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IMPLEMENTATION OF CO_2 SOURCE-SINKS MATCH DATABASE DEVELOPMENT. CASE STUDY: WEST JAVA

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ABSTRACT

Carbon capture and storage (CCS) is widely recognized as a significant technology in mitigating carbon dioxide (CO2) emissions from major industrial facilities, such as power plants and refineries. CCS involves the capture of concentrated CO2 streams from point sources, followed by subsequent safe and secure storage in appropriate geological reservoirs. We developed spatial database system using Geographic Information System (GIS) tools to facilitate source-sink matching between CO2 emitter and CO2 storage to foster the implementation of CCS/CCUS technologies in Indonesia. In this study, we proposed workflow approach to determine the location of CO2 sinks/storage candidates given limited data available. Additionally, this method spatially characterizes and represents probable clusters where opportunities for CCS/CCUS implementation are present. We consider the existing pipeline route and Right of Ways (ROW) to minimize the potential cost related to transportation of CO2 using pipeline. The priority of available storage is classified based on the storage capacity, distance, and other technical criteria to determine the optimal location of potential CO2 injection. We applied the workflow to Coal Fired Power Plant in West Java as the CO2 source, and we obtained 6 depleted fields that are connected to the existing ROW with CO2 storage capacity of 42.03 MMT.
Keywords: GIS, CCS, CCUS, Source-sink match, carbon storage

I. INTRODUCTION

The technology known as Carbon capture and storage (CCS) involves the process of capturing carbon dioxide (CO2) emissions from high CO2 sources such as power plants or petrochemical industry and 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 (Department of Energy & Climate Change. et al., 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. However, to date, there have been no field-scale CCS projects implemented in Indonesia. 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 Indonesian Green House Gasses (GHG) emission level has reached 619.2 MtCO2-eq in 2021 (Ritchie et al., 2020) and will reach its peak from energy sector is predicted to reach 1.669 GtCO2-eq 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 GtCO2-eq by national effort, and even could achieve 1,223 GtCO2-eq if there is also international effort. Various strategies can be adopted by Indonesia to reduce its CO2 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 CO2 emissions, and the utilization of carbon capture storage (CCS) and utilization (CCU) technologies (IEA, 2021). In Indonesia, there has been an increased focus on carbon CCS and CCUS in recent years such the initial potential of CCS/CCUS implementation both in global and basin scope (Iskandar et al., 2013; Iskandar & Syahrial, 2009) 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, Utilization, and Storage (CCUS) is a crucial component in reducing carbon dioxide (CO2) emissions in the atmosphere. This process involves three essential steps, namely capturing, transporting, and storing CO2. Geological formations, such as saline formations, salt formations, shale basins, oil and gas reservoirs, or coal beds CO2 can act as underground storage for the captured CO2 through Carbon Capture and Storage (CCS) scheme. Alternatively, captured

CO2 could be utilized to manufacture products that offer environmental, economic, and social benefits through before 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 CO2 release to 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 involved, can yield substantial cost savings. Specifically, such clusters offer optimalization of economy, particularly in terms of capital expenses for surface facilities such as compression instrument, as well as in the construction of pipelines for transporting CO2 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.

In order to implement this approach, a geographical location and relationship between CO2 sources and CO2 sinks is required. An optimum match between the two should be achieved by gaining a better understanding of the spatial relationship between CO2 sources and CO2 storages, 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 CO2 emissions into storage. A field scale of source-sink match for CCUS development in South Sumatera have been done in similar concept by Usman et al. (2021).

Several studies of CO2 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 CO2 sources and potential candidates of CO2 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 of CO2 source and sinks was also studied in Taiwan (Chauvy et al., 2022), considering CO2 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 limitation of Source-sink study globally as there is no detailed data, thus only local and regional scale study are available although a layout of global scheme of CCS has been proposed by Wei et al., (2021).

In this study, we created a spatial database to match CO2 sources and sinks, including case studies in West Java within a GIS environment. This aims to support the advancement of CCS/CCUS projects in Indonesia. The proposed CO2 source-sink-clustering system maps the connections between potential sources and storages based on the existing pipeline right-of-way (ROW) network. The advantage of this approach is that the locations of existing and future oil and gas pipelines are already known, allowing us to anticipate a significant reduction in costs related to land release and permit processes.

II. METHODS

A. Workflow for Determining CO2 Source and Sinks

In order to perform CO2 Source and Sinks matching, we follow the steps as shown in Figure 1. the first step is to identify the available CO2 emitter and potential storage in the area. In this case, we selected high producing CO2 facilities such as Central Processing Plant, Coal-fired Power Plant, Petrochemical Industry, Cement Industry, etc. as the main CO2 source. Next is to determine the available potential storage in the area by mapping all available gas and oil fields near the selected CO2 emitter. The collected information of the available fields will be crucial especially the subsurface properties and storage capacity. Sometimes, the storage capacity should be reviewed and recalculate to obtain valid number as it will be used for the next steps.

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 CO2 source and the oil/gas fields, we also filtered out all the fields that not yet developed or still in exploration stage. If the scenario of the project is CCS, we will select the depleted field only, however if the scenario is for CCUS we will consider the producing field especially the fields that need to be improved by implementing Enhanced Oil/Gas Recovery. Lastly, we prefer to select the field that was operated by Pertamina as to simplify the permit process.

