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Mapping The Potential CO_2 Source-Sinks for Carbon Capture Storage From Industry in Indonesia

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ABSTRACT - The increasing trend of carbon reduction programs in Indonesia has been intensified to achieve Net Zero Emission in 2060. One of the options to achieve this commitment is to implement a Carbon Capture and Storage (CCS) program in Indonesia as this technology reduces carbon dioxide (CO_2) by taking the CO_2 directly from the emitter and safely injecting it into the depleted reservoir. This study aims to map the potential of CCS Storage from oil and gas-depleted reservoirs as the sink candidates and its connectivity with the available CO_2 Source from the cement, petrochemical, and fertilizer industries. The depleted oil and gas reservoir storage capacity is calculated from the available data of oil and gas in place with its ultimate recovery. The pipeline right of way is also mapped to evaluate the connectivity of the CO_2 emitter and CO_2 storage. There are four major regions that could potentially developed for further CCS implementation programs. The South Sumatra Region holds 3 $MtCO_2$ annual emissions from the industry and is connected to surrounding storage via pipeline with a total capacity of 584 MtCO2. West Java and East Java hold advantages for CCS as West Jawa has available storage of 612 $MtCO_2$ while East Java has 345 $MtCO_2$ while the annual emissions from industry in West Java and East Java are 13 $MtCO_2$ and 9 $MtCO_2$ respectively. In Kalimantan, the potency is 15 $MtCO_2$ annual emission with 1,945 $MtCO_2$ storage capacity.
Keywords: GIS, CCS, CCUS, Source-sink match, carbon storage.

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INTRODUCTION

The technology known as carbon capture and storage (CCS) involves the process of capturing carbon dioxide (CO_2) emissions from high CO_2 sources such as power plants or the petrochemical industry followed by transporting and storing it underground in geological formations. CCS is seen as a potential way to reduce greenhouse gas emissions from these sources and mitigate climate change (Asian Development Bank 2013; Raza et al. 2019; Turan et al. 2021).

Indonesia is a major emitter of greenhouse gases, primarily due to its reliance on coal-fired power plants and deforestation. The country has expressed interest in CCS as a way to reduce its emissions and meet its commitments under the Paris Agreement (World Bank 2023). However, currently, the country is still in the early stages of developing CCS technology and policy, and there are significant technical and economic challenges that must be addressed before CCS can be widely deployed (Turan et al. 2021). The recent project and study related to CCS and CCUS development in Indonesia (Carbon Limits 2024) are presented in Table 1.

The Indonesian Green House Gasses (GHG) emission level has reached 619.2 $MtCO_2$-eq (million tonnes of CO_2 equivalent) in 2021 (Ritchie et al., 2020) and will reach its peak from the energy sector is predicted to reach 1.669 $GtCO_2$-eq (Giga tonnes of CO_2 equivalent) if there is no effort in reducing the emissions (Minister of Environment and Forestry 2022). Based on Indonesia's Nationally Determined Contribution (Minister of Environment and Forestry 2022), the GHG emission in that year could be reduced to 1.311 $GtCO_2$-eq by national effort and even could achieve 1.223 $GtCO_2$-eq if there is also international effort. Various strategies can be adopted by Indonesia to reduce its CO_2 emissions. These strategies include the expansion of renewable and green energy, improvement in plant efficiency, converting fuel from coal to natural gas and renewable energy, the application of regulations and carbon taxes on total CO_2 emissions, and the utilization of carbon capture storage or carbon capture utilization and storage (CCUS) technologies (IEA 2021). In Indonesia, there has been an increased focus on carbon CCS and CCUS in recent years such as the initial potential of CCS/CCUS implementation both in global and basin scope (Iskandar et al. 2013; Iskandar & Syahrial 2009; Saputra et al. 2018; Sugihardjo 2022) for Coal Fired Power Plant (D.I. Usman 2018), and pilot project in Gundih (Marbun et al. 2019; Mulyasari et al. 2021; Sapiie et al. 2015).

Carbon capture and storage is a crucial component in reducing carbon dioxide emissions in the atmosphere. This process involves three essential steps, namely capturing, transporting, and storing CO_2. Geological formations, such as saline formations, salt formations, shale basins, oil and gas reservoirs, or coal beds CO_2 can act as underground storage for the captured CO2 through the CCS scheme. Alternatively, captured CO_2could be utilized to manufacture products that offer environmental, economic, and social benefits before being stored through Carbon Capture and Utilization (CCU) (Chauvy et al. 2022). The implementation of CCS and CCUS provides a way to mitigate the impacts of climate change by reducing the amount of CO_2 released into the atmosphere from the industry (Zhang et al. 2020). According to the Global CCS Institute's recent findings (2021), there is growing recognition that creating hub clusters for facilities, where multiple stakeholders both in storage and source sectors are involved, can yield substantial cost savings. Specifically, such clusters offer optimization of economy, particularly in terms of capital expenses for surface facilities such as compression instruments, as well as in the construction of pipelines for transporting CO_2 streams from sources to nearby sinks. This shift towards cluster-based approaches highlights the importance of proximity between sources and sinks in achieving efficient and cost-effective CCUS implementation.

To implement this approach, a geographical location and relationship between CO_2 sources and CO_2 sinks is required. An optimum match between the two should be achieved by gaining a better understanding of the spatial relationship between CO_2 sources and CO_2 storage, as well as the infrastructure connecting the hub. By utilizing this approach, investors can gain a better understanding of the location aspect if they wish to inject their high CO_2 emissions into storage. A field-scale of the source-sink match for CCUS development in South Sumatra has been done in a similar concept by (Usman et al 2021).

