Technical Evaluation for CO_2 Sequestration Opportunity in Saline Aquifer Asri Basin, Offshore Southeast Sumatra, Indonesia

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[**Abstract**] - Indonesia has officially ratified the Climate Change Convention through the enactment of Law No. 6 of 1994, which pertains to the ratification of the United Nations Framework Convention on Climate Change. Indonesia intends to achieve a 29% reduction in emissions by employing various measures, including the adoption of Carbon Capture and Storage (CCS) or Carbon Capture Utilization and Storage (CCUS) technology. This platform will serve as a means to facilitate the execution of these initiatives. Pertamina Hulu Energi OSES is presently capitalizing on the prospect of harnessing the potential of the saline Asri Basin for the purpose of carbon capture and storage. This study aims to assess the viability of injecting CO_2 into a saline aquifer by examining both surface and subterranean criteria. The process of surface screening commences by examining the carbon dioxide (CO_2) sources in the vicinity of the Asri Basin. According to the geographical mapping of the area, there exist numerous sources within a square radius of 400 kilometers, with the closest target being situated in the vicinity of Cilegon. Subsequently, a transportation scenario is presented, whereby a comparative analysis of the expenses associated with pipeline and vessel transportation is conducted. The following chapter centers its attention on the subsurface reservoir properties in order to ascertain the extent of carbon capture storage. Based on the computation of storage, three possible outcomes can be identified: a conservative estimation, an optimal estimation, and an upper estimation. The reservoir parameter is employed for monitoring models through three distinct displays, including CO_2 gas saturation, pressure increase, and pressure reservoir. The determination of the most economically optimal and sustainable alternative for the CCS project necessitates an evaluation from both surface and subsurface perspectives.

[Keywords] Carbon Capture Storage; CO_2 Source; Reservoir; Saline Asri Basin.

[INTRODUCTION]

Background

In consideration of the escalating concerns around greenhouse gas emissions and the consequential global warming phenomenon, it is incumbent upon governments and select multinational corporations to assume responsibility for mitigating these challenges. The issue of climate change has been raised in international forums, including the Kyoto Protocol, Paris Agreement, and most recently, COP 26. Indonesia is among the nations participating in the itinerary of this global conference. The ratification of the United Nations Framework Convention on Climate Change by Indonesia has been formalized through the enactment of Law Number 6 of 1994. Indonesia aims to achieve a 29% reduction in emissions by implementing various measures, including the adoption of Carbon Captured Storage / Carbon Capture Utilization Storage (CCS/CCUS) technology. Furthermore, with international assistance and adherence to the Low Carbon Compatible with Paris scenario, the country's emission reduction target is expected to increase to 41% (PPID Ministry of Environment, 2021). In order to mitigate the emissions of this particular greenhouse gas, it is imperative to develop a technological solution that enables the collection of carbon dioxide from the atmosphere. Subsequently, the captured carbon dioxide can be sequestered by injecting it into subsurface geological formations. One of the technological advancements that might be pursued by oil and gas firms is the implementation of Carbon Capture Storage (CCS). The Asri Basin is situated in the Southeast Sumatra Block, including an area of approximately 3500 km2. It is characterized by a sediment thickness of up to 16,000 feet, as reported by Sukanto et al. in 1998. The territory in question is situated within the Java Sea, positioned between the islands of Java and Sumatra. It extends in a northerly direction from West Java and in an easterly direction from South Sumatra. The basin under consideration is delimited by the Sunda Shelf to the north, the Billiton Basin and the Karimun Java Basin to the east, the West Java Basin and the Seribu Platform to the south, and the Lampung Highlands to the west (Sukanto et al., 1998). The Asri Basin is situated in the offshore region of the Southeast Sumatra Block, covering an area of approximately 3500 km2. It is characterized by a sediment thickness that can reach up to 16,000 feet, as depicted in Figure 1 (left). According to the study conducted by Sukanto et al. in 1998, it was found that the territory in question is situated within the Java Sea, positioned between the islands of Java and Sumatra. It extends in a northerly direction from West Java and in an easterly direction from South Sumatra. The basin under consideration is delimited by the Sunda Shelf to the north, the Billiton Basin and the Karimun Java Basin to the east, the West Java Basin and the Seribu Platform to the south, and the Lampung Highlands to the west (Sukanto et al., 1998).

Geological/Stratigraphical Settings

The Asri basin can be classified as a back-arc basin, a half-graben rift basin, and a composite extensional style, sag type basin, as described by Young and Atkinson (1993). According to Aldrich et al. (1995), The area is encompassed by north-south normal faults that exhibit a westward dip, while the southern boundary is characterized by a regional wrench system oriented in the northwest-southeast direction. The structural style and depositional systems of the Asri Basin were impacted by three notable tectonic eras. The evolution of the basin can be divided into three distinct phases, which are referred to as rift initiation, rifting, and post-rift sag (Tonkin & Hemawan, 1999). This information is illustrated in Figure 1 on the right side. During the rift initiation phase, which occurred from the Paleocene to the Earliest Oligocene, the process of extension and the presence of pre-existing weaknesses in the Mesozoic crust led to the formation of a sequence of mini-basins. The primary deposition is attributed to the Banuwati Formation, which is characterized by the accumulation of sediments in the form of alluvial fan deposits. Additionally, lacustrine sediments can be observed overlaying the western and northern sides of the basin. During the Early to Late Oligocene period, a phase of rifting took place, leading to the development of en-echelon faults on both the eastern and western edges of the basin.

