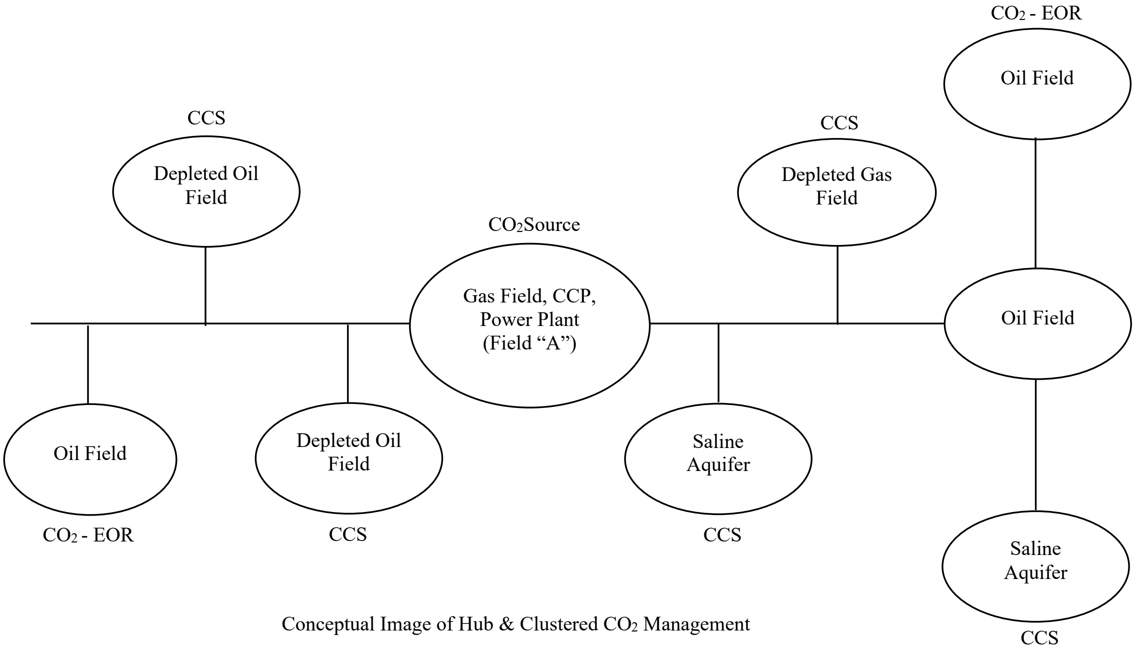


Figure 3
Schematic diagram of conceptual source-sink match mapping

The conceptual resource-sink matching of Hub and Cluster involves several key components (Figure 3): Firstly, a primary CO_2 source with significant emissions acts as the central hub. Secondly, the CO_2 generated from this source is transported through pipelines to be injected into depleted oil and gas reservoirs and saline aquifers, adhering to Carbon Capture and Storage (CCS) principles. Thirdly, when the oil and gas reservoirs still hold potential for additional production, the transported CO_2 can serve a dual purpose as Enhanced Oil Recovery (EOR), aligning with the Carbon Capture, Utilization, and Storage (CCUS) concept. Lastly, this research's chosen mode of transportation for CO_2 distribution focuses exclusively on piping, while other methods like shipping and trucking are excluded from discussion. In Figure 3, the pipeline is portrayed as blue and brown lines; this pipeline is presented as the connector between the CO_2 source and sinks. Therefore, the pipeline route with spatial information is essential for this approach. In this study, the pipeline data is digitized from WebGIS of the Ministry of Energy and Mineral Resource and our previous unpublished study; then, we integrate the information with our initial mapping as the vector line data in GIS environment. The vector line of the pipeline could serve as the path in network analysis that connects the CO_2 source and sinks.

RESULTS AND DISCUSSION

Preliminary mapping in South Sumatra

The process of mapping CO_2 sources to oil and gas reservoirs in South Sumatra involves a multidisciplinary approach, combining geospatial analysis, geological assessments, engineering feasibility studies, and ongoing monitoring to facilitate carbon capture, utilization, and storage (CCUS) initiatives effectively. This integrated approach aims to maximize the utilization of CO_2 while minimizing its environmental impact. Sources In this research, the sources of CO_2 considered encompass a range of industries, including PLTU (Coal-Based) power plants, petrochemical facilities such as fertilizer or ammonia factories, Central Processing Plants (CPP), and cement plants, among others. These diverse sources collectively contribute to the CO_2 emissions under study. As for CO_2 sinks (Figure 3), the focus is primarily on Oil and Gas reservoirs with statuses that include depleted (abandoned or shut-in) and Producing. The research also involves a thorough mapping and analysis of pipelines with pre-existing right-of-way (ROW) to assess their connectivity with both CO_2 sources and sinks. It's noteworthy that in the region of South Sumatra, a significant proportion of fields and CO_2 sources exhibit interconnectivity, highlighting the complexity of CO_2 transport and storage dynamics in this area.