Table 1
Current CCS and CCUS Project in Indonesia. Most of the development areis still in the early stage (modified from Carbon Limits (2024)

No	Projects	Conducted by	Status	Onstream Target Schedule	CO_2 Stored Potential
1	Tangguh EGR/CCUS	BP Berau Ltd.	• FEED Preparation • Pre - Feasibility Study has been conducted • POD Ubadari dan Vorwata EGR/CCUS has been approved	2026	25 million tCO2 for 10 yrs
2	Gundih CCUS/CO2-EGR	Pertamina, CoE ITB, JGC, J-Power, JANUS & Supported by METI Japan	• Pre-FEED Study toward to Gundih CCUS Project	2026	3 million tCO2 for 10 yrs
3	Sukowati CO2-EOR	Pertamina, LEMIGAS, JAPEX & Supported by METI Japan	• Subsurface Study by Pertamina • Study CO2-EOR as CCUS by Pertamina, LEMIGAS, JAPEX & Supported by METI Japan	Pilot Test 2026-2027 Full Scale: 2030	14 million tCO2 for 15 yrs
4	CCS Sakakemang	Repsol Sakakemang B.V.	• Internal discussion in Repsol	2027	30 million tCO2 for 15 yrs
5	Abadi CCS/CCUS	Inpex Masela Ltd.	• Pre Feasibility Study	-	70 million ton of Native CO2 by 2055
6	CCS Joint Study for Clean Fuel Ammonia Production in Central Sulawesi	PT. Panca Amara Utama, JOGMEC, Mitsubishi & ITB	• Pre - Feasibility Study	2024/2025	10 million tCO2 for 20 yrs
7	East Kalimantan CCS/CCUS Study	PT. Kaltim Parna Industri & ITB	• Pre – Feasibility Study has been started from 1 Nov 2021 until 28 Feb 2022	-	10 million tCO2 for 10 years
8	Study of CCUS for Coal to DME	PT. Pertamina (Persero) & ITB	• Pre – Feasibility Study has been conducted from July – Oct 2021	-	13 - 65 million tCO2 for 10 years, depends on the scenarios
9	Arun CCS/CCUS	ODIN Reservoir Consultants & PEMA	• Preparing for Joint Feasibility Study	2028	-
10	Ramba CCUS	PT Pertamina (Persero)	• Subsurface study • MRV Modeling	2030	-

Several studies of CO_2 Source-Sink Matching have been conducted in recent years to promote the development of CCS and CCUS. Zhu et al. (2019) conducted a study focused on identifying optimal spatial matches with a particular emphasis on transportation cost considerations of significant CO_2 sources and potential candidates of CO_2 geological storage sites in China's Jiangsu province. A carbon reduction model from Coal-fired Power Plant was also proposed in China based on CO2 Source-Sink matching (Fan et al. 2021). The geographic relationship between CO_2 source and sinks was also studied in Taiwan (Chauvy et al. 2022), considering CO_2 source magnitude and storage capacity as well as other surface characteristics. Sun et al. (2021) conducted a case study in Spain that applied a multi-criteria analysis in their hubs and clusters approach to identify economically attractive and dispersed CCS sites, thereby reducing development costs. Currently, there is a limitation to the Source-sink study globally as there is no detailed data, thus only local and regional scale studies are available although a layout of the global scheme of CCS has been proposed by Wei et al. (2021).

There are limited studies that discuss the source and sinks for CCS implementation from the cement, petrochemical, and fertilizer industries in Indonesia scale. In this study, we focused on applying the CO_2 source and sink match for cement, petrochemical, and fertilizer industries in Indonesia as these industries contribute significantly to the national emission. We analyzed the potential of CO_2 source and sinks for each region based on their availability. This study is intended to understand the spatial relationship between said emitter with nearby depleted oil and gas reservoirs. We evaluate the availability of CO_2 sources and storage and present the map of the potency of each region. We also identify the connectivity between emitter and storage candidates from each area using existing pipeline ROW. We present the estimation of annual CO_2 cumulative emission and the estimation of storage capacity for each potential region in Indonesia.

METHODOLOGY

Workflow for determining CO_2 source and sinks

To perform CO2 Source and Sink matching, we follow the steps as shown in Figure 1. The first step is to identify the available CO_2 emitter and potential storage in the area. In this study, we identify high CO_2 emitter from fertilizer, petrochemical, and cement industry as the main CO_2 source. Next is to determine the available potential storage in the area by mapping all available gas and oil fields near the selected CO_2 emitter. The identified gas and oil fields are then evaluated to determine their depletion status. In this study, we only consider depleted oil and gas reservoirs as our main target for CCS. Secondly, the fields will be screened to obtain optimal pairs between source and sinks. In our previous works, we filtered and categorized the fields based on the radial and effective distance between the CO_2 source and the oil/gas fields, we also filtered out all the fields that were not yet developed or were still in the exploration stage (Nugraha et al. 2024).

In this study, we employed a Geographic Information System (GIS) environment to investigate and establish spatial connectivity between CO_2 sources and their corresponding sinks. GIS tools have a wide range of applications in performing spatial analyses, such as identifying the optimal locations for industrial hubs or planning routes (Matejicek 2017; Rikalovic et al. 2014; Sun et al. 2021; Yildirim et al. 2017). In the context of our research, the GIS environment facilitated the integration of various geospatial data layers, including CO_2 emission sources, geological features, existing pipelines, and potential storage reservoirs, enabling us to identify and assess potential matches between sources and sinks to analyze the connectivity between the sources and the storage sites via pipelines.