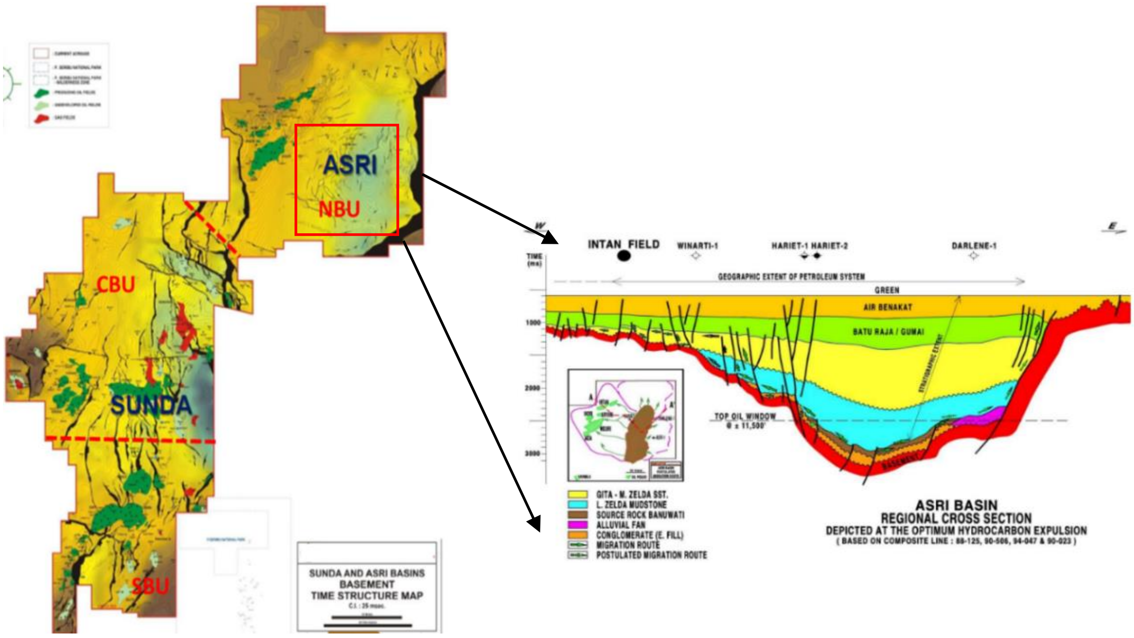


Figure 1 Asri basin location (left), Asri basin regional cross-section (right)

The basin initiated a process of symmetrical subsidence. Subsequently, the fault system located to the east saw rapid subsidence, resulting in the formation of a half-graben structure inside the basin. This geological process led to the deposition of the Talang Akar Formation, which consists of sediments ranging from fluvial to paralic in nature. During the initial phase of the Miocene epoch, there was a reduction in extensional activity that coincided with the sedimentation of the Gita Member within the Talang Akar Formation. During the Early Miocene epoch, the basin development entered a phase known as post-rift sag, characterized by the occurrence of regional subsidence and the deposition of marine limestones and shales. This process also involved the onlap of the basin borders and the continued accumulation of sediments, which eventually formed the Batu Raja Formation. During the Middle to Late

Miocene period, a basin was formed as a result of the second phase of faulting and moderate volcanic activity. The NE-SW faults had significant effects on the Tertiary cover in the region. The period characterized by basin reversion led to the uplift and erosion of the margins of the basin, as well as intrabasinal highs. Additionally, fault-related traps were formed as a result of this process (Tonkin & Himawan, 1999). The process of deposition commenced with the presence of basement rock, which primarily comprised granitoid igneous rock and low-grade metamorphic rock throughout the early to late Cretaceous period (Slameto, 2006, Figure 2).

The Banuwati Formation, which was deposited during the Eocene epoch, is primarily composed of conglomerate and sandstone sediments. The depositional setting is situated within an alluvial fan. The Talang Akar Formation exhibits a clear stratigraphic division into two distinct portions spanning the early Oligocene to the early Miocene. The Lower Talang Akar Formation, also known as Zelda, is composed of claystone and conglomerate sandstone, which are considered as deposits from an alluvial system. The primary focus of this study is the Upper Talang Akar Formation (referred to as Gita), which aims to investigate the injection of CO_2 into the interval characterized by interbedded coals, claystone, and sandstones. Typically, the sandstones exhibit a coarse-grained texture that transitions to a finer-medium grained quartz arenite, displaying obvious porosity and permeability. These characteristics suggest that the sandstones were deposited within a fluvio-deltaic system. The Gita Member possesses a reservoir for intermittent production. There will be a lengthy discussion in the next session regarding the topics labeled as 33-1, 34-1, 34-2, 35-1, and 33-2. During the early Miocene period, the Batu Raja Formation, which primarily comprises shallow marine carbonate deposits, was impacted by a transgression event. The Gumai Formation is a sedimentary deposit that exhibits alignment and is located above the Batu Raja Formation. It provides clear evidence of a significant rise in sea level. The composition of this strata comprises marine shale and sandstone. During the Middle-Late Miocene period, the Air Benakat Formation was composed of sandstone, shale, and mudstone that were deposited in a shallow marine environment. During the Upper Miocene period, the Parigi Formation was composed of claystone and limestone that were deposited in a shallow marine environment (Wight et al., 1986). During the Upper Miocene to Pleistocene period, the most recent geological formation consists of a deposit. The formation in question is classified into two distinct categories: non-member members and marine members, as documented by Todd and Pulunggono in 1971. The marine assemblage is composed of claystone, limestone, glauconite sandstone, and fossil fragments within the depositional environment of the inner shelf. Conversely, the nonmarine component is primarily composed of claystone, sandstone, tuff lignite, and is formed within a deltaic system.