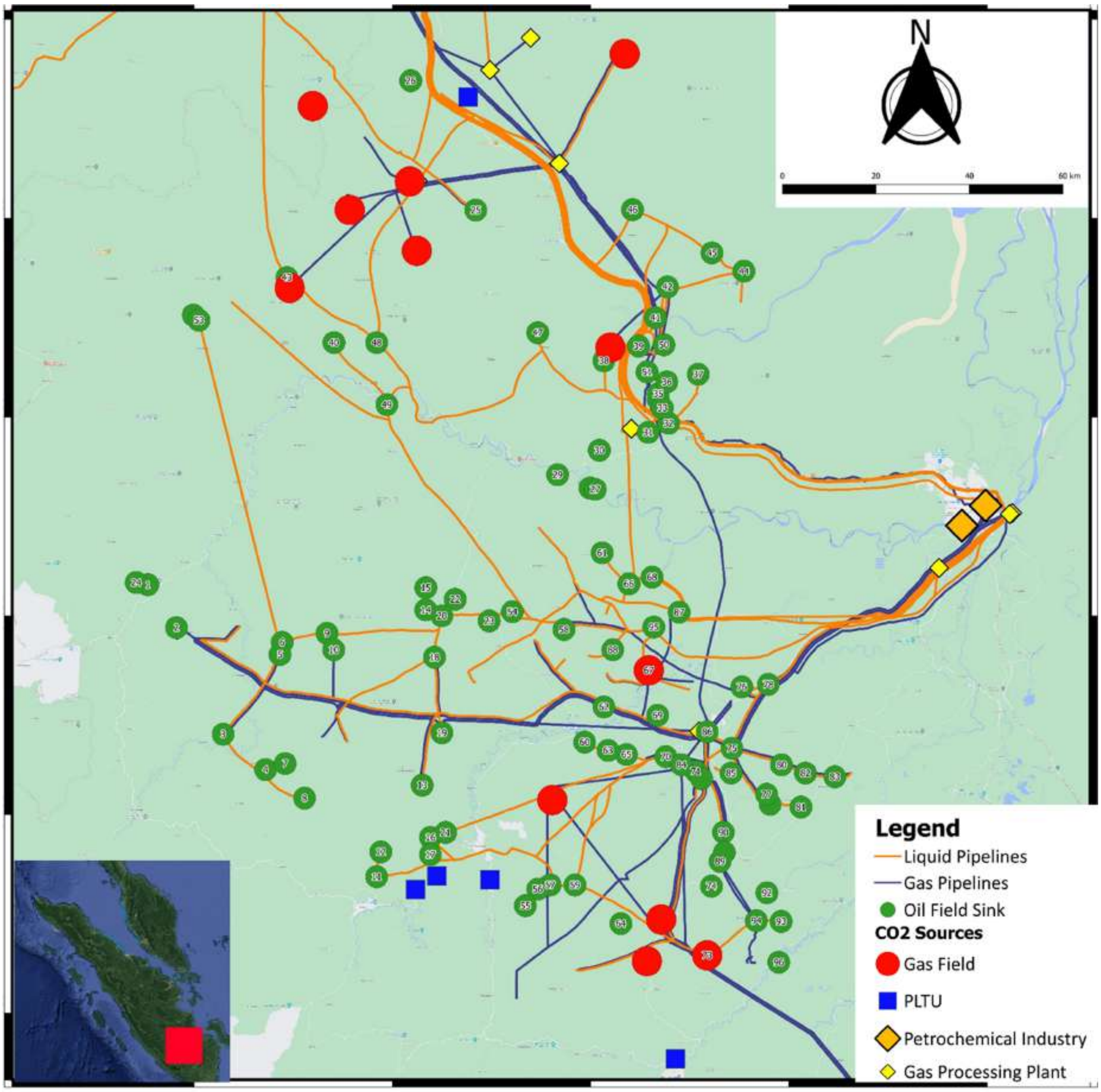


Figure 4
The initial mapping of CO_2 potential sources in south sumatra is in the high CO_2 producing gas field, coal-fired power plant, and petrochemical industry. The green circles are oil and gas fields that can be utilized as CO_2 geological storage. Yellow and blue lines are the row of existing liquid and gas pipelines.