The use of GIS tools provided us with a comprehensive view of the spatial relationships between the CO_2 sources and sinks. Specifically, we were able to identify the most suitable locations for the storage of CO_2 in order to support the attainment of Indonesia's Zero Net Emission target by 2050. The tools also allowed us to visualize the extent to which CO_2 sources were geographically distributed across various industries (Bolstad 2019).

By leveraging the available spatial data, we were able to screen and identify candidate locations for CCS and CCUS within the Indonesian context rapidly and accurately. The GIS tools enabled us to match CO_2 sources with their corresponding sinks and to determine the optimal pipeline routes to transport CO_2 from the sources to the selected storage sites. By utilizing GIS, we aimed to analyze and map the geographical relationships between CO_2 emission sources and potential storage sites. This approach allowed us to evaluate the feasibility and suitability of connecting CO_2 sources with appropriate sinks in terms of spatial proximity.

After the number of fields has been sorted out, the storage and CCS project must be assessed further in more detail. The detailed assessment includes performing technical analysis, including reservoir modelling for oil/gas estimation, geomechanics and seal integrity study, surface facilities, risk assessment, and lastly, the economic evaluation. However, this study focuses solely on the analysis of sources and sinks, as a comprehensive technical analysis requires comprehensive data.

Data collection

In our study, the data was collected from the open data repository of the Ministry of Environment and Forestry, the Ministry of Energy and Mineral Resources, and the Ministry of Industry. We also use an internal unpublished study by ITB & JANUS (2020) related to CCS mapping in Indonesia, including the oil and gas dataset. This data was collected from various unpublished studies, conference presentations, and summaries of previous research. While these sources are not publicly available, they were carefully reviewed to ensure accuracy and consistency. Pipeline vector data was digitized from various reports or obtained from the data repository of Geospatial Information Agency (BIG) through their official portal (https://tanahair.indonesia.go.id/). This repository provides comprehensive and reliable geospatial datasets to support the spatial analysis of this study. Although the data utilized in this study were obtained from the official government repository managed, we recommend caution when using this data for detailed technical studies. Spatial distortions may occur during the digitization process and potentially affect the accuracy required for high-precision applications. For broader or less detail-sensitive analyses, however, the data remains a reliable and valuable resource

Identification of CO_2 sources

The CO_2 is emitted from a large variety of sources, including large stationary sources that produce significant amounts of CO_2 (Bains et al., 2017)especially CO2, must be significantly reduced to prevent catastrophic global warming. Carbon capture and reliable storage (CCS. It is worth noting that not all sources of CO_2 emissions are suitable for capture and storage, and the feasibility of CCS/CCUS depends on the specific characteristics of the source and the availability of appropriate storage sites. Some of the major sources of CO_2 that can be captured using CCS include: 1). Power plants: CO_2 can be captured from the flue gas emitted by power plants that burn fossil fuels such as coal power plants, natural gas, and oil; 2). Industrial facilities: CCS can be applied to industrial processes such as cement, steel, and chemical production, which are major sources of CO_2 emissions; 3). Natural gas processing: CO_2 can be captured from natural gas fields before it is sent to pipelines for distribution; 4). Bioenergy: CCS can be used in bioenergy plants that produce electricity by burning biomass such as wood or other plant-based materials; 5). Direct air capture (DAC) is a technology that captures CO_2 directly from the atmosphere, it can be used as a source of CO_2 for CCS.

In this study, we concentrated on identifying significant CO_2 sources from the petrochemical and cement industry that produce over 1,000,000 tCO_2 annually. Data from significant CO_2 producers, petrochemical industries, cement industries, and pulp and paper industries, was collected from various reports and documented in our GIS database. To perform an accurate mapping of CO_2 sources, both geospatial data and annual CO_2 emission data are necessary. The data is then plotted on a map, serving as the focal point of the source-sink analysis.

Calculation of storage capacity

The captured CO_2 is transported to the subsurface storage or geological storage. The CO_2 storage utilizes the depleted oil & gas reservoir or deep saline aquifer to store the supercritical CO_2 that was transported from the CO_2 source. We focused on depleted oil & gas fields as our main target as Indonesia has a significant amount of depleted reservoirs. Here, we identify and collect the data of depleted reservoirs near the CO_2 Source and assess them based on their capacity and distance from the source.

In this study, we identify the depletion status by comparing the cumulative production and the Estimated Ultimate Recovery (EUR). If the cumulative production / EUR is higher than 55% then the field is considered as a depleted reservoir. Thus, we evaluate the production status first from our database to classify its depletion status before calculating the storage capacity.