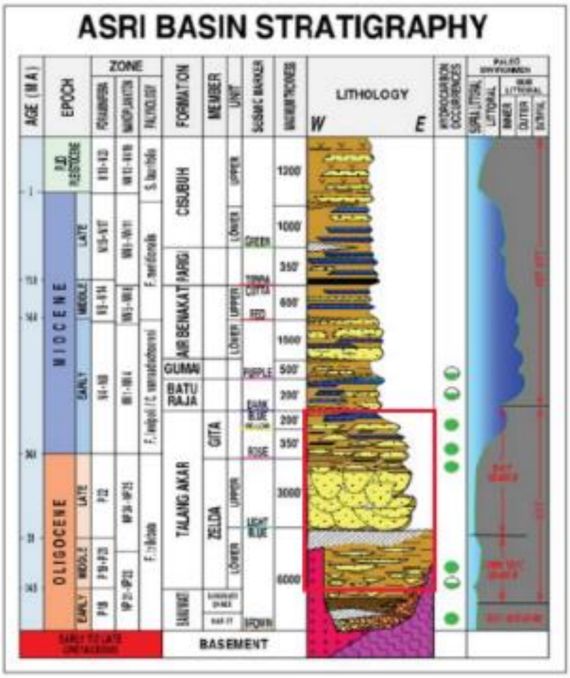


Figure 2 Asri basin stratigraphy (Ralanarko et al, 2020)

[METHODS AND MATERIALS]

Methods

The methodology employed in this study is characterized by a multi-method approach, incorporating both qualitative and quantitative methods. Qualitative analysis is produced by the collection of data from seismicity sources, CO_2 sources, and well reports pertaining to Harriet-1, Harriet-2, and Chessy-1 Field. Furthermore, the determination of volumetric interest in a well is achieved through the calculation of quantitative data using reservoir characterisation and analysis interpretation. The inquiry opens with two distinct forms of study, namely surface analysis and subterranean analysis (see Figure 3). The successful implementation of geological storage necessitates the comprehensive understanding and accurate assessment of surface and subsurface characterization, selection, and performance prediction. In order to facilitate CO_2 injection, it is imperative that the surface effectively reaches the CO_2 sources located in the vicinity of the target field. This will enable the determination of an appropriate CO_2 delivery scenario, taking into consideration factors such as distance and available volume, as seen in Figure 3.

Furthermore, the subsurface data requires the determination of seismicity magnitude for further examination pertaining to the risk associated with CO_2 injection. The data included in this study is sourced from a widely recognized global website known as the IRIS Earthquake Browser. This website is dedicated to documenting historical earthquake events and producing comprehensive seismicity maps. Furthermore, the reservoir characterisation encompasses nine indicators that will be subjected to further research in the subsequent section. In order to conduct a comprehensive analysis, it is imperative to consider various factors like the lithology of the reservoir, its depth, the total gross thickness, porosity, permeability, drive mechanism, initial pressure, temperature, and the provenance of the seal. The Hariet 1 and 2 exhibit comparable physical attributes, such as permeability, total gross thickness, beginning pressure, and temperature, as indicated in Table 1. Moreover, the economic standpoint is predicated upon the quantification of CO_2 emissions that would be introduced into the subsurface, the financial implications associated with the establishment and infrastructure of the facility, and the potential for producing cash subsequent to the injection process.

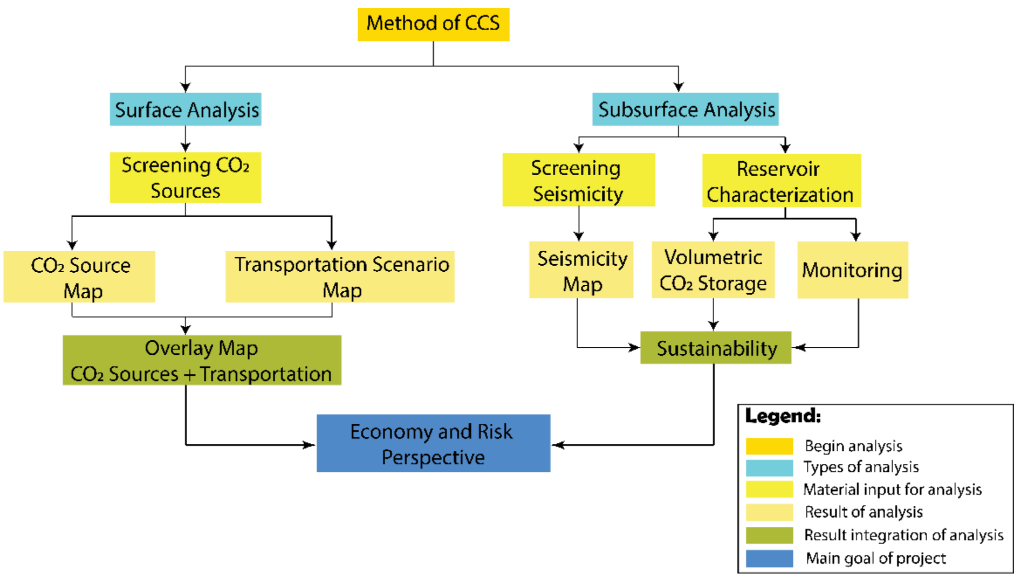


Figure 3 Flow chart CCS study

Table 1 Data requirement for CCS analysis: CO_2 sources (left) and reservoir characterization (right)