In this study, we employed a Geographic Information System (GIS) environment to investigate and establish spatial connectivity between CO2 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 CO2 emission sources, geological features, existing pipeline, and potential storage reservoirs, enabling us to identify and assess potential matches between sources and sinks with the aim of analyzing 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 CO2 sources and sinks. Specifically, we were able to identify the most suitable locations for the storage of CO2 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 CO2 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 carbon capture and storage (CCS) and carbon capture, utilization, and storage (CCUS) within the Indonesian context rapidly and accurately. The GIS tools enabled us to match CO2 sources with their corresponding sinks and to determine the optimal pipeline routes to transport CO2 from the sources to the selected storage sites. By utilizing GIS, we aimed to analyze and map the geographical relationships between CO2 emission sources and potential storage sites. This approach allowed us to evaluate the feasibility and suitability of connecting CO2 sources with appropriate sinks in terms of spatial proximity.

After the number of fields have been sorted out, the storage and CCS project must be assessed further with more detail. The detailed assessment includes perform 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.

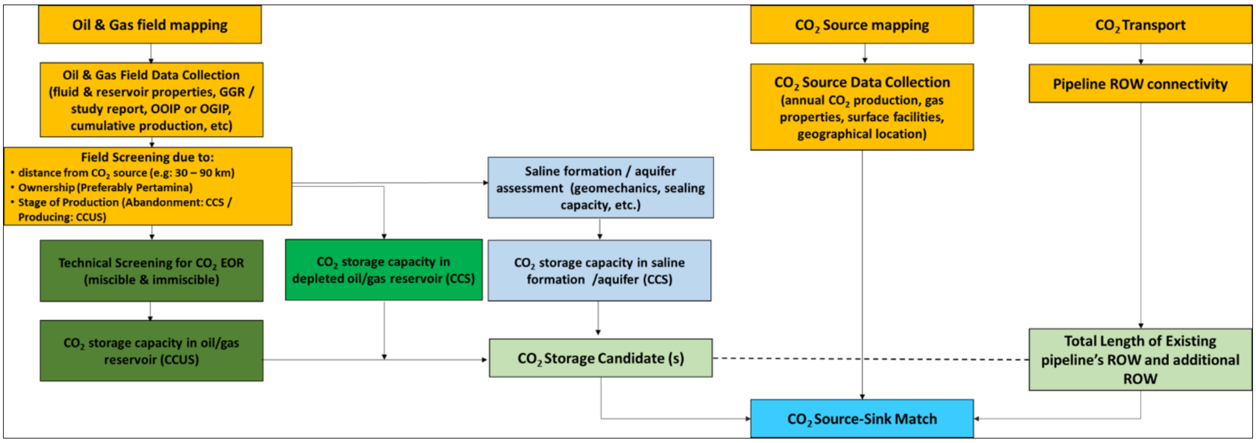

Figure 1. Schematic workflow of CO2 source and sinks matching determination

B. Identification of CO2 Sources

The CO2 is emitted from large variety of sources, including large stationary sources that produce significant amount of CO2 (Bains et al., 2017). It's worth noting that not all sources of CO2 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 CO2 that can be captured using CCS include:

- Power plants: CO2 can be captured from the flue gas emitted by power plants that burn fossil fuels such as coal power plant, natural gas, and oil.
- Industrial facilities: CCS can be applied to industrial processes such as cement, steel, and chemical production, which are major sources of CO2 emissions.
- Natural gas processing: CO2 can be captured from natural gas fields before it is sent to pipelines for distribution.
- Bioenergy: CCS can be used in bioenergy plants that produce electricity by burning biomass such as wood or other plant-based materials.
- Direct air capture (DAC) is a technology that captures CO2 directly from the atmosphere, it can be used as a source of CO2 for CCS

In this study, we concentrated on identifying significant CO2 sources that produce over 1,000,000 tCO¬2 annually. Data from various industries that are significant CO2 producers, such as central processing plants, coal-fired power plants, petrochemical industries, cement industries, and pulp and paper industries, was collected and documented in our database. To perform an accurate mapping of CO2 sources, both geo-spatial data and annual CO2 emission data are necessary. The data is then plotted on a map, serving as the focal point of the source-sink analysis.

C. Calculation of Storage Capacity

The captured CO2 is transported to the subsurface storage or geological storage. The CO2 storage utilizes the depleted oil & gas reservoir or deep saline aquifer to store the super critical CO2 that was transported from CO2 source. We focused on depleted oil & gas fields as our main target as Indonesia has significant amount of depleted reservoir. Here, we identify and collect the data of depleted reservoirs near the CO2 Source and assess based on its capacity and distance from the source.

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To determine the potential of CO2 sinks, there is also a need to calculate CO2 storage capacity. CO2 storage capacity pyramid which is presented in Figure 2, was proposed by Bachu et al., (2007) as one of the methods to classify the value of CO2 storage based on data availability. As it is evident on the scheme, the goal of the current study is to calculate the theoretical capacity using only a limited set of data, therefore further study should be done to increase the conviction into effective capacity or even matched capacity. This approach considers both regional and local scales in selecting suitable CO2 fields for injection. It can minimize the costs and time required in identifying appropriate CO2 fields, while enabling more focused and measurable field selection. Therefore, the use of our database can enhance the efficiency and effectiveness of selecting field candidates for CO2 injection.