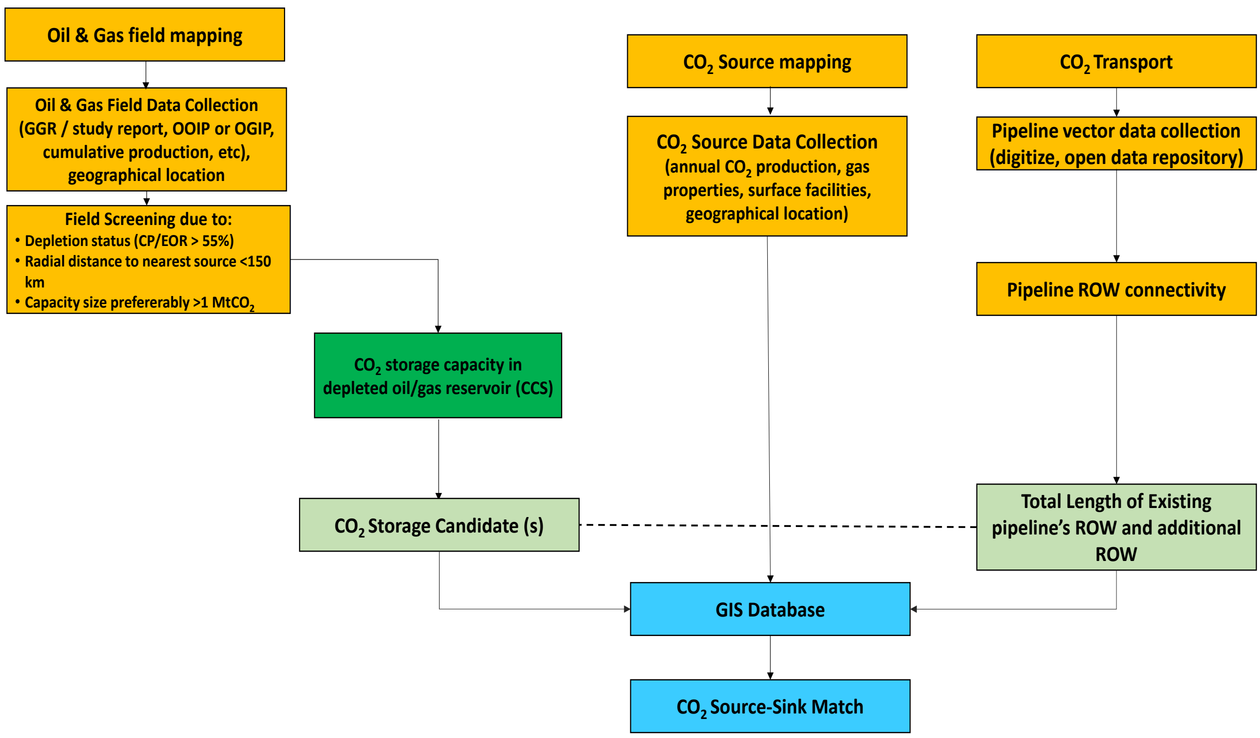

Figure 1
Workflow for CO_2 Source and Sink Identification. All collected data is converted to spatial format and analyzed using a GIS environment.

To enhance the study's significance, fields with a calculated storage capacity of less than 1 million tCO_2e will be excluded from consideration for CCS/CCUS sinks, as they are not economically viable (with less than 2 MMSCFD of CO_2 for 20 years). Additionally, the reservoir depth must be deeper than 800 m (approximately 2,600 ft) to minimize the risk of early CO_2 breakthrough or leakage. (Al Adasani & Bai 2011).

This study particularly uses by (Goodman et al. 2011)saline formations, and unmineable coal seams is provided. The oil and gas reservoirs are assessed at the field level, while saline formations and unmineable coal seams are assessed at the basin level. The US-DOE methodology is intended for external users such as the Regional Carbon Sequestration Partnerships (RCSPs equation to calculate CO_2 storage capacity. Goodman's model is deemed to be practical, as well as requires less data compared to other correlations, thus ideal for preliminary study as the available subsurface data is often limited. In comparison, we also use the CLSF model as another calculation method (Bachu et al. 2007)Australia on September 15, 2004, a Task Force was created to review and identify standards for CO_2 storage capacity estimation. This Task Force presently consists of Canada (lead. In a depleted reservoir, we could simplify the equation into the recovery factor of HCPV (Hydrocarbon Pore Volume) as the total volume that could be injected by CO_2. The equations for calculating CO_2 storage capacity are presented in Table 3.

Table 3
Example of depleted oil and gas fields dataset used in this study

Long	Lat	FIELD	BLOCK_NAME	GN_HC_TYPE	POL_PROV	Area (km^2)	RES_MAG	Storage Capacity Class ($MtCO_2$)
106.70	-4.57	Intan Northeast	SOUTHEAST SUMATRA	Oil & Gas Fields	West Java Sea	5.7	10-100 million bo	1-50
103.89	-2.63	Kluang	KLUANG	Oil & Gas Fields	Sumatera Selatan	8.2	10-100 million bo	1-50
102.30	1.05	Kurau	MALACCA STRAIT	Oil & Gas Fields	Riau	12.3	10-100 million bo	1-50
106.53	-4.98	Karmila	SOUTHEAST SUMATRA	Oil & Gas Fields	West Java Sea	4.6	10-100 million bo	1-50
105.47	4.18	Tembang	SOUTH NATUNA SEA BLOCK "B"	Gas Fields	South China Sea	45.6	100,000-1mil mmscfg	1-50
100.99	0.97	Libo	ROKAN	Oil & Gas Fields	Riau	69.5	100,000-1mil mmscfg	1-50
103.70	-3.44	Rambutan	SOUTH SUMATRA	Oil & Gas Fields	Sumatera Selatan	9.8	1-10 million bo	1-50
104.18	-3.19	Abab	SUMBAGSEL AREA-2	Oil & Gas Fields	Sumatera Selatan	38	10-100 million bo	1-50
117.50	0.48	Sangatta	SANGATA	Oil & Gas Fields	Kalimantan Timur	19.7	10-100 million bo	1-50
104.24	-3.88	Kuang	SUMBAGSEL AREA-2	Oil & Gas Fields	Sumatera Selatan	33.2	10-100 million bo	1-50
114.05	-7.31	Maleo	MADURA OFFSHORE BLOCK	Gas Fields	East Java Sea	16.6	100,000-1mil mmscfg	1-50
103.59	-1.65	Kenali Asam	JAMBI-PT. PERTAMINA	Oil & Gas Fields	Jambi	14.4	100-1000 million bo	1-50
111.91	-7.15	Sukowati	TUBAN	Oil & Gas Fields	Jawa Timur	2.4	100-1000 million bo	1-50
100.74	1.67	Balam South	MAHATO	Oil & Gas Fields	Riau	15.47	100-1000 million bo	1-50
102.24	0.69	Zamrud	COASTAL PLAINS AND PEKANBARU (CPP)	Oil & Gas Fields	Riau	26.9	100-1000 million bo	1-50
108.43	-6.50	Jatibarang	JAWA BAGIAN BARAT	Oil & Gas Fields	Jawa Barat	64.8	100-1000 million bo	1-50
105.57	5.25	Anoa	NATUNA SEA BLOCK "A"	Oil & Gas Fields	South China Sea	14.18	10-100 million bo	50-100
107.50	-5.89	L-Parigi	LAPISAN PARIGI	Gas Fields	West Java Sea	35.9	1-10 million mmscfg	50-100
117.64	-0.18	Attaka	EAST KALIMANTAN & ATTAKA	Oil & Gas Fields	Makassar Strait	54.9	100-1000 million bo	100-175
117.43	-0.32	Badak	SANGA-SANGA	Oil & Gas Fields	Kalimantan Timur	74.2	1-10 million mmscfg	175-275
97.26	5.05	Arun	B BLOCK	Gas Fields	Aceh	81.8	> 10 million mmscfg	>550