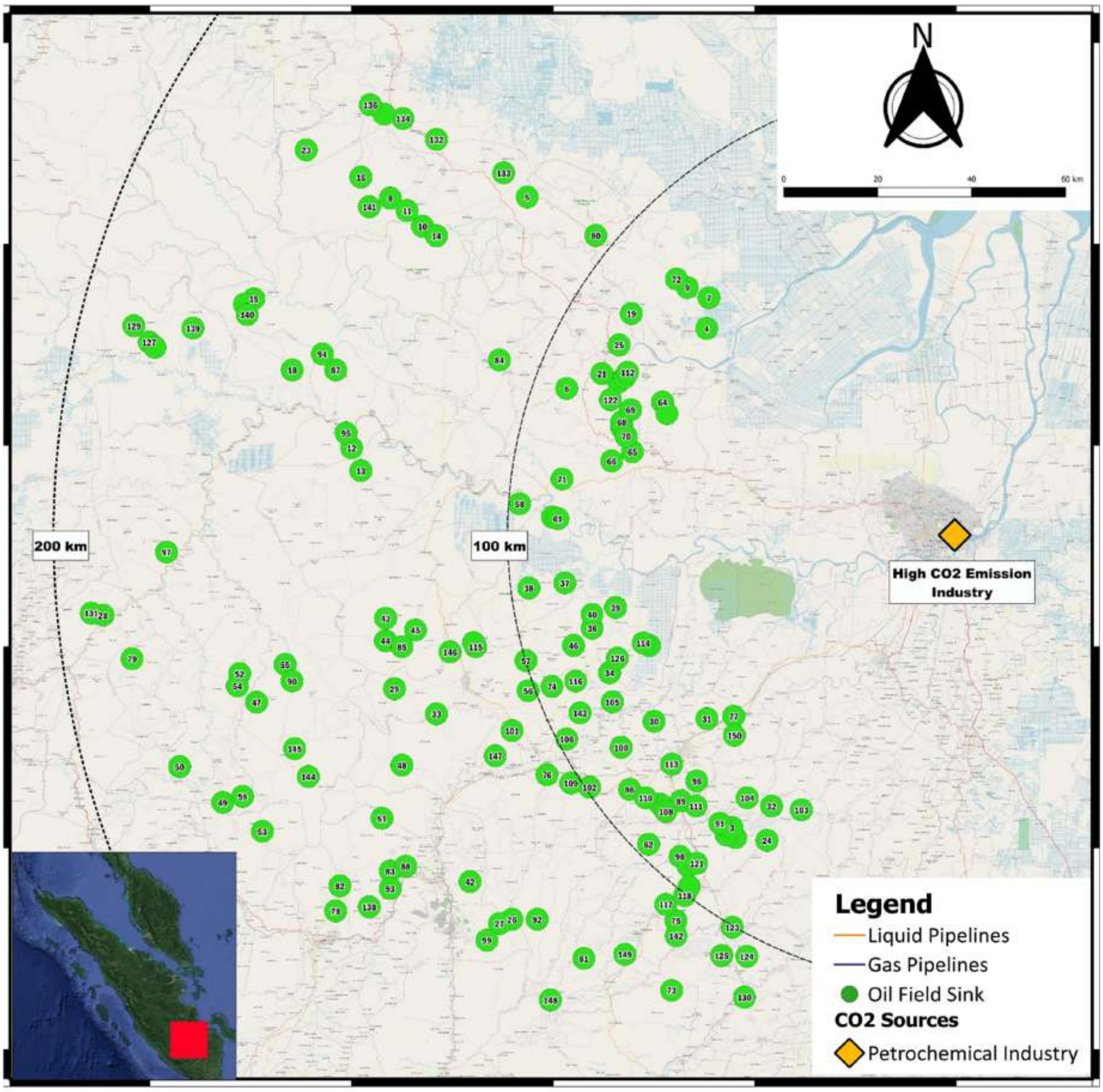
CO_2 Source Selection

The selection of CO_2 sources, which is the focus of this research, is Palembang City, in the form of the Petrochemical Industry with, an annual CO_2 emission potential of > 2 million tons of CO_2. The data is taken from the Sustainability Report (2017), which calculates the emission from production emission and energy consumption. Based on the map, the location of the CO_2 Source, which is the focus of this study is connected to the existing ROW so that it can facilitate CO_2 transportation. After the selection is made, buffers are created with a 100 km and 200 km radius to classify sinks that are closer to the CO_2 source. Storage in the 100 km zone will be prioritized over the 200 km zone, provided the capacity is sufficient (Figure 5).