To enhance the significance of the study, fields with a calculated storage capacity of less than 1 million tCO2e will be excluded from consideration for CCS/CCUS sinks, as they are not economically viable (with less than 2 MMSCFD of CO2 for 20 years). Additionally, the reservoir depth must be deeper than 800 m (approximately 2600 ft) to minimize the risk of early CO2 breakthrough or leakage. (Al Adasani & Bai, 2011).

This study particularly uses Goodman et al., (2011) equation to calculate CO2 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 CLSF model as other calculation method (Bachu, et al., 2007). In 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 CO2. The equations for calculating CO2 storage capacity is presented in Table 2.

Table 1. Correlations for Calculating CO2 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*

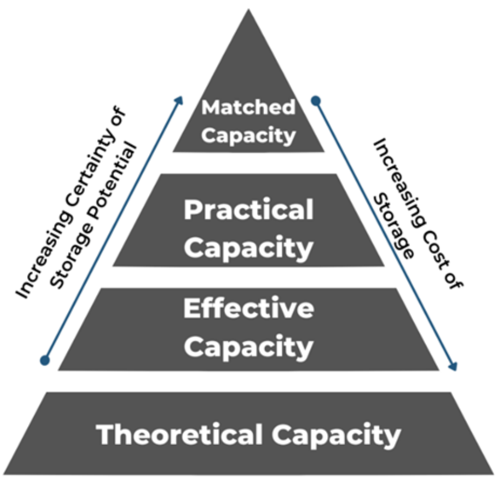

Figure 2. Storage Capacity Pyramid (Bachu et al, 2007)

D. Pipeline Route Proposal

The purpose of using spatial analysis for the CO2 Source-Sink Matching is to assess the initial calculation related the infrastructure availability. The CO2 could be transported through train and truck for short distance and small CO2 quantities or using pipelines and shipping for transporting megatons of CO2 per year (Mtpa) as this method could be more effective due to economies scale (NPC, 2019). In this case, we suggest pipeline as the transportation method from CO2 Source to CO2 Storage as it is the most effective mode of transport for large scale CO2 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 carbon dioxide (CO2). By utilizing existing ROW effectively, we can reduce costs associated with land clearance and permit acquisition (Yildirim et al., 2017). 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 CO2 transportation, the ROW of existing pipelines can still be utilized. The following diagram illustrates the scheme of CO2 sources and sinks management that are connected by pipelines (Figure 3). The blue and brown lines represent pipeline connection between source and sinks.

In our approach, we prioritize sinks that are connected to the source by pipeline network, provided that the sinks have sufficient storage capacity. In the event that 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 to existing pipeline can be varied and sensitive to price scenario so the calculation must be done iteratively to obtain 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.

The pipeline route is predicted based on its nearest distance or the shortest length possible between source and its targeted sinks. To perform this calculation, we trace the availability of ROW first and plan the pipeline route based on the ROW route. Then, in the case that there is no available ROW a new pipeline route is proposed to connect the source or sink location with main existing route. Although sometimes the nearest route is achieved by building new route, it is not preferable as the land permit and clearance cost could be significant.