Table 4
Correlations for calculating CO_2 storage capacity

Storage Type	CO_2 Storage Capacity	
	US DOE (effective storage capacity)	CLSF
Gas Reservoir	$M_{CO2t} = \rho_{CO2r} \times A \times h \times \phi \times (1 - S_w) \times B \times E$	$M_{CO_2t} = \rho_{CO_2r} R_f (1 - F_{IG}) OGIP \left[\frac{(P_s Z_r T_r)}{(P_r Z_s T_s)}\right]$ $M_{CO2e} = C_m \times C_b \times C_h \times C_w \times C_a \times M_{CO2t} \equiv C_e \times M_{CO2t}$
Deep Saline Aquifer (structural & stratigraphic traps)	$M_{CO2} = A \times h \times \phi \times \rho_{CO2} \times E$	$\min M_{CO2e} = \rho_{CO2}(P_i, T) \times V_{CO2e} \leq M_{CO2e} \leq \max M_{CO2e} = \rho_{CO2}(P_{max}, T) \times V_{CO2e}$ $V_{CO2t} = V_{trap} \times \phi \times (1 - S_{wirr}) \equiv A \times h \times \phi \times (1 - S_{wirr})$ $V_{CO2e} = C_c \times V_{CO2t}$

Simplification for Gas Reservoir: RF x HCPV gas x CO_2 density

Simplification for Aquifer: PV aquifer x CO_2 density x *E*

Figure 2
Distribution of identified depleted oil and gas reservoirs for CO_2 storage candidates. The assumption of average CO_2 density is 350 kg/m3

Pipeline route proposal

The purpose of using spatial analysis for the CO_2 Source-Sink Matching is to assess the initial calculation related the infrastructure availability. The CO_2 could be transported by train and truck for short distances and small CO_2 quantities or using pipelines and shipping for transporting megatons of CO_2 per year (Mtpa) as this method could be more effective due to economies of scale (NPC 2019). In this case, we suggest pipeline as the transportation method from CO_2 Source to CO_2 Storage as it is the most effective mode of transport for large-scale CO_2 in the long term (Becattini et al. 2022; Smith et al. 2022) although for very long distance the shipping is potentially cheaper. To minimize the financial risk and lower the capital investment, it is crucial to assess the availability of right-of-way (ROW) pipelines in the area as a means of transporting CO_2. By utilizing existing ROW effectively, we can reduce costs associated with land clearance and permit acquisition (Yildirim et al. 2017)the natural gas transmission pipeline (NGTP. As a result, in our workflow, we prioritize sinks that are connected to existing oil or gas pipelines. It is important to note that while most CCS/CCUS projects will construct new pipelines specifically for CO_2 transportation, the ROW of existing pipelines can still be utilized. The following diagram illustrates the scheme of CO_2 sources and sink management that are connected by pipelines (Figure 2). The blue and brown lines represent the pipeline connection between the source and sinks.

This study uses the pipeline route based on the existing oil and gas pipeline that is available from our previous study (Carbon Limits, 2024; ITB & JANUS, 2020) and the open data repository of Geospatial Information Agency. The line is digitized to create vector data while gincluding the attribute data to be able to be utilized in a GIS environment.

In our approach, we prioritize sinks that are connected to the source by a pipeline network, provided that the sinks have sufficient storage capacity. If the combined capacity of the connected sinks is insufficient, we will evaluate storage candidates outside of the existing pipeline network. The limitation of the distance between the outside storage candidates and to existing pipeline can be varied and sensitive to the price scenario so the calculation must be done iteratively to obtain the most optimal scenario. By considering these factors, we aim to optimize the cost-effectiveness of carbon capture and storage (CCS) while ensuring adequate storage capacity.

RESULT AND DISCUSSION

Overview of ccs potential in sumatra

In Sumatra, there are several promising candidates for CO_2 hubs based on their storage capacities and industrial CO_2 emitters. North Sumatra offers a substantial storage capacity of 807 $MtCO_2$, primarily concentrated in the depleted Arun Field, which accounts for 580 $MtCO_2$. Central Sumatra has an even greater potential with a storage capacity of 910 $MtCO_2$, mainly in the Minas (350 $MtCO_2$) and Duri (170 $MtCO_2$) fields. In contrast, South Sumatra has a total storage capacity of 584 $MtCO_2$, but no single large depleted reservoir is currently available since the Suban and Sumpal fields are still in plateau production. These variations in storage capacities across the region provide opportunities for future CCS projects, particularly in areas where industrial CO_2 emissions are concentrated.

In terms of CO_2 sources, North Sumatra currently lacks active emitters, as the fertilizer industry in the area is on hold due to a gas supply disruption from Arun. Central Sumatra has only the Dumai Refinery, which emits 1.9 $MtCO_2$ annually. However, South Sumatra presents the strongest potential for a CCS hub, with 3 $MtCO_2$ of annual emissions from a fertilizer plant and a refinery in Palembang, alongside over 2 $MtCO_2$ from a cement industry in Ogan Komering. Given the region's significant CO_2 emissions and ample storage capacity, South Sumatra is the most viable candidate for developing a CCS hub in Sumatra.

Overview of CCS potential in Java

West and East Java present significant potential for CCS initiatives, with substantial storage capacities and active CO_2 sources. In West Java, the total estimated storage capacity is 612 $MtCO_2$, with a majority of this—approximately 380 $MtCO_2$—located offshore. One of the more promising onshore fields is Jatibarang, where a pilot project using the huff-and-puff method has already been conducted. East Java, on the other hand, has a storage capacity of around 345 $MtCO_2$, although, like West Java, most of its capacity lies offshore. These geological formations provide ample opportunities for long-term CO_2 storage in the region.

In terms of CO_2 sources, West Java has four major industries that collectively emit around 13 $MtCO_2$ annually, primarily from facilities located near Jakarta and Cilegon. Meanwhile, East Java hosts the industrial region of Gresik, home to several cement and fertilizer plants. This study identifies four cement factories and one fertilizer plant emitting a combined total of 9 $MtCO_2$ per year. However, only one cement plant and one fertilizer plant are directly connected to an existing pipeline network. The availability of sufficient CO_2 sources, storage sites, and infrastructure such as ROW pipelines makes both regions strong candidates for CCS hubs, enabling effective emission reduction strategies in Java.

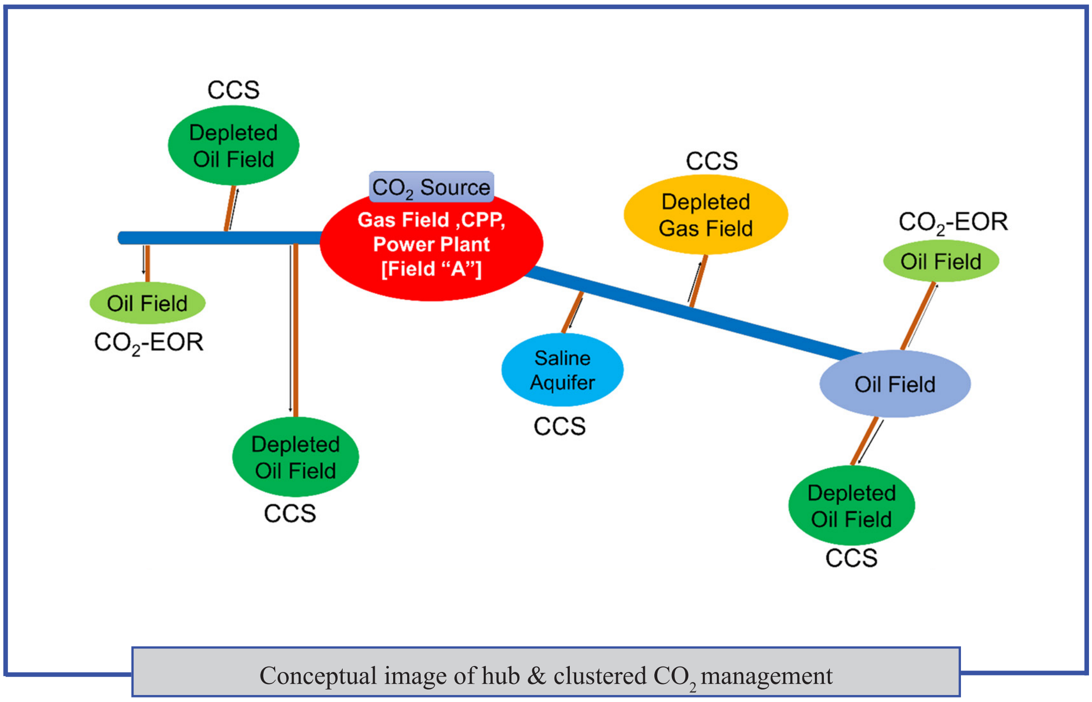

Figure 3
Conceptual diagram of CO_2 source – sink match management.

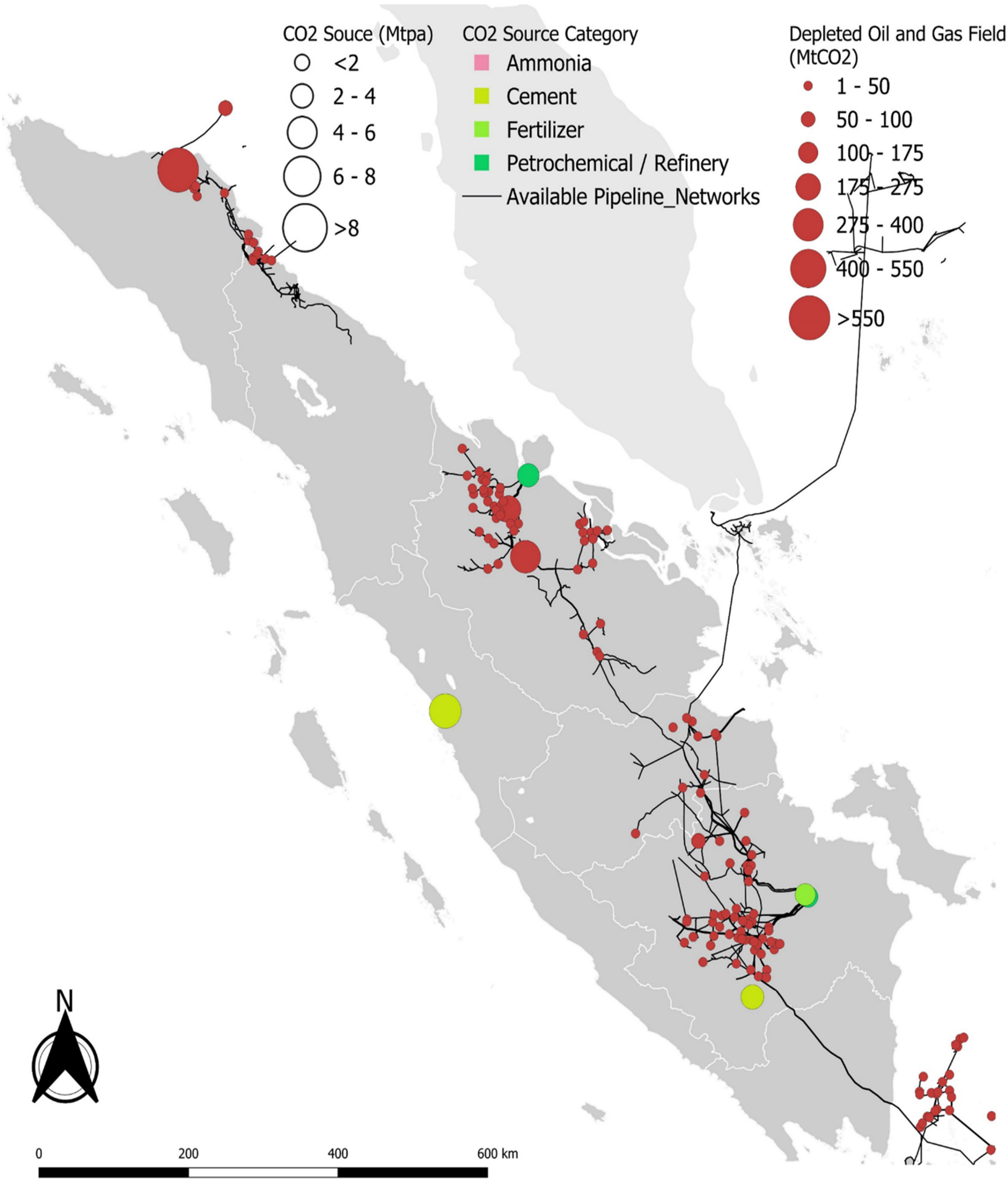

Figure 4
CO_2 source-sink matching potential in Sumatra

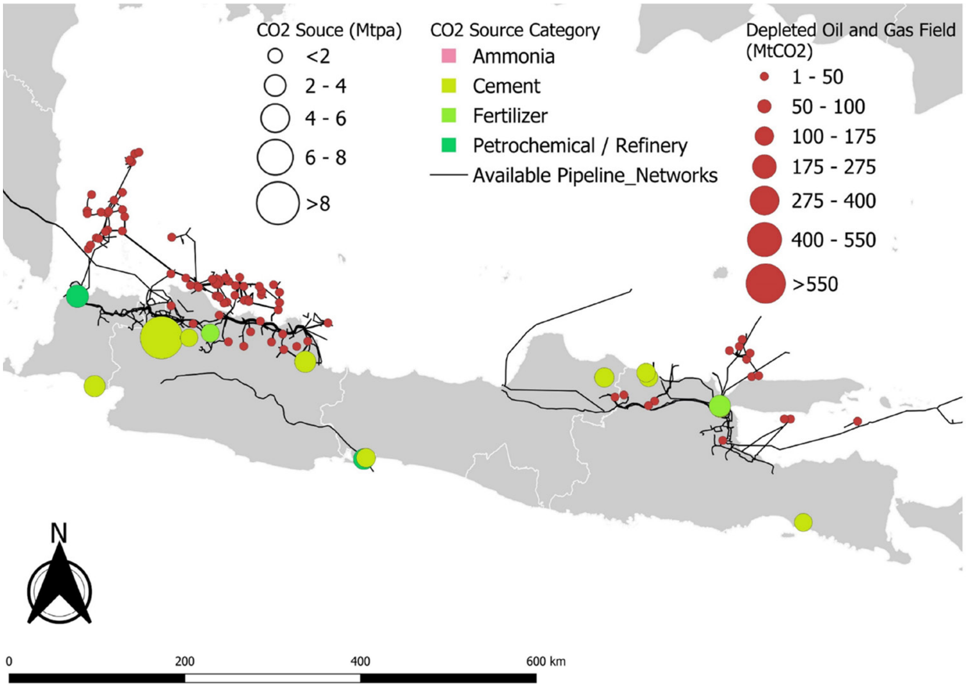

Figure 5
CO_2 source-sink matching potential in West Java and East Java

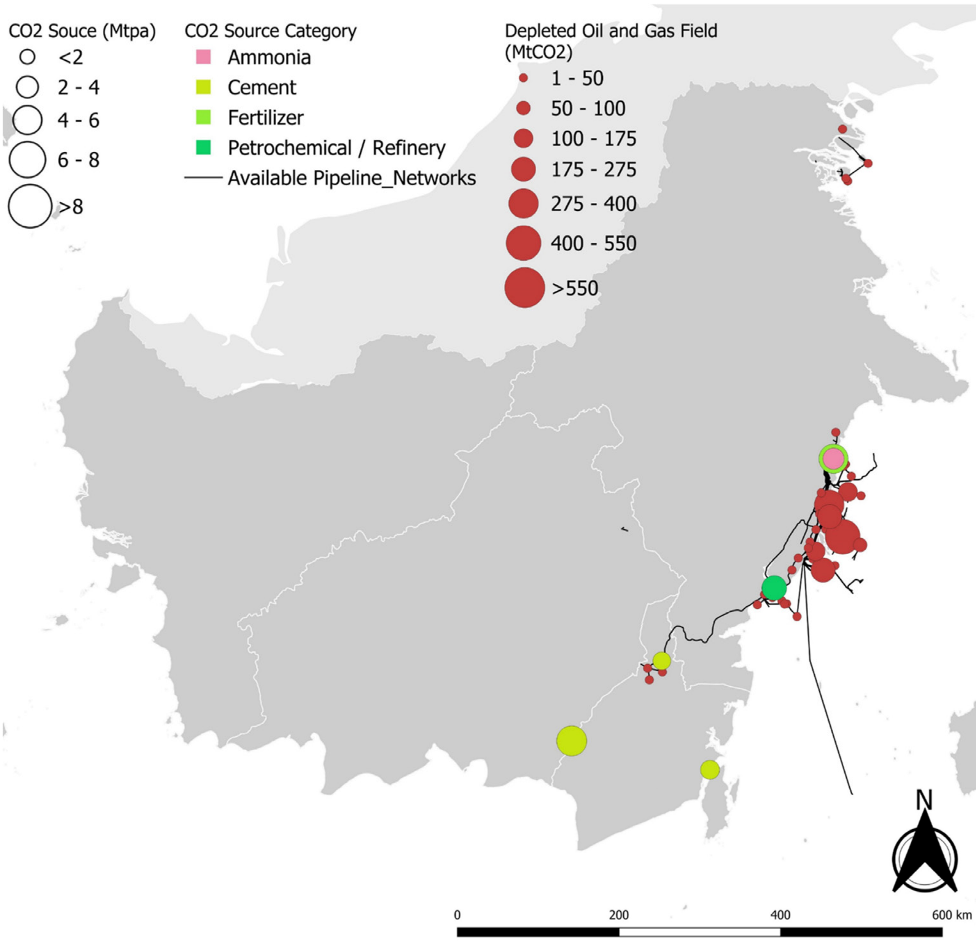

Figure 6
CO_2 source-sink matching potential in Kalimantan

Overview of CCS potential in Kalimantan

Kalimantan offers a substantial storage capacity for Carbon Capture and Storage (CCS) with an estimated 1,945 $MtCO_2$. The largest contribution to this capacity comes from the Tunu Field, which holds around 450 $MtCO_2$. Most of Kalimantan's storage potential is concentrated offshore, particularly in the eastern region, making it a key area for large-scale CCS projects. These offshore fields provide a significant opportunity for long-term CO_2 storage near to industrial emitters in the region.

East Kalimantan is home to six major CO_2 sources, emitting around 15 $MtCO_2$ annually. Despite this high emission rate, only four industries are connected to the existing pipeline ROW infrastructure. One of the challenges is the cement industry, which is located 200 km from the nearest storage cluster, making transportation a logistical issue. On the other hand, a nearby refinery emits over 2 $MtCO_2$ and is located close to the nearest storage cluster, enhancing its CCS feasibility. Additionally, petrochemical and fertilizer industries in the Bontang area are well-connected to depleted fields via existing pipelines, making them strong candidates for CCS integration.

CONCLUSION

In conclusion, this study has succeeded in performing CO_2 source identification from the existing cement, petrochemical, and fertilizer industries. We have identified that more than 66 $MtCO_2$ is emitted annually from these industries in Indonesia. The total storage capacity from depleted reservoirs in Indonesia is almost 5,193 $MtCO_2$.

The South Sumatra Region holds 3 $MtCO_2$ annual emissions from the industry and is connected to surrounding storage via pipeline with a total capacity of 584 $MtCO_2$. Both West Java and East Java hold advantages for CCS as the West Java available storage 612 $MtCO_2$ while East Java 345 $MtCO_2$ while the annual emissions from industry in West Java and East Java are 13 $MtCO_2$ and 9 $MtCO_2$ respectively. Furthermore, there is a potency of 15 $MtCO_2$ annual emission with 1,945 $MtCO_2$ storage capacity in Kalimantan.

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GLOSSARY OF TERMS

Symbol	Description	Unit
CCS	Carbon Capture Storage	
CCU	Carbon Capture Utilization	
CCUS	Carbon Capture Utilization & Storage	
EOR	Enhanced Oil Recovery	
ROW	Right of Ways	
CO2	Carbon Dioxyde	
H2S	Sulphuric Acid	
MTCO2	Million/Mega Tonnes of CO_2	
GTCO2	Giga Tonnes of CO_2	
MTCO2EQ	Equivalent of Million tonnes of CO_2	
GHG	Green Hous Gases	
GIS	Geographic Information System	
HCPV	Hydrocarbon Pore Volume	

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