RANKING OF INDONESIA SEDIMENTARY BASIN AND STORAGE CAPACITY ESTIMATES FOR CO_2 GEOLOGICAL STORAGE

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ABSTRACT

The various possible strategies to combat global warming are explored within a wide-ranging of efforts. Practical solutions will need to stop or even reverse the build-up of CO_2 in the environment by using existing technology that has not been integrated, carbon dioxide capture and storage (CCS) (Hansson, 2008). The main objectives of this study are to develop criteria for sedimentary basins ranking system in terms of their suitability for CO_2 storage and estimate the storage capacity available. We adapt the method developed by Bachu (2003) to the Indonesia geological characteristics. Once the criteria has been developed and the basins ranked based on their suitability, oil and gas fields located within these basins were estimated their potential storage capacity using the methodology developed by Carbon Sequestration Leadership Forum (CSLF). From 60 identified sedimentary basins, Kutei, Tarakan and South Sumatera basins are respectively positioned in top three of the ranking system. Well known geological structure, adequate data, relatively stable geological structure and established infrastructures are the main factors make these basins have higher suitability. Estimation result showed from 48 fields that are considered depleted from their Np/Ult ratio (hydrocarbon cumulative production over ultimate recovery), Riau and South Sumatera region have large storage capacities which are around 229 and 144 $MtCO_2$ respectively. The ranking of Indonesia sedimentary basins can then be used in making decisions for the large-scale implementation of CCS Project. The potential storage capacity might increase as data more available. The estimates resulted from this study is not a conclusive estimation where degree of geological and economic uncertainty associated with a capacity estimate is still high. However, from this estimation shows that Indonesia has huge potential of CO_2 storage in depleted oil and gas reservoirs

Keywords: *Ranking of sedimentary basin, basin suitability, CO_2 geological storage, storage capacity estimates*

I. INTRODUCTION

The evergrowing need for energy to drive economic growth in both developed and developing countries, coupled to an overwhelming dependence on fossil fuels, has led to rising atmospheric levels of CO_2 and to climate change. In the meanwhile CO_2 is the unavoidable product of fossil fuel consumption. Therefore, the use of fossil fuels collides directly with global environmental concerns. Unfortunately, fossil fuels are difficult to replace, but stabilising the atmospheric concentration of carbon dioxide requires a nearly complete transition to a carbon-neutral economy (Hester et al., 2010). The various possible strategies to combat global warming are explored within a wide-ranging. Some of practical solutions to utilise the world's huge remaining fossil-

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fuel resources without adding an unmanageable burden of carbon dioxide to the atmosphere by using existing technology that has not been integrated, carbon dioxide capture and storage (CCS) (Hansson, 2008).

In Indonesia excellent opportunities exist in deploying this low carbon technology because of the availability of sedimentary basins that contain geological media such as oil and gas reservoirs and CO_2 captured ready from gas processing plant. The opportunities may take advantage of the fact that in time part of the existing gas infrastructure may become available for transport of the captured CO_2 and capacity of geological media as more fields are depleted. However, the suitability of existing sedimentary basins and the capacity of the geological formation have not been assessed and estimated yet.

The main objectives of this study are to develop criteria for sedimentary basins ranking system in terms of their suitability for CO_2 storage and estimate the storage capacity available. We adapt the method developed by Bachu (2003) to the Indonesia geological characteristics. Once the criteria has been developed and the basins ranked based on their suitability, oil and gas fields located within these basins were estimated their potential storage capacity using the methodology developed by Carbon Sequestration Leadership Forum (CSLF).

II. DEVELOPMENT CRITERIA OF SCREENING AND RANKING

A regional study of crustal type and present tectonic setting has identified 60 Tertiary sedimentary basins in Indonesia. In the west mostly developed in the Tertiary Period, while in the eastern Indonesia initiated earlier since Mesozoic or event Palaeozoic era. However, they are variously suited for CO_2 storage. The first step in the process of site selection for CO_2 storage is the basin-scale suitability assessment. Therefore to assess the suitability of the basins we modified and adapted the method developed by Bachu (2003) in which he used for Canada sedimentary basins to specifically Indonesia sedimentary basins. The suitability criteria developed and applied to the Indonesia Sedimentary Basin can be expanded to include other factors that can be assessed in a qualitative manner. A set of 10 criteria, with several classes each, has been adapted for the assessment and ranking of sedimentary basins in terms of their suitability for CO_2 storage.

Most of the categories were qualitatively and uniformly applied across the basin. The criteria development of Indonesian basins relate to hydrogeology, coal and CBM, salts and etc. are excluded due to the information used is either not available or it requires significant effort and resources for processing. Most of the data are commonly readily available from national or state geological survey organisations such as regional maps or published maps cover the whole Indonesia regions as follows:

- Indonesian tectonic and structural map published by BPMIGAS and several Universities Consortium (Aug, 2008)
- Western Indonesia chronostratigraphic tertiary correlation diagram,
- Stratigraphic summary of eastern Indonesia,
- Status of Indonesia sedimentary basin (Dec, 2006),
- Regional heatflow map of Indonesia,
- Sesimic data and drilling record,
- Earthquake zone map of Indonesia,
- Sedimentary basin classification based on tectonic plate framework (Koesoemadinata, 1978),
- Total sediment thickness map (Pertamina and UNOCAL, 1997),
- Indonesia oil and gas reserves database maintained by LEMIGAS (LEMIGAS, 2009),
- Leads and prospect maps,
- List of depleted oil and gas fields (LEMIGAS, 2009).

Table 1 is a modified version of the basin-scale criteria for CO_2 storage developed by Bachu (2003) that have been specifically adapted to Indonesian sedimentary basins. For each criterion, the classes are arranged from least favourable to most favourable from left to right across the table increasing CO2 storage potential.

Onshore & offshore: Sedimentary basins location affects much the accessibility of storage sites. It also provides an important economic consideration, and creates public perception and land use issues of preferential for CO_2 storage. This criterion is defined from sedimentary basin map of Indonesia that showing the location of the basins. ***Geothermal:***

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Table 1
Criteria for assessing Indonesia sedimentary basins for CO_2 storage

CRITERIA	Increasing CO_2 Storage Potential →				
	CLASSES				
	1	2	3	4	5
On/Off Shore	Deep Offshore	Shallow Offshore	Onshore		
Geothermal	Warm (>400C/km)	Moderate	Cold (<300C/km)		
Maturity	Unexploration	Exploration	Development	Production Basin	
Geology	Extensive Faulted and fracture	Moderately Faulted and fracture	Limited Faulting and fracturing		
Tectonic Setting	For Arc	Back Arc	Platform	Deltaic	Rift Vally
Depth (meter)	Shallow (<1,500m)	Intermediate (1,500-3,500 m)	Deep (>3,500 m)		
Size	Small	Medium	Large	Giant	
Hydrocarbon Potential	None	Small	Medium	Large	Giant
Accessibility	Inaccessible	Difficult	Acceptable	Easy	
Infrastructure	None	Minor	Moderate	Extensive	

Category of each class on criterion for geothermal regime is based on heatflow map. This criterion reflects the storage volume where as the density of CO_2 is higher in colder basins than in warmer basins, allowing more CO_2 to be contained within the same unit volume of rock. ***Maturity:*** The maturity indicates the availability and intensity of data in the region such as seismic and drilling. The development of 4 classes of this criterion is according to seismic data distribution, drilling records and basin status. ***Geology:*** This criterion is based on faults and fractures intensity and distribution of Indonesia structural map. The regions with such characteristics may raise the issue of safety which will lead to a potential and risk for either catastrophic escape or significant continuous leakage of CO_2 to the surface (Bachu, 2003). ***Tectonic setting:*** Basins located in tectonically active areas are the least favourable because they are prone to large earthquakes and have a potential risk for leakage. This criterion is defined in accordance with crustal type and relative plate motion of basin classification.

Depth: Depth is one of the most important elements in determining injected CO_2 phase behaviour and variation of CO_2 properties in underground. We used total sediment thickness map. ***Basin size:*** reflects the overall storage volume achievable, as the larger the basin the greater the likelihood of having laterally extensive reservoir and seal pairs, possibly in multiple stratigraphic intervals, and therefore the greater the likelihood of injectable pore volume (CO_2CRC, 2010). ***Hydrocarbon potential:*** This criterion provides potential application of oil and gas reservoirs of being used as CO_2 geological formation as they have already pore volume and seal pairs. To define each classes of hydrocarbon potential we used reserves and resources data. ***Accessibility***: Accessibility reflects the variability in conditions in terms of getting the captured anthropogenic CO_2 from source to the point of storage site and ease of future developments (Bachu, 2003 and CO_2CRC, 2010). ***Infrastructure:*** Existing infrastructure potentially to be reused is one of the semi-soft criteria in determining the start up of CO_2 storage project.

III. RANKING OF SEDIMENTARY BASINS

We divided into 5 steps systematically to rank identified sedimentary basin using the method developed by Bachu as summrazied briefly in the figure below:

1. For each criterion has its own score reflecting the basin suitability (Table 1). Using the formula as

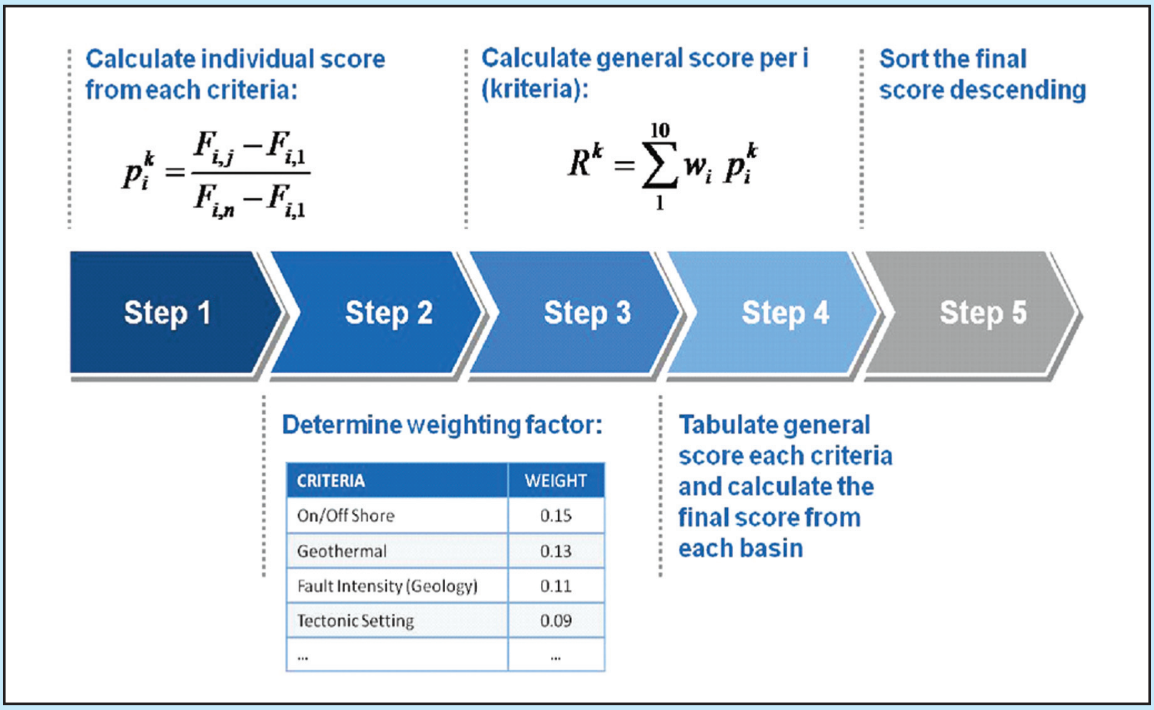

Figure 1
Steps for ranking sedimentary basin

Table 2
Scores and weight assigned to the criteria and classes

NO	Criteria	SCORE					
		Class					
		J=1	J=2	J=3	J=4	J=5	Weight
1	On/ Offshore	1	4	10	-	-	0,15
2	Geothermal	1	3	7	-	-	0,13
3	Maturity	1	2	4	8	-	0,11
4	Geology	1	3	7	-	-	0,11
5	Tectonic Setting	1	8	10	13	15	0,09
6	Depth (meter)	1	3	5	-	-	0,09
7	Size	1	3	5	9	-	0,08
8	HC Potential	1	3	7	13	21	0,08
9	Accessibility	1	3	6	10	-	0,08
10	Infrastructures	1	3	7	10	-	0,08

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depicted on the first step figure above, individual score from each criterion is calculated. In essence, the formula normalizes the criteria that have different degree of importance into dimensionless variable.

2. Step 2 comprises determining the weighting factor that has been defined as follows:

   The weights for the criteria were re-assigned to meet the condition in Indonesia and to reflect local circumstances and priorities. Although score and weighting factor are defined subjectively but they are controlled with the given data and arrived at according to common sense and based on sound engineering judgment. This is not a surprise, as there will always be gray areas where we have to interpret the data for criteria developement, and make educated definition for each score and weigth.

3. Next is employing the equation on the step 3 above where we have to calculate general score from each criterion.

Table 3
List of ranking sedimentary basin in terms of basin suitability

Rank	IND BASIN	Final Score	Rank	IND BASIN	Final Score
1	KUTEI	0.9128	31	LARIANG	0.4644
2	TARAKAN	0.7773	32	SPERMONDE	0.4576
3	SOUTH SUMATERA	0.7579	33	BANGGAI	0.4305
4	SERAM	0.7347	34	TUKANG BESI	0.4276
5	NORTH WEST JAVA	0.7259	35	SAHUL	0.4262
6	BARITO	0.7221	36	SOUTH HALMAHERA	0.4252
7	CENTRAL SUMATERA	0.7150	37	GORONTALO	0.4245
8	NORTH SUMATERA	0.7019	38	SOUTH BALI-LOMBOK	0.3979
9	SALAWATI	0.6904	39	MINAHASA	0.3929
10	NORTH EAST JAVA	0.6830	40	MISSOL	0.3839
11	BINTUNI	0.6650	41	BILLITON	0.3821
12	BENGKULU	0.6655	42	BIAK	0.3655
13	WEST NATUNA	0.6432	43	SOUTH JAVA	0.3599
14	BONE	0.6095	44	SALABANGKA	0.3515
15	MELAWI	0.6039	45	WAROPEN	0.3515
16	PEMBUANG	0.5905	46	NORTH HALMAHERA	0.3315
17	PATI	0.5876	47	WEBER	0.3265
18	NORTH EAST JAVA SEA	0.5854	48	TANIMBAR	0.3129
19	TIMOR	0.5731	49	SOUTH SERAM	0.3129
20	AKIMEUGAH	0.5717	50	JAYAPURA	0.3129
21	KETUNGAU	0.5339	51	SOUTH SULA	0.3065
22	SULA	0.5176	52	NORTH OBI	0.3065
23	ASEM-ASEM	0.5139	53	SOUTH OBI	0.3065
24	SOUTH MAKASSAR	0.5128	54	WEST WEBER	0.2865
25	BUTON	0.5065	55	WEST BURU	0.2865
26	SUNDA	0.4985	56	EAST HALMAHERA	0.2615
27	WAIPOGA	0.4980	57	FLORES	0.2532
28	ARU	0.4905	58	SAVU	0.2268
29	EAST NATUNA	0.4718	59	MANUI	0.1980
30	SIBOLGA	0.4705	60	BURU	0.1765

4. The fourth step is tabulating general score from the whole criteria before summing up the total score. At this point, the total score of basin suitability has been resulted.
3. In the end, in order to see which basin position on the top ten rank, we have to sort descending based on the total score.

IV. STORAGE CAPACITY ESTIMATION METHODOLOGY

After having ranking the sedimentary basins subsequent assessment is the estimate of potential CO_2 storage capacity of depleted oil and gas fields located within these sedimentary basins. We defined depleted oil and gas fields which have Np/Ult ratio (hydrocarbon cumulative production over ultimate recovery) more than or equal ≥ 55%. Screening result from our databases showed there are 142 depleted oil and gas fields are considered depleted. Data availability is a major constraint in estimating CO_2 storage capacity in such scale of assessment. Therefore, only 66 fields from 142 fields had complete data to be estimated.

Oil and gas fields are comprised of certain number of reservoirs that are considered as a single discrete, hence estimating CO_2 storage capacity in the scale of field is possible by summing the individual reservoirs. We used the methodology for estimating storage capacity in depleted oil and gas reservoirs that initially developed by CSLF but then simplified by Poulsen et al. The formula (Eq. 1) assumes that volume previously occupied by the produced hydrocarbons becomes, by and large, available for CO_2 storage. It also represents the scale of calculation which is theoretical storage capacity or maximum upper limit to a capacity estimate.

$$MCO_2t = \rho CO_2r \times [R_f \times A \times h \times \varphi \times (1 - S w) - V_{iw} + V_{pw}] \quad \text{...... (1)}$$

Poulsen et. al, 2009 (Eq. 2) in his report Geological Assessment for CO_2 Storage in the Bohai Basin, East China, basically eliminates some variables by not taking into account fraction of injected gas, volumes of injected and produced water. This assumes that the reservoir is not flooded during secondary and tertiary oil recovery (pressure-depleted fields).

$$MCO_2 = \rho_{CO_2r} \times UR \times Seff \quad \text{...... (2)}$$

V. RESULT AND DISCUSSION

By compiling data on the criteria above and totaling the score of each basins, different basins can be compared, contrasted and ranked for their suitability for CO_2 storage. The results show not all sedimentary basins are equally suitable for CO_2 storage, only Kutei, Tarakan and South Sumatera basins listed on the top three rank among the others. Table 3 below shows the ranking of identified 60 sedimentary basins in terms of their suitability for CO_2 storage:

It indicates that these basins have high suitability for CO_2 storage where most of them are comprised of well characterized reservoirs that lead to higher data intensity. The second is they are located in relatively stable geological activity, although we realize that there is seismic activity occurs in South Sumatera, but the distribution of earthquake hypocenter is deep (>150 km), if any, only present very scattered. Existing infrastructure that are already built in place, the ease for future development particularly of getting CO_2 captured to storage sites and having adequate depth are also the main factors why these basins are favorable. This ranking can be then used in making decisions for the large-scale implementation of CCS Project.

The initial estimates (Figure 2) show Riau and South Sumatera are considered have large storage capacities which are around 229 and 144 million ton of CO_2 respectively. Below is the result of storage capacity estimation from depleted oil and gas fields in Indonesia by using the methodology that developed by Poulsen et al.:

This is not apart from the fact that many oil and gas fields were discovered in these regions and hydrocarbon extraction has been going on since a century ago. Moreover, Riau region is located in extensive Central Sumatera Basins and South Sumatera region has basin that extends to the north of Lampung region. Extensive petroleum activities in East Kalimantan have provided potential depleted hydrocarbon reservoirs in where this region has CO_2 storage capacity almost 130 $MtCO_2$. In the meanwhile, storage capacity in Java Island is circa 105 $MtCO_2$ in total.

The distribution of CO_2 storage capacity map above reflects theoretical maximum storage capacity

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