No	City / Province	Power Station	Capacity (MW)	Year Open	Status	CO_2 Emission (Mt/year)	Distance from Asri saline aquifer field (km)
1	South Sumatra	Bukit Asam Muara Enim Power Station	260	1989-1995		1,34	327
2		Gura Power Station	300	2011	Operating	1,63	311
3	Lampung	Tarahan Power Station	200	2007-2008		1,12	174
4		Sebalang Power Station	200	2015		1,02	291
5	Bangka Belitung	Bangka Baru Power Station	60	2014	Operating	0,31	291
6	Banten	Suralaya Power Station	4025	1984-2011	Operating	21,25	153
7		Suralaya-3 Power Station	625	2011	Operating	2,69	155
8		Lontar Power Station	945	2011	Operating	4,47	151
9		Serang Power Station	660	2017	Operating	2,74	151
10		Merak Power Station	120	2014	Operating	0,62	150
11		Jawa-7 Power Station	991	2019	Operating	4,12	160
12		Cilegon PIIP Power Station	40	2017	Operating	0,21	172
13		Serang PLN Power Plant	105	1992-1993		0,63	176
14		Labuan Power Station	632	2009-2010		32,6	214
15		Babelan Power Station	280	2017		1,44	169
16	West Java	Pindo Delhi Power Station	50	2007		0,28	209
17		Indo Bharat Power Station	37	2008		0,2	219
18		Indorama Power Station	60	2006	Operating	0,34	230
19		Indramayu Power Station	990	2010-2011		4,82	233
					Total	81,83	3936

Field	Hariet 1	Hariet 2	Chessy-1
Reservoir lithology	Sandstone	Sandstone	Sandstone
Reservoir Depth (mD)		8397 - 9424	5130
Total Gross thickness (mD)	561	561	761
Porosity (%)	15.3	18.75	19.6
Permeability (mD)	44	44	57
Drive mechanism	Saline aquifer	Saline aquifer	Saline aquifer
Original pressure (psi)	4500	4500	1580
Temperature (ºF)	276.4	276.4	102
Seal / proven oil/gas storage	No	No	No

[RESULT (AND ANALYSIS)]

Surface Analysis

As indicated by its geographical positioning, the Asri Basin is in close proximity to many sources of carbon dioxide (CO_2), as illustrated in Figure 4. These sources include steam plant power facilities, petrochemical industries, CO_2 removal operations, and gas processing industries. Within a 100 kilometer radius, the emission of carbon dioxide (CO_2) is primarily attributed to the gas processing sector located at Pabelokan. Within a 200 km radius, there exist several steam power plants and a petrochemical industry that contribute to the emission of carbon dioxide (CO_2). Specifically, the Tarahan steam power plant emits approximately 0.77 million metric tons (MT) of CO_2 per year, while the Cilegon steam power plants emit around 24.81 MT/Year. Additionally, the Labuan steam power plant emits approximately 2.43 MT/Year, the Lontar steam power plants emit around 3.64 MT/Year, and the petrochemical industry in Cilegon contributes approximately 0.13 MT/Year of CO_2 emissions. The maximum distance of the most remote carbon dioxide (CO_2) sources is approximately 300 kilometers. Within this range, there are several notable CO_2-emitting facilities. Specifically, the Jakabaring region hosts gas power plants that collectively emit approximately 0.08 million metric tons (MT) of CO_2 annually. Additionally, the Subang area houses a CO_2 removal facility that emits approximately 0.03 MT of CO_2 per year. Lastly, the Indramayu region accommodates a steam power plant responsible for emitting approximately 3.81 MT of CO_2 annually.

The carbon dioxide (CO_2) is gathered and transferred through the precombustion technique. The proposed system aims to integrate hydrogen, carbon monoxide, carbon dioxide, and minor concentrations of other gases in order to generate syngas. Subsequently, the syngas undergoes a chemical reaction wherein carbon monoxide (CO) and water (H_2O) are converted into hydrogen (H_2) and carbon dioxide (CO_2), leading to the formation of a gas mixture characterized by a substantial presence of hydrogen and carbon dioxide. The content of carbon dioxide (CO_2) varies within the range of 15% to 50% and is suitable for the processes of collection, separation, and transportation. With a carbon dioxide (CO_2) concentration ranging from 5% to 15%, this particular methodology exhibits a higher level of cost-effectiveness compared to post-combustion methods. Following the completion of the capture procedure, the subsequent step to be taken into account is the distribution of CO_2 to the designated field.

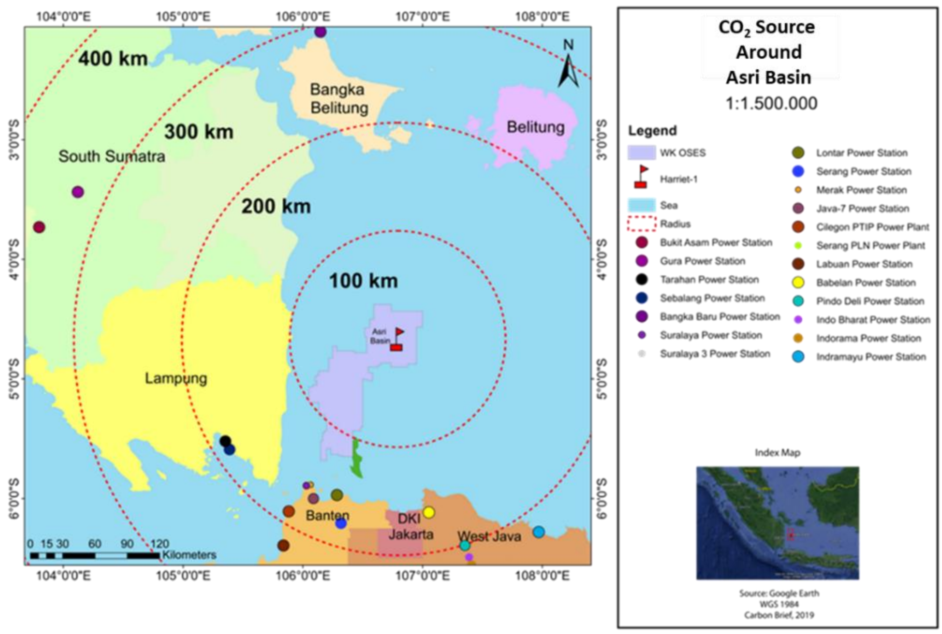


Figure 4 CO_2 sources around Asri basin

Carbon dioxide (CO_2) can be dispersed within the field using one of three methods, contingent upon the chosen route of transportation. The composition of the system includes pipes, vessels, and vehicles. The Asri Basin, on the other hand, is situated in an offshore location. This section will mostly center on the subject matter of pipelines and vessels. Transport appropriateness is determined by multiple criteria. Typically, the pipeline functions under conditions of elevated pressure, ensuring that carbon dioxide (CO_2) remains in a predominantly dense phase throughout its transportation. Subsequently, the operating cost and utility performance exhibit ideal characteristics. In the interim, shipping serves as a viable option for numerous global regions, encompassing shipments of varying volumes ranging from 10,000 to 40,000 m^3. Nevertheless, the expense exceeds the utilization of the pipeline. The concept has the potential for application in the shipping industry, primarily because of the availability of vessel routes.