Site Screening

In our methodology for screening and selecting CO_2 storage sites, we initiate the process by collecting data and establishing criteria for scoring and ranking these potential sites. It is important to note that this study exclusively focuses on CO_2 storage sites that are technically feasible for CO_2 capture using available well data. A total of 14 criteria, outlined in Table 1, are employed to assess the suitability and compatibility of these sites with CO_2 capture. Each criterion is assigned a weight, reflecting its relative importance within the criteria set. The prospective CO_2 storage sites are then evaluated against each criterion, receiving a range of scores. The cumulative weighted score yields a final index value used to rank the sources. Among the various methods utilized for the screening process, this study particularly emphasizes Subsurface Data Analysis, encompassing elements such as storage reservoirs, boundary zones, traps, potential injectivity, prospective storage resources, and existing seismic data. These processes are comprehensively depicted in the figure below, outlining the study's components, methods, and scope of work.

Regarding field selection, our analysis relies on the availability of field data. The study area features numerous wells with indications of oil or gas. Still, the quality and completeness of this data significantly impact the extent to which these wells can be further assessed. The well-log data plays a pivotal role in this regard.



Potential CO_2 storage in South Sumatera region

Figure 5
The map of potential CO_2 sinks in south sumatra as depleted oil and gas field. The CO_2 source is shown as yellow diamond with total emission >2 million tCO_2e. The 100 km and 200 km radial distance from CO_2 source is drawn on the map to categorized the oil and gas fields.

While various screening methods are presented in the table, this study exclusively conducts Subsurface Data Analysis, concentrating on evaluating of components like storage reservoirs. Our analysis has identified 15 fields with substantial potential for CO_2 storage, with the minimum cutoff storage capacity of 2 $MtCO_2$ for a single field. These fields' total combined CO_2 storage capacity reach 475 $MtCO_2$, which is adequate to store emitted CO_2 from our selected source. To facilitate a detailed examination of CO_2 transport and storage logistics, we've divided the assessment into two distinct scenarios: one within a 100 km radius from the CO_2 emission sources and another extending to a broader 200 km radius. These scenarios offer nuanced insights into the spatial dynamics of CO_2 management. The visual representation is depicted in (Figure 5), which illustrates the geographical distribution of these scenarios about potential storage sites and emission sources.

To connect the CO_2 source to the 15 storage candidates located in South Sumatra, a pipeline is required to serve as the distribution facility for CO_2. The challenge of CO_2 transportation is that the distance between CO_2 source and storage is very far (>60 km), even to the nearest candidate. However, in South Sumatra, existing ROW is available to significantly reduce the cost of pipeline construction as opening new ROW and land clearance could be avoided. Thus, the pipeline route is proposed based on the existing pipeline, which connects the CO_2 source in Palembang to the surrounding storage candidates (Figure 6). We calculate the pipe length using vector length analysis in GIS and, the route is selected based on the shortest distance between CO_2 Source and selected sinks. As only 15 sink candidates are selected, the pipeline route is focused on these fields.

In our study, we have prioritized to pipeline routes that run close to each other, as this significantly reduces the overall pipeline length. This strategic approach allows multiple fields to be served by a single main pipeline. However, due to the dispersed nature of several fields in the region, two main pipeline routes are required to reach our target destinations. The first route, extending 222 km in a northwest direction from the CO_2 source, connects Fields 17, 5, 141, and 140. Meanwhile, the second route links fields to the southwest of the CO_2 source, with the farthest point being Field 79. This route spans a pipeline length of 217 km to reach Field 79 in the southwest. Based on spatial calculations, a pipeline with a total distance of 600 kilometers is needed to connect all 475 $MtCO_2$ storage from 15 potential fields.

CONCLUSIONS

The outcomes of this study have employed a rigorous and quantitative approach to identify and evaluate CO_2 storage sites in South Sumatra. Through a systematic screening process involving 14 distinct criteria, each assigned a weighted score, we have ensured that only technically viable CO_2 capture and storage options are considered. Subsurface Data Analysis, which encompasses critical factors such as storage reservoirs, boundary zones, traps, potential injectivity, prospective storage resources, and existing seismic data, has been pivotal in enhancing the reliability of our assessments. Our research has led to the identification of 15 high-potential CO_2 storage fields, each boasting a substantial cutoff storage capacity of up to 2 $MtCO_2$, with the total storage capacity in this region reaching 475 $MtCO_2$. These quantitative findings underscore the vast potential for large-scale CO_2 storage within our study area and provide adequate storage potential for the CO_2 source, which emits 2 $MtCO_2$ annually. Moreover, our consideration of spatial dynamics, with two distinct scenarios within a 100 km and 200 km radius of CO_2 emission sources, has provided precise quantitative insights into the geographical distribution of these storage sites about emission sources.

Lastly, by optimizing the pipeline infrastructure and capitalizing on existing Right of Ways, we have quantitatively demonstrated a practical approach to significantly reducing transportation costs for CO_2 distribution. The proposed 600-kilometer pipeline route, informed by spatial calculations, further emphasizes the potential for cost-effective infrastructure utilization in facilitating large-scale CO_2 management. In essence, this research not only equips stakeholders with a data-driven framework for strategically selecting CO_2 storage sites but also provides quantitative evidence of the technical feasibility and spatial considerations that underpin effective CO_2 capture and storage initiatives. However, it's imperative to underscore that obtaining more detailed data is essential for accurately calculating the requisite CO_2 volumes for each field, a critical step for advancing our analytical efforts.

Table 1
Criteria for CO_2 storage site screening

Parameter Values			
Field Location		Fair	Good
		Offshore	Onshore
Depth		Fair	Good
		< 800 m	> 800 m
Porosity	Poor	Fair	Good
	< 3%	3% < X <15%	> 15%
Reservoir Lithology	Poor	Fair	Good
	Tight Formation/Shale	Carbonate/Naturally Frac. Reservoir	Sandstone
Permeability	Poor	Fair	Good
	< 1.5 mD	1.5 mD < X < 200 mD	> 200 mD
Field Operator	Poor	Fair	Good
	Non-Pertamina	JOB w/Pertamina	Pertamina
Field Status	Poor	Fair	Good
	Producing	Abandoned	Depleted/Temp. Shut In
Distance from Source	Poor	Fair	Good
	> 200 km	100 km < X < 200 km	< 100 km
Calculated Storage Capacity	Poor	Fair	Good
	< 1 MMT	1 MMT < X < 7 MMT	> 7 MMT
Pipeline ROW Availability	Poor	Fair	Good
	No ROW (Stranded Field)	Need Additional ROW to Integrate w/Existing ROW	Fully Integrated with Existing ROW
Network Required for Full CO_2 Sequestration	Poor	Fair	Good
	> 6 Sinks	3 Sinks/Field < X < 6 Sinks/Field	1 Sinks/Field < X < 3 Sinks/Field
Total Pipeline Length Required	Poor	Fair	Good
	> 400 km	200 km < X < 400 km	0 km < X < 200 km
Caprock Lateral Continuity		Fair	Good
		Lateral Variation Medium to Large Faults	Stratigraphically Uniform, Little or No Faults
Caprock Thickness (Chadwick, 2008)	Poor	Fair	Good
	< 65 ft	65 ft < X < 320 ft	> 320 ft

Potential CO_2 storage in South Sumatera region

Figure 6
Selected CO_2 Storage based on the screening process and the most efficient pipeline routes facilitating >2 million tCO_2e annually for 25 years. The total storage capacity is larger than 475 $MtCO_2$.

GLOSSARY OF TERMS

Unit	Definition	Symbol
	Carbon Capture and Storage	CCS
	Carbon Capture, Utilization and Storage	CCUS
	Enhanced Oil Recovery	EOR
SCF	Initial Gas In Place	IGIP
STB	Initial Condensate in Place	ICIP
	Carbon Dioxide	CO_2
	Hydrogen Sulfide	H_2S
Ppm	Parts Per Million	
MSTB	Thousand Stock Tank Barrels	
kg/m^3	Density	ρ
MMSCFD	Million Standard Cubic Feet Per Day	

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