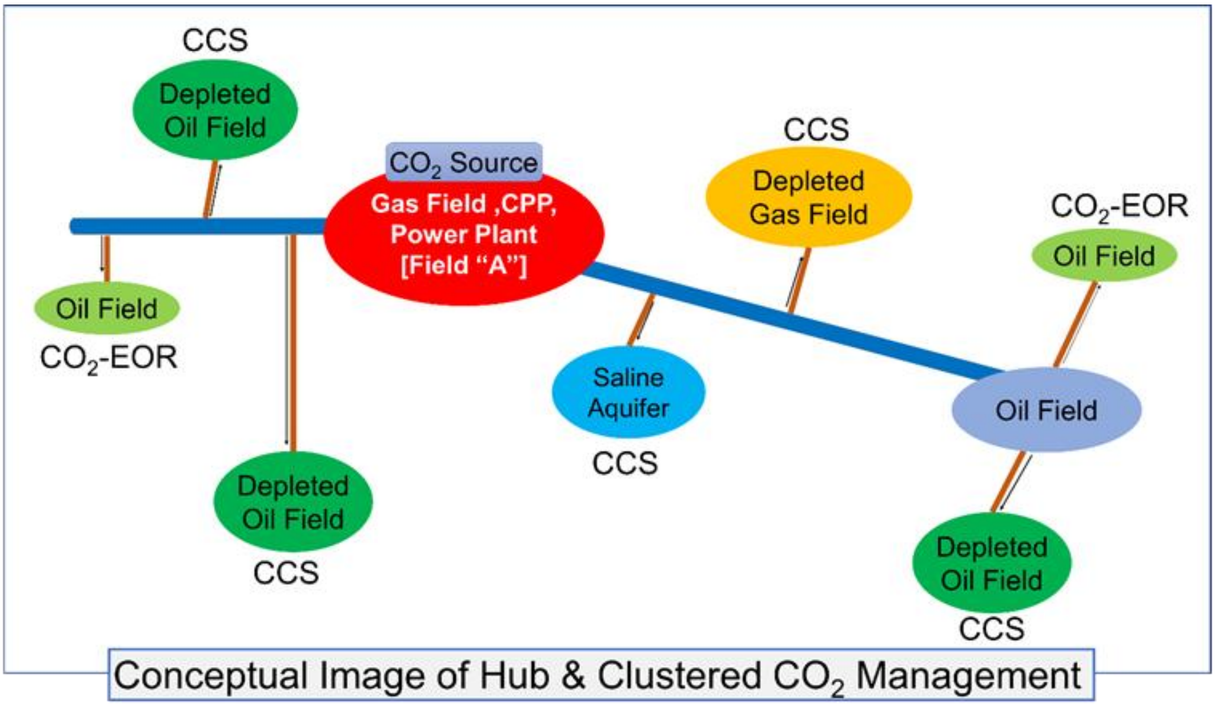

Figure 3. Conceptual diagram of CO2 Source – sink match Management.

III. RESULTS AND DISCUSSION

We applied the methodology which is mentioned in previous section to one of the big coal-fired power plant in West Java. The CO2 mapping process in West Java, with Coal-fired Power Plants as the main CO2 source, involves the identification and selection of potential CO2 sinks based on established criteria. The representation of the depleted hydrocarbon fields, coal-fired power plant is depicted in Figure 4, where the green circles denote the depleted oil fields and red circles denotes depleted gas fields, while the CO2 source is represented by a blue square. The name of the field and its detailed data is not permitted to be published in this works and the accurate location of each feature are not presented. Further technical evaluations are necessary to determine the feasibility of each sink in the West Java region.

In this study, we select the coal-fired power plant that emit significant quantities of CO2 annually. This power plant supply significant electricity for Java, Bali, and Madura that generates over 600 MW of electricity, resulting in a substantial annual CO2 emission of over 2 million tonnes. For the 20-year project lifespan, a minimum injection of 40 million tonnes of CO2 is expected to reach zero emission for this coal-fired power plant. Therefore, it is necessary for the storage capacity to be adequate to accommodate that volume of CO2.

The drawback of this coal-fired power plant location is the absence of depleted reservoirs within a 30 km radius of the coal-fired power plant, making the connection to the nearest storage relatively further away. However, one advantage of this coal-fired power plant is the availability of pipeline networks near the coal-fired power plant location, which reduces the land acquisition process. In addition, the location of the coal-fired power plant is close to the sea, making transportation via shipping easier, although we did not consider it in this study and further investigation is needed.

In order to prioritize and select appropriate fields for CO2 storage, we divided the potential fields into three clusters based on radial distance from the CO2 source: 30 km, 60 km, and 90 km. Before proceeding with field selection and calculation, a screening process was conducted using criteria provided by Al Adasani & Bai (2011) to identify the most suitable target fields based on reservoir properties and remaining oil in place. The focus of this study was on depleted oil or gas fields, without considering the potential for CO2 enhanced oil recovery (EOR) or enhanced gas recovery (EGR). Therefore, the CO2 injected in this CCS scheme would be stored exclusively in depleted reservoirs without any further utilization. While the nearest field within the 30 km cluster would be preferred due to lower transportation costs, Figure 4 illustrates that no available field falls within this radius. As a result, the selection of potential storage sites must be extended to the wider clusters. We employ screening criteria based on parameters as shown in Table 3.

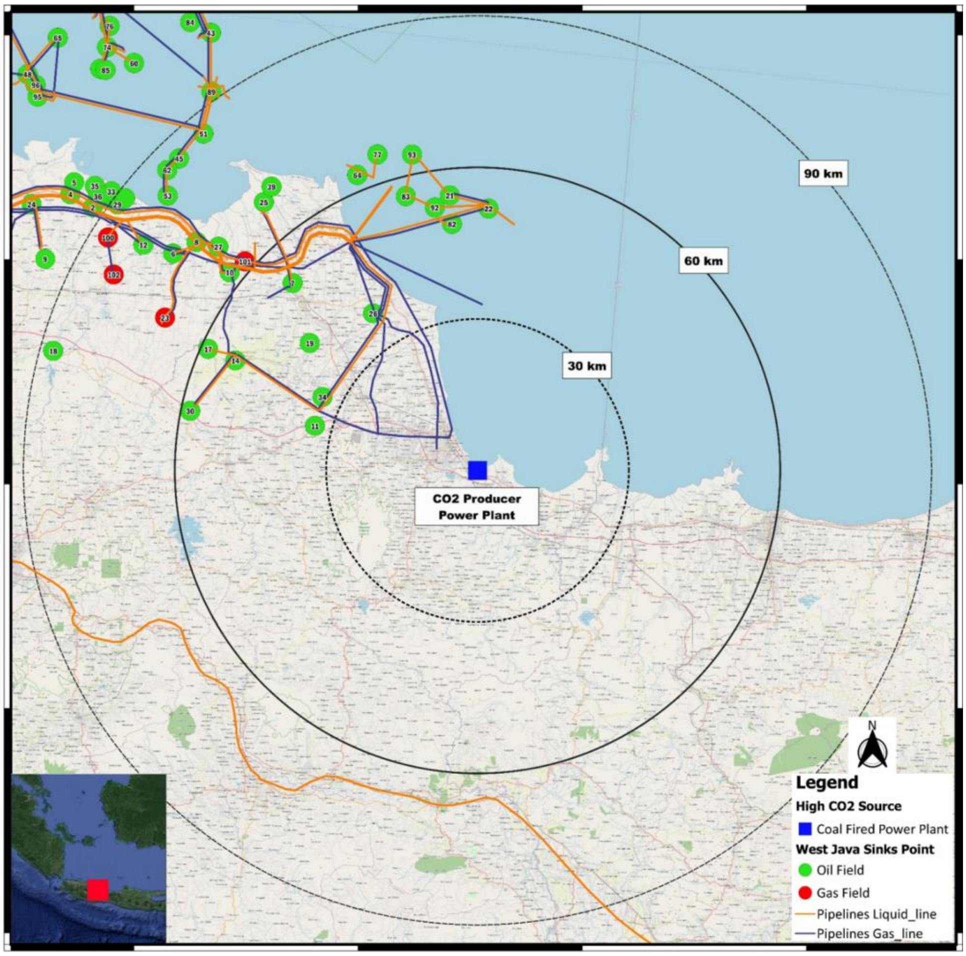

Figure 4. Initial mapping of the identification of CO2 sources in the form of coal-fired power plants and available oil and gas fields as CO2 Storage candidates in the proximity CO2 source. The blue square represents CO2 Source, green and red circles represent oil and gas fields respectively. Most of the possible candidates for CO¬2 storage are in the northwestern direction from the power plant.

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Table 3. Parameter Criteria for CO2 Storage Screening

Parameter Values			
Field Location		Offshore	Onshore
		Fair	Good
Depth		< 800 m	> 800 m
		Fair	Good
Porosity	< 3%	3% < X <15%	> 15%
	Bad	Fair	Good
Reservoir Lighology	Tight Formation/Shale	Carbonate/Naturally Frac. Reservoir	Sandstone
	Bad	Fair	Good
Permeability	< 1.5 Md	1.5 mD < X < 200 mD	> 200 mD
	Bad	Fair	Good
Field Operator	Non Pertamina	JOB w/Pertamina	Pertamina
	Bad	Fair	Good
Field Status	Producing	Abandoned	Depleted/Temp. Shut In
	Bad	Fair	Good
Distance from Source	> 100 km	30 km < X < 100 km	< 30 km
	Bad	Fair	Good
Calculated Storage Capacity	< 1 MMT	1 MMT < X < 7 MMT	> 7 MMT
	Bad	Fair	Good
Pipeline ROW Availability	No ROW (Standed Field)	Need Additional ROW to Integrate w/Existing ROW	Fully Integrated with Existing ROW
	Bad	Fair	Good
Network Required for Full CO_2 Sequestration	> 6 Sinks	3 Sinks/Field < X < 6 Sinks/Field	1 Sinks/Field < X < 3 Sinks/Field
	Bad	Fair	Good
Total Pipeline Length Required	> 400 km	200 km < X < 400 km	0 km < X < 200 km
	Bad	Fair	Good

Parameter Values			
Caprock Lateral Continuity		Lateral Variation Medium to Large Faults	Stratigraphically Uniform, Little or No Faults
		Fair	Good
Caprock Thickness (Chadwick, 2008)	< 65 ft	65 ft < X < 320 ft	> 320 ft
	Bad	Fair	Good

Based on the calculation and mapping of CO2 sinks in West Java Area, there are several possible candidates for CCS application as there are several depleted fields with significant storage capacity. Most of the fields are located Northwest of the Coal-fired Power plant with some of the fields are located off-shore which complicating the transportation. In this study we will only consider the onshore fields as the transportation via pipeline is preferable. However, further study must also be performed especially on the older fields in order to ensure well integrity and avoid leakage in the long term.

There are 34 fields within a 90 km radius of the coal-fired power plant (CFPP), including offshore fields. All of these fields are non-producing or depleted fields since this study only considers the scenario for carbon capture and storage (CCS). Although there are several producing fields that are potentially applicable for the scenario of carbon capture, utilization, and storage (CCUS), this paper does not discuss them. The available pipeline route is also presented on the map, with the blue and yellow lines indicating the gas and oil pipeline routes, respectively. These existing routes will be included in the analysis to determine the proposed route for connecting the CO2 source and the CO2 sinks. The inclusion of these routes will help to assess the feasibility and cost-effectiveness of connecting the CFPP with the selected CO2 sinks.

Several feasible fields for the CCS candidate can be seen on the table below (Table 3) with respect to storage capacity. These depleted oil and gas fields are selected as the largest storage capacity for CO2 injection emitted by this Coal-fired Power Plant. The three biggest storage capacity is from Field 23, Field 102, and Field 18 while the nearest is Field 14. The selected CCS sink candidates are further prioritized based on their capacity and presented in Figure 7. The blue circles indicate the most suitable and prioritized CCS sites, while the green circles denote the secondary options that require additional study. The four fields that have been classified as priority candidates are insufficient to meet the required storage capacity of 40 MtCO2. Hence, it is essential to consider additional secondary options to achieve the target storage capacity of 40 MtCO2. Sites that fail to meet the minimum storage capacity are excluded from the map. The total capacity of these fields reaches 42.03 MMT of CO2 which is adequate for the injection of 40 MtCO2 for 20 years.

The proposed route is presented on the Figure 5. We separated between the existing ROW with the green line while the new ROW with brown line. All of pipeline dedicated for CO2 must be constructed separately from existing pipe, although the ROW is still usable for new CO2 pipe. The total length of the existing ROW that connects the main CO2 Source to the sink candidates is about 199.4 km to reach all priority depleted fields. However, there is need to build new pipeline route for connecting the Coal-fired power plant to the main pipeline route as there is no existing ROW yet. At least 9.2 km is necessary to connect the coal-fired power plant to main existing ROW available. Moreover, it should be noted that Field 18, which is one of the priority candidates, is currently not connected to the existing pipeline network. As such, it is necessary to construct additional 23.872 km of pipeline route ROW to accommodate the transportation of CO2 to Field 18. Based on our calculations, it has been determined that the construction of additional ROW of pipeline route with a minimum length of 33.1 km is necessary to establish a connection between the coal-fired power plant and all of the candidate sinks. To reach Field 18, we conclude that taking the route from Field 102 is better than connecting from Field 30 as the necessary new ROW is shorter.

Table 4. Storage Capacity of oil and gas fields in the proximity of CO2 Source. Length of pipeline is measured from coal fired power plant to the specific selected site. The total storage capacity of CO2 could reach 42.03 MMT which is enough to store CO2 emission from the Coal Power Plant for 20 years

Field ID	Status	HC Type	Pipeline Length (km)	Storage Capacity (MMT)
Field 17	Shut-in	Oil & Gas	61.6 km	2.58
Field 18	Shut-in	Oil & Gas	139.8 km	7.44
Field 30	Shut-in	Oil & Gas	70.1 km	6.85
Field 34	Shut-in	Oil & Gas	36.3 km	4.68
Field 23	Shut-in	Oil & Gas	104.9 km	11.22
Field 102	Shut-in	Gas Field	115.9 km	9.26

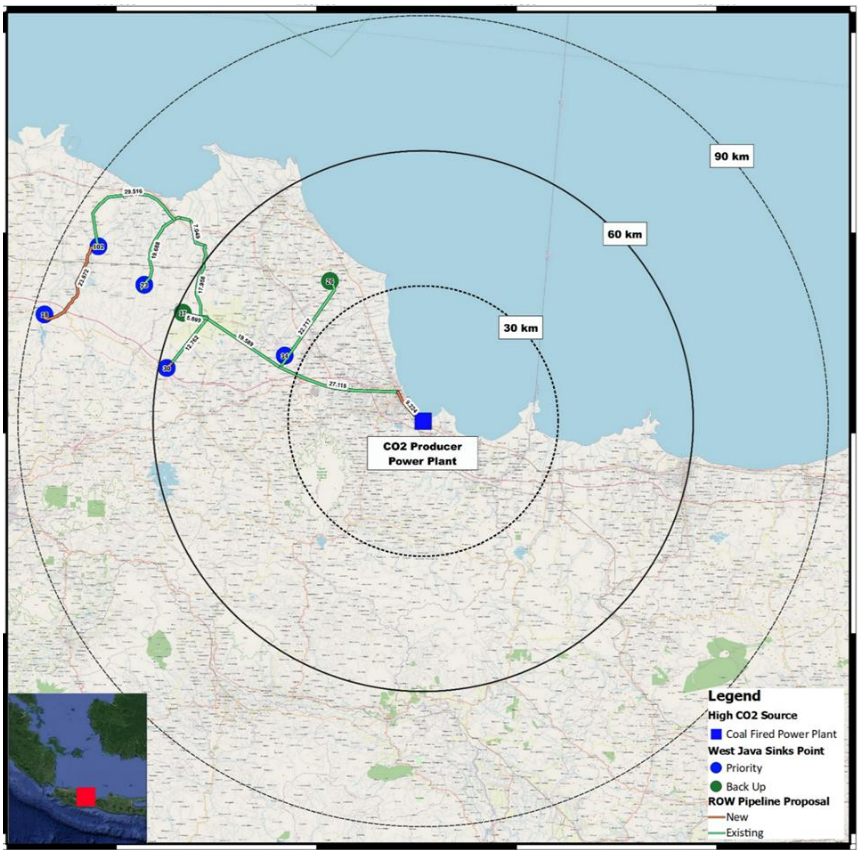

Figure 5. The selected candidates for CO2 storage based on the priority level. The blue circles represent priority fields that suitable for CCS, while the green circles represent second priority as the storage capacity is lower. Green and brown line represent suggested pipeline route for CO2 transportation. The former would be pipeline route using existing ROW while the latter is the new route.

IV. CONCLUSION

Based on this research and analysis, it can be concluded that to support Indonesia's goal of reaching Zero Net Emissions by 2050, scenarios for both CCS and CCUS are necessary to capture high CO2 emissions from various industries. Our proposed method is source-sink matching to assess the potential for implementing CCS and CCUS in Indonesia. The method and workflow were demonstrated through a case study on a coal-fired power plant in West Java. This plant produces 2 million tons of CO2 annually, which will total 40 million tons over a 20-year project. To determine the best locations for CCS, we evaluated depleted oil reservoirs based on factors such as proximity, storage capacity, pipeline connectivity, and production status. There are six potential candidates with a combined storage capacity of 42.03 MMT of CO2.

The source-sink matching method can be used to identify storage potential that is relatively close to the CO2 source. This workflow is suitable for conditions with limited data but clear geographical information. We also consider the availability of Right-of-Way (ROW) pipelines in the storage determination, as this can significantly reduce the land acquisition cost. By utilizing geographical location and availability of spatial data, we can quickly screen and focus on more in-depth and detailed studies. Further detailed studies must be carried out after this study is completed to confirm the subsurface parameters.

The findings of this study can assist policymakers and energy companies in the selection of optimal CCS sites and in implementing strategies to achieve climate change goals. The study highlights the importance of prioritizing CCS sites based on storage capacity to ensure successful implementation of CCS technologies.

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REFERENCES

Al Adasani, A., & Bai, B. (2011). Analysis of EOR projects and updated screening criteria. Journal of Petroleum Science and Engineering, 79(1–2), 10–24. https://doi.org/10.1016/j.petrol.2011.07.005

Bachu, S., Bonijoly, D., Bradshaw, J., Burruss, R., Christensen, N. P., Holloway, S., Mathiassen, O.-M., & Forum, C. S. L. (2007). Phase II Final Report from the Task Force for Review and Identification of Standards for CO2 Storage Capacity Estimation. Estimation of CO2 Storage Capacity in Geological Media - Phase 2 -, August 2005, 43. http://www.cslforum.org/publications/documents/PhaseIIReportStorageCapacityMeasurementTaskForce.pdf

Bachu, S., Bonijoly, D., Bradshaw, J., Burruss, R., Holloway, S., Christensen, N. P., & Mathiassen, O. M. (2007). CO2 storage capacity estimation: Methodology and gaps. International Journal of Greenhouse Gas Control, 1(4), 430–443. https://doi.org/10.1016/S1750-5836(07)00086-2

Bains, P., Psarras, P., & Wilcox, J. (2017). CO2 capture from the industry sector. Progress in Energy and Combustion Science, 63, 146–172. https://doi.org/10.1016/j.pecs.2017.07.001

Becattini, V., Gabrielli, P., Antonini, C., Campos, J., Acquilino, A., Sansavini, G., & Mazzotti, M. (2022). Carbon dioxide capture, transport and storage supply chains: Optimal economic and environmental performance of infrastructure rollout. International Journal of Greenhouse Gas Control, 117(October 2021), 103635. https://doi.org/10.1016/j.ijggc.2022.103635

Bolstad, P. (2019). GIS Fundamentals: A First Text on Geographic Information Systems, 6th edition.

Chauvy, R., Lai, Y., & Chen, P. (2022). A Geographical Source-sink Matching for Carbon capture and Utilization deployment in Taiwan. International Journal of Greenhouse Gas Control, 119(1), 103722. https://doi.org/10.1016/j.ijggc.2022.103722

Department of Energy & Climate Change., Global CCS Institute., & Asian Development Bank. (2013). Prospects for carbon capture and storage in Southeast Asia.

Fan, J. L., Xu, M., Wei, S., Shen, S., Diao, Y., & Zhang, X. (2021). Carbon reduction potential of China’s coal-fired power plants based on a CCUS source-sink matching model. Resources, Conservation and Recycling, 168(June 2020), 105320. https://doi.org/10.1016/j.resconrec.2020.105320

Goodman, A., Hakala, A., Bromhal, G., Deel, D., Rodosta, T., Frailey, S., Small, M., Allen, D., Romanov, V., Fazio, J., Huerta, N., McIntyre, D., Kutchko, B., & Guthrie, G. (2011). U.S. DOE methodology for the development of geologic storage potential for carbon dioxide at the national and regional scale. International Journal of Greenhouse Gas Control, 5(4), 952–965. https://doi.org/10.1016/j.ijggc.2011.03.010

IEA. (2021). Net Zero by 2050: A Roadmap for the Global Energy Sector. International Energy Agency, 224. https://www.iea.org/reports/net-zero-by-2050

Iskandar, Utomo P., Usman, U., & Sofyan, S. (2013). Ranking of Indonesia sedimentary basin and storage capacity estimates for CO2 geological storage. Energy Procedia, 37, 5172–5180. https://doi.org/10.1016/j.egypro.2013.06.433

Iskandar, Utomo Pratama, & Syahrial, E. (2009). Carbon Capture And Storage (Ccs) - Enhanced Oil Recovery (Eor): Global Potential In Indonesia. Scientific Contributions Oil and Gas, 32(3), 228–238. https://doi.org/10.29017/scog.32.3.855

Marbun, B. T. H., Prasetyo, D. E., Prabowo, H., Susilo, D., Firmansyah, F. R., Palilu, J. M., Silamba, I. C., Santoso, D., Kadir, W. G. A., Sule, R., Kardani, I., Saprudin, W., & Andhika, B. (2019). Well integrity evaluation prior to converting a conventional gas well to CO2 injector well – Gundih CCS pilot project in Indonesia (phase 1). International Journal of Greenhouse Gas Control, 88(October 2018), 447–459. https://doi.org/10.1016/j.ijggc.2019.06.006

Matejicek, L. (2017). Assessment of Energy Sources Using GIS. In Assessment of Energy Sources Using GIS. https://doi.org/10.1007/978-3-319-52694-2

Minister of Environment and Forestry. (2022). Enhanced NDC Republic of Indonesia 2022. https://www.ptonline.com/articles/how-to-get-better-mfi-results

Mulyasari, F., Harahap, A. K., Rio, A. O., Sule, R., & Kadir, W. G. A. (2021). Potentials of the public engagement strategy for public acceptance and social license to operate: Case study of Carbon Capture, Utilisation, and Storage Gundih Pilot Project in Indonesia. International Journal of Greenhouse Gas Control, 108, 103312. https://doi.org/10.1016/j.ijggc.2021.103312

NPC. (2019). Meeting the dual challenge: a roadmap to at-scale deployment of carbon capture, use, and storage. December 2019.

Raza, A., Gholami, R., Rezaee, R., Rasouli, V., & Rabiei, M. (2019). Significant aspects of carbon capture and storage – A review. Petroleum, 5(4), 335–340. https://doi.org/10.1016/j.petlm.2018.12.007

Rikalovic, A., Cosic, I., & Lazarevic, D. (2014). GIS based multi-criteria analysis for industrial site selection. Procedia Engineering, 69, 1054–1063. https://doi.org/10.1016/j.proeng.2014.03.090

Ritchie, H., Roser, M., & Rosado, P. (2020). CO_2 and Greenhouse Gas Emissions. Our World in Data.

Sapiie, B., Danio, H., Priyono, A., Asikin, A. R., Widarto, D. S., Widianto, E., & Tsuji, T. (2015). Geological characteristic and fault stability of the Gundih CCS pilot project at central Java, Indonesia. 1, 110–113. https://doi.org/10.1190/segj122015-029

Smith, N., Boone, P., Oguntimehin, A., Essen, G. Van, Guo, R., Reynolds, M. A., Friesen, L., Cano, M., & Brien, S. O. (2022). International Journal of Greenhouse Gas Control Quest CCS facility : Halite damage and injectivity remediation in CO 2 injection wells. International Journal of Greenhouse Gas Control, 119(May), 103718. https://doi.org/10.1016/j.ijggc.2022.103718

Sun, L., Jiang, Y., Guo, Q., Ji, L., Xie, Y., Qiao, Q., Huang, G., & Xiao, K. (2021). A GIS-based multi-criteria decision making method for the potential assessment and suitable sites selection of PV and CSP plants. Resources, Conservation and Recycling, 168(September 2020), 105306. https://doi.org/10.1016/j.resconrec.2020.105306

Turan, G., Zapantis, A., Kearns, D., Tamme, E., Staib, C., Zhang, T., Burrows, J., Gillespie, A., Havercroft, I., Rassool, D., Consoli, C., & Liu, H. (2021). Global status of CCS 2021. Global CCS Institute, 1–43. https://www.japanccs.com/wp/wp-content/uploads/2021/10/0-4-GCCSI_Jarad-Daniels.pdf

Usman, D. I. (2018). Prospect for Co2 Eor To Offset the Cost of Ccs At Coal Power Plants. Scientific Contributions Oil and Gas, 39(3), 107–118. https://doi.org/10.29017/scog.39.3.94

Usman, U., Saputra, D. D., & Firdaus, N. (2021). Source Sink Matching for Field Scale CCUS CO2-EOR Application in Indonesia. Scientific Contributions Oil and Gas, 44(2), 97–106. https://doi.org/10.29017/scog.44.2.586

Wei, Y. M., Kang, J. N., Liu, L. C., Li, Q., Wang, P. T., Hou, J. J., Liang, Q. M., Liao, H., Huang, S. F., & Yu, B. (2021). A proposed global layout of carbon capture and storage in line with a 2 °C climate target. Nature Climate Change, 11(2), 112–118. https://doi.org/10.1038/s41558-020-00960-0

Yildirim, V., Yomralioglu, T., Nisanci, R., Çolak, H. E., Bediroğlu, Ş., & Saralioglu, E. (2017). A spatial multicriteria decision-making method for natural gas transmission pipeline routing. Structure and Infrastructure Engineering, 13(5), 567–580. https://doi.org/10.1080/15732479.2016.1173071

Zhang, Z., Pan, S. Y., Li, H., Cai, J., Olabi, A. G., Anthony, E. J., & Manovic, V. (2020). Recent advances in carbon dioxide utilization. Renewable and Sustainable Energy Reviews, 125(March), 109799. https://doi.org/10.1016/j.rser.2020.109799

Zhu, Q., Wang, C., Fan, Z., Ma, J., & Chen, F. (2019). Optimal matching between CO2 sources in Jiangsu province and sinks in Subei-Southern South Yellow Sea basin, China. Greenhouse Gases: Science and Technology, 9(1), 95–105. https://doi.org/10.1002/ghg.1835