The proximity between the locations ranges from around 100 to 400 kilometers, with a total of ten identified sources emitting carbon dioxide (CO_2). The data suggests that shipping is the predominant transportation method favored in the Asri region. This aspect is predicated upon the geographical proximity and operational feasibility, as exemplified by the legal option for Asri to utilize shipping as a means of transportation. Specifically, this entails the transfer of goods from Kalijapat Harbour to Pabelokan Harbour, followed by onward sailing to Asri for the purpose of CO_2 injection processing. In Pabelokan, there exist two distinct categories of jetties. The first is the north jetty, which is primarily designated for fulfilling operational area necessities. Conversely, the second is the south jetty, specifically intended for facilitating crew shift activities (refer to Figure 5, top). The shipping industry demonstrates a notable level of effectiveness and efficiency, as seen by adherence to legal regulations and the utilization of existing operational methods. However, the distribution process necessitates further financial support in order to facilitate a smoother transition. In contrast, the pipeline scenario will establish an alternative pathway that diverges from the existing shipping lanes. The potential origin of this pathway is depicted in the provided table. Based on the data presented in the table, there exist a number of possible emitters that are presently in operation, slated for future implementation, or in the developmental stage. The proposed pipeline path is illustrated in the lower portion of Figure 5.

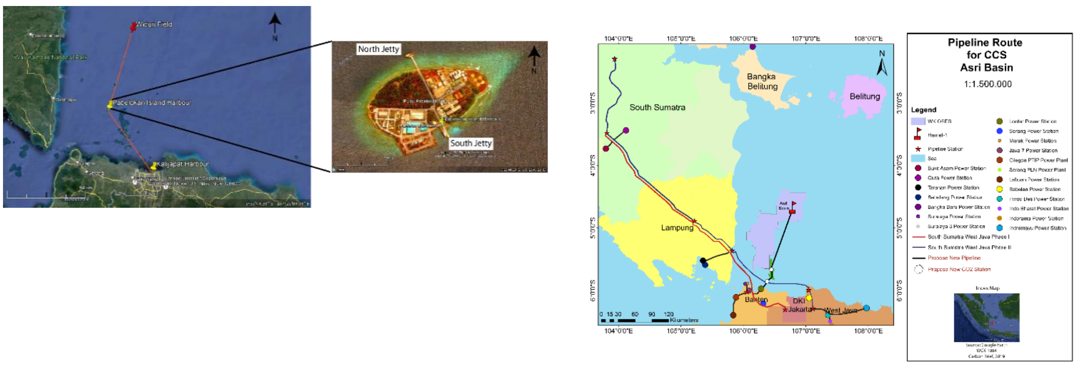


Figure 5 CO_2 sources transportation: shipping route (top) and pipeline trend (bottom)

Subsurface Analysis

The Asri basin, situated inside an active margin zone, has seen seismic activity. Analysis of historical data reveals a significant number of earthquake occurrences within this region, with magnitudes ranging from 4 to 4.9 on the Richter scale (Figure 6). Currently, the northern region exhibiting the highest magnitude is situated beyond the operational scope of OSES. In the specific domain of CO_2 injection, Harriet, there is an absence of seismic activity associated with earthquake epicenters. Therefore, it may be concluded that the injection of CO_2 into the subsurface can be performed without inducing seismic reactivation.

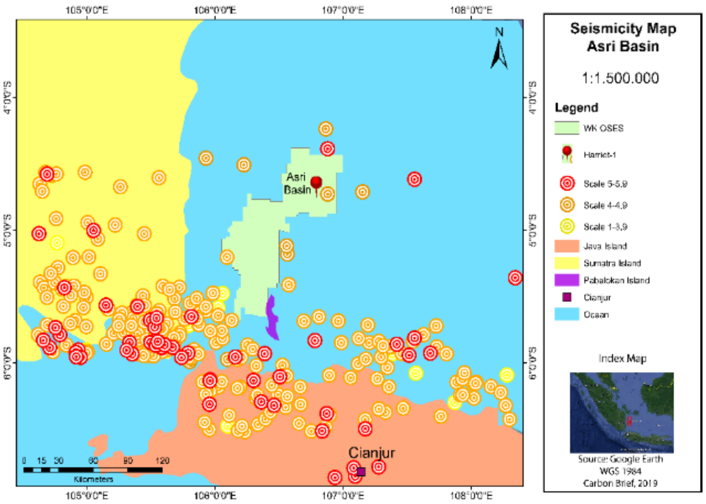


Figure 6 Seismicity map around Asri basin

Further analysis of the Asri Basin necessitates the acquisition of reservoir characterization data, as indicated by the lithologies present in the basin (see to Table 1, located at the bottom of the document). The table includes three distinct interests, namely Harriet 1, Harriet 2, and Chessy-1. The dataset comprises information pertaining to lithology, reservoir depth, total gross thickness, porosity, permeability, starting pressure, and temperature. The permeability values of Harriet 1 and Harriet 2 exhibit similarity, and the reservoir interval is inferred to possess greater depth compared to Chessy-1, based on the initial pressure and temperature data. The provided data will be utilized for the purpose of calculating the estimation of volumetric CO_2 storage. Furthermore, it is imperative to ensure that the levels of CO_2 remain within a safe range when conducting monitoring system analysis. The computation of volumetric CO_2 storage is contingent upon several factors, including the interpretation of zones P90, P50, and P10, the net to gross ratio, the porosity specific to the zone under consideration, and the density of CO_2. The analytical calculation provided below is used to determine these values.

Storage Potential (GT) = (GRV (m^3) x NTG x Porosity x CO_2 Density (kg/m^3) x Efficiency Factor) / (1000 x 1000000 x 1000)

P90 Low estimate (Hi-probability)

The parameter values, namely net to gross, porosity, and CO_2 density, which are obtained from the interpretation region, were assigned a low estimation (Table 2). Furthermore, the computation of storage encompasses two distinct types: one that excludes the efficiency component, and another that incorporates it. The efficiency factor exhibits a range of values from 0.01 to 0.05. The observed volume of CO_2 storage is larger in the absence of an efficiency factor compared to when an efficiency factor is considered. The storage capacity initiates at 33 GT in the absence of an efficiency factor, however it begins at 0.30 when considering the efficiency factor, as seen in Table 2.

P50 Best estimate (Likely probability)

The numerical values of the parameters, including net to gross ratio, porosity, and CO_2 density, are obtained from the designated interpretation region based on the most reliable estimations (Table 2). Furthermore, the calculation of storage encompasses two distinct types: the first kind does not incorporate the efficiency factor, while the second type incorporates it. The efficiency factor values span a range of 0.01 to 0.05. The observed volume of carbon dioxide (CO_2) storage is higher in the absence of an efficiency factor, compared to when an efficiency factor is taken into account. In the absence of the efficiency factor, the initial storage capacity is recorded as 74 GT. However, after considering the efficiency factor, the initial storage capacity is significantly reduced to 0.75 (Table 2).

P10 Hi-estimate (Low probability)

The parameter's numerical values, including net to gross, porosity, and CO_2 density, determined from the interpretation region, are reported to be high according to the upper estimations (Table 2). Furthermore, the calculation of storage encompasses two distinct types: the first kind does not incorporate the efficiency factor, while the second type incorporates it. The range of efficiency factor values spans from 0.01 to 0.05. The observed volume of carbon dioxide (CO_2) storage is comparatively higher in the absence of an efficiency factor, as opposed to when an efficiency factor is taken into account. The storage capacity initially commences at 130 GT in the absence of an efficiency factor. However, after considering the efficiency factor, the storage capacity only begins at 1.39 (Table 2).

Table 2 Storage calculation probability

To maintain CO_2 levels within an acceptable range, it is imperative for the monitoring system to do supplementary machine learning analysis utilizing ccsnet.ai. The approach utilizes ccsnet.ai, a modeling tool that incorporates many parameters including reservoir permeability, initial pressure, temperature, thickness, injection rate, depth to top perforation, perforation thickness, and irreducible water saturation to simulate CCS (carbon capture and storage). However, due to the lack of productivity in the target field, the perforation data is being overlooked. Meanwhile, in order to compensate for the limited availability of data pertaining to the wells of interest, the analogue value of the Widuri Field is utilized for the determination of irreducible water saturation. Table 3 presents the quantitative data pertaining to the availability of slots for the building of monitoring models within the CCS system. Given the scarcity of available data pertaining to Harriet-1 and Harriet-2, it can be inferred that their respective values are comparable. Consequently, it may be posited that these figures are mutually reinforcing, provided that the radii of the wells in question are in close proximity.

Table 3 Availability data for parameter monitoring CCS

Well	Permeability (mD)	Initial Pressure (bar)	Reservoir Temperature (C)	Reservoir Thickness (m)	Injection Rate (Mt/year)	Depth to top perforation (m)	Perforation thickness (m)	Irreducible Water Saturation
Harriet 1	44	300	136	174	1,74	11	11	0.10
Harriet 2	44	300	136	174	1,74	11	11	0.10
Chessy-1	57	109	39	15	0,15	11	11	0.10

Based on the observed thickness of the reservoir, it can be inferred that a radius of 2400 meters will experience a gas saturation of 70% over a distance of 150 meters. Furthermore, the area located at a distance of 250 meters from the injection point, characterized by a gas saturation level of 100 percent, is likely to encounter the most significant consequences. In contrast, it can be shown from Figure 7A (Left) that beyond a distance of 2400 meters, there is an absence of a notable gas saturation phase. The pressure gradient experienced during the injection process would result in a variation of around 15 to 20 bar across a distance of 500 meters. Subsequently, within a range spanning from 500 to 1300 meters in radius, there is an observed elevation in pressure of roughly 10-15 bar. In contrast, at a distance of 1300 meters, the pressure measurement indicates a range of 5-10 bar (Figure 7B, left).

The pressure within the reservoir serves as an indicator of the reservoir's thickness. In this particular scenario, the increase in pressure will be mitigated by the presence of a reservoir thickness measuring 150 meters. Significant pressure variations are observed inside a 100-meter width encompassing a radius of 500 meters, reaching a magnitude of 330 bar. Furthermore, the section gradually narrows to a width of 0 meters, resulting in notable consequences at a distance of 400 meters. Nevertheless, within the span of 100 to 150 meters in thickness, a consistent impact is exerted by a pressure of 300 bar at a distance of 4000 meters. In addition, it can be observed that the pressure impact in the upper 150 meters is lower, measuring around 310 bar, and exhibits a larger radius, as depicted in Figure 7C (Left).

The gas saturation levels of 70% along a 1900-meter radius will be influenced by the thickness of the Chessy-1 reservoir. Furthermore, it is worth noting that the region located at a distance of 100 meters from the injection source, characterized by a gas saturation level of 100 percent, may encounter the most significant consequences. Subsequently, at a distance of 1900 meters, the gas saturation phase is observed, exhibiting a range spanning from 0% to 50% (Figure 7A, Right). During the process of injection, there is an observed increase in pressure of 20 bar across a distance of 750 meters. Subsequently, throughout a range spanning from 750 to 2000 meters in radius, there is an observed elevation in pressure by an estimated range of 10 to 15 bar, as depicted in Figure 7B (Right). The pressure within the reservoir serves as an indicator of the reservoir's thickness. Given a reservoir thickness of 15 meters, the increase in pressure will be quite straightforward. Within a zone spanning 15 meters in width and possessing a radius of 750 meters, a significant impact is exerted by a pressure of 130 bar. Nevertheless, it is worth noting that within the specified distance range of 750-1500 meters, a consistent pressure of 15 bar can be applied. Furthermore, at elevation 1500 meters, the data presented in Figure 7C (Right) demonstrates a decrease in the effects of pressure, with reduction of roughly 10 bar.

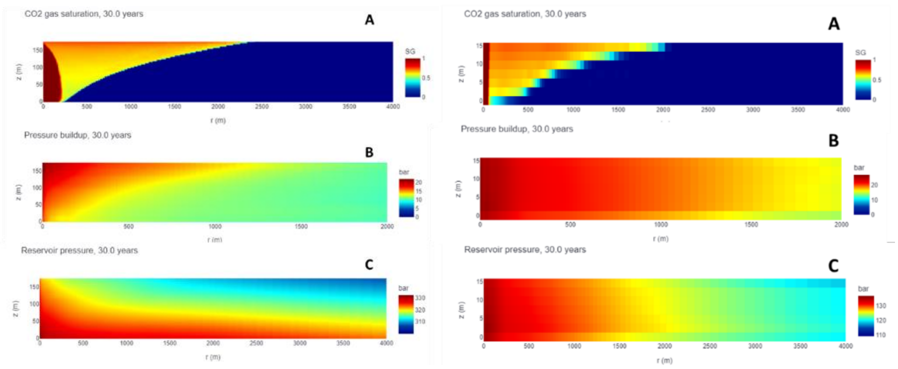
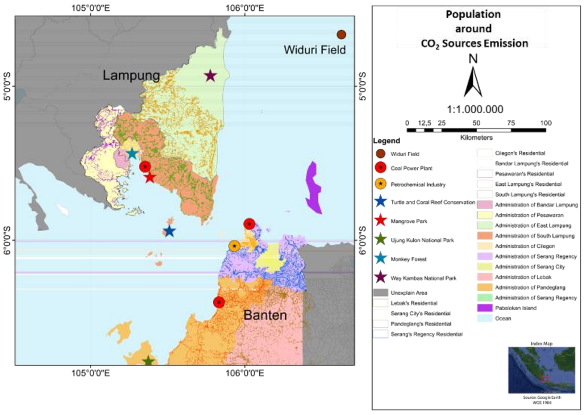


Figure 7 Monitoring model CCS in Harriet (left) and Chessy (right) based on ccsnet.ai

Due to the presence of CO_2 emission sources in close proximity to the Asri saline aquifer Field, which have deleterious effects on living species, the development of carbon capture and storage (CCS) is regarded as a more feasible alternative. According to data from the Statistic Center (2020), the emissions from the majority of CO_2 sources are concentrated in the vicinity of a residential population comprising 3,825,052 individuals. Moreover, these emissions have a detrimental impact on the biodiversity of both animal and plant species. As illustrated in Figure 8, the surrounding area has five distinct conservation areas that serve as habitats for indigenous species including the Sumatran elephant, Sumatran tiger, and Sumatran rhinoceros. These groups face health-related challenges that are distinct in their efforts to mitigate CO_2 emissions within their social contexts. Hence, it can be concluded that the CCS (Carbon Capture and Storage) technology is the most suitable and effective solution for these particular locations.



No	Area	Total Population (People)
	Banten Province	
1	Cilegon	2,478
2	Serang City	2,595
3	Serang Regency	936
4	Pandeglang	463
5	Lebak	405
	Lampung Province	
6	East Lampung	1,110,340
7	South Lampung	1,064,301
8	Bandar Lampung	1,166,066
9	Pesawaran	477,468
	Total	**2.286,541**

Figure 8 Population distribution mapping of life living around Asri Basin

The primary determinant in economic calculations is the utilization of a seven percent real discount rate. The consideration of taxes and CO_2 emissions is neglected. The optimization approach utilizes a comparable level of design specificity to that of an economics scoping study. During this phase of model construction, it is crucial to consider the following assumptions as they hold significant importance: The carbon dioxide (CO_2) flow rates remain consistent throughout the entirety of the project. This includes the processes of capturing, transporting, and storing CO_2. The costs per metric ton of CO_2 saved are computed, taking into account the emissions and expenses connected with the power generation necessary for the carbon capture and storage (CCS) network. To effectively finalize the budget proposal for the project's continuance, it is imperative to undertake a comprehensive assessment of the project's estimation. However, it is important to note that this study will just focus on the economic aspect of transferring CO_2 to the designated area.

[DISCUSSION]

The evaluation of the CCS project will be conducted by considering both the general surface facility and subsurface criteria, with the aim of assuring the viability of CO_2 injection. The initial analysis stems from carbon dioxide (CO_2) sources. It would be advantageous to assess the extent to which the CO_2 sources have the capacity to contribute to CO_2 injection beneath the saline surface of the Asri Basin. Based on the analysis of data and maps, it is evident that the distribution of CO_2 sources spans a geographical range of 100 to 400 kilometers, predominantly encompassing two significant Indonesian islands, namely Sumatra and Java. The region of interest in Sumatra encompasses six sources of carbon dioxide (CO_2) emissions, each with a radius ranging from 170 to 330 kilometers. These sources collectively provide a total of 5.42 million metric tons of CO_2 each year. Java Island is characterized by the presence of 14 carbon dioxide (CO_2) emission sources, located within a radius ranging from 150 to 210 kilometers from the designated area of interest. These sources collectively contribute to a total annual CO_2 emission of 76.41 million metric tons. In order to facilitate the movement of CO_2 from the Asri basin to various target locations, it is imperative to identify a suitable means of transportation, given the presence of many CO_2 sources strategically located within the basin area.

There are two potential means of transportation for carbon capture and storage (CCS) based on the distance and geographical placement of the carbon dioxide (CO_2) source: pipelines and ships. The transportation of CO_2 via pipelines will utilize pre-existing infrastructure, such as the South Sumatra West Java pipeline. In order to establish a direct connection with a carbon dioxide (CO_2) source, it is necessary to utilize four connecting pipes originating from a source, such as a power plant or chemical industry, which will then be linked to the main pipeline. This main pipeline will afterwards transport the CO_2 to Pabelokan Island, terminating at the Harriet well, which serves as a designated place for CO_2 injection. In the event that carbon dioxide (CO_2) is transported via maritime vessels, it will be gathered at designated stations situated in the closest coastal areas surrounding Asri. In the Sumatra region, carbon dioxide (CO_2) will be gathered via a pipeline located at the Tarahan station, whereas in the Java region, CO_2 will be collected using an already established pipeline situated at the Cilegon station.

Therefore, the vessel that will be utilized has the capability to promptly capture carbon dioxide at designated station locations for transportation to Pabelokan. Consequently, carbon dioxide (CO_2) will be transported via the pre-existing pipeline to the Harriet facility. Furthermore, in order to address the economic aspect, numerous scenarios have been identified for the purpose of introducing CO_2 into the designated region of Harriet. The initial situation entails the transportation of 10 million metric tons per annum (Mtpa) of carbon dioxide (CO_2) by a "point-to-point" method. This requires the utilization of a 10-kilometer onshore feeder followed by a 180-kilometer offshore pipeline, resulting in a combined pipeline length of 190 kilometers from the source to the storage location. This situation would have implications for the economy in terms of network costs. The amount of 4.24 million dollars is indicated in Table 4.

The second scenario involves a "point-to-point" transportation situation, wherein a total of 2.5 million metric tons per annum (Mtpa) of carbon dioxide (CO_2) is delivered through a 10-kilometer feeder to a designated port. Subsequently, the CO_2 is further transported via ship to storage locations located at varying distances of 180, 500, 750, or 1,500 kilometers from the coastal region. The price would be subject to a rise in accordance with the injection distance. The cost of the ship's network infrastructure, which spans a distance of 180 kilometers, amounts to 17.13 million dollars. Subsequently, it can be shown that a vessel situated at a distance of 500 kilometers would incur an expenditure amounting to 18.70 million dollars. Furthermore, the ship's fundamental scenario, encompassing a 750 km network, incurred a cost of $20.05 million. Furthermore, the ship base scenario, which spans 1500 kilometers, has accumulated network expenses amounting to 24.92 million dollars (as indicated in Table 4).

Table 4 Estimation cost for transportation: pipeline and shipping option

Schema	Option	Cost Item								Network Cost (M$)
		Feeder				Spine				
		CAPEX (M$)	Annuity (M$)	OPEX (M$)	Cost (M$)	CAPEX (M$)	Annuity (M$)	OPEX (M$)	Cost (M$)	
Network 1, 10 Mtpa CO_2, Pipeline spine	Pipe base case, 180 km offshore spine	16,72	1,40	0,07	1,63	375,12	31,46	5,28	40,78	42,41
	Unit Cost ($/T CO_2)									4,24
Network 2, 2,5 Mtpa CO_2, Ship spine	Ship base case, 180 km spine	12,82	1,08	0,07	1,27	154,15	12,93	24,50	41,55	42,82
	Unit Cost ($/T CO_2)									17,13
	Ship base case, 500 km spine	12,82	1,08	0,07	1,27	174,44	14,63	26,34	45,48	46,75
	Unit Cost ($/T CO_2)									18,70
	Ship base case, 750 km spine	12,82	1,08	0,07	1,27	193,76	16,25	27,77	48,87	50,13
	Unit Cost ($/T CO_2)									20,05
	Ship base case, 1500 km spine	12,82	1,08	0,07	1,27	237,52	19,91	35,08	61,04	62,31
	Unit Cost ($/T CO_2)									24,92

[CONCLUSIONS]

The study has two perspectives. One of the primary categorizations is surface analysis and subsurface analysis. Based on a preliminary examination, the Asri basin, which serves as the screening CO_2 source, is encompassed by over 30 CO_2 sources, comprising a gas processing plant, a coal power station, and a chemical factory. The transportation of capturing CO_2 can be offered through the utilization of pipelines and shipping, depending on the rate of CO_2

injection and the specific injection model scenario. Moreover, the examination of subsurface conditions is influenced by regional geology and the identification of reservoirs. According to the seismicity data, it may be inferred that the site in question exhibits a higher level of safety compared to other locations within the Asri Basin. Additionally, the estimation of storage is based on reservoir characterization and is separated into three likelihood categories. Furthermore, it has been projected that the implementation of the monitoring schema will enhance the progress of the project. The inclusion of several data points such as CO_2 gas saturation, pressure increase, and reservoir pressure is essential in the process of constructing a model for performing simulations. Lastly, upon completion of the project, a key objective would involve the mitigation of carbon dioxide emissions in order to safeguard the biodiversity in the Asri basin of Indonesia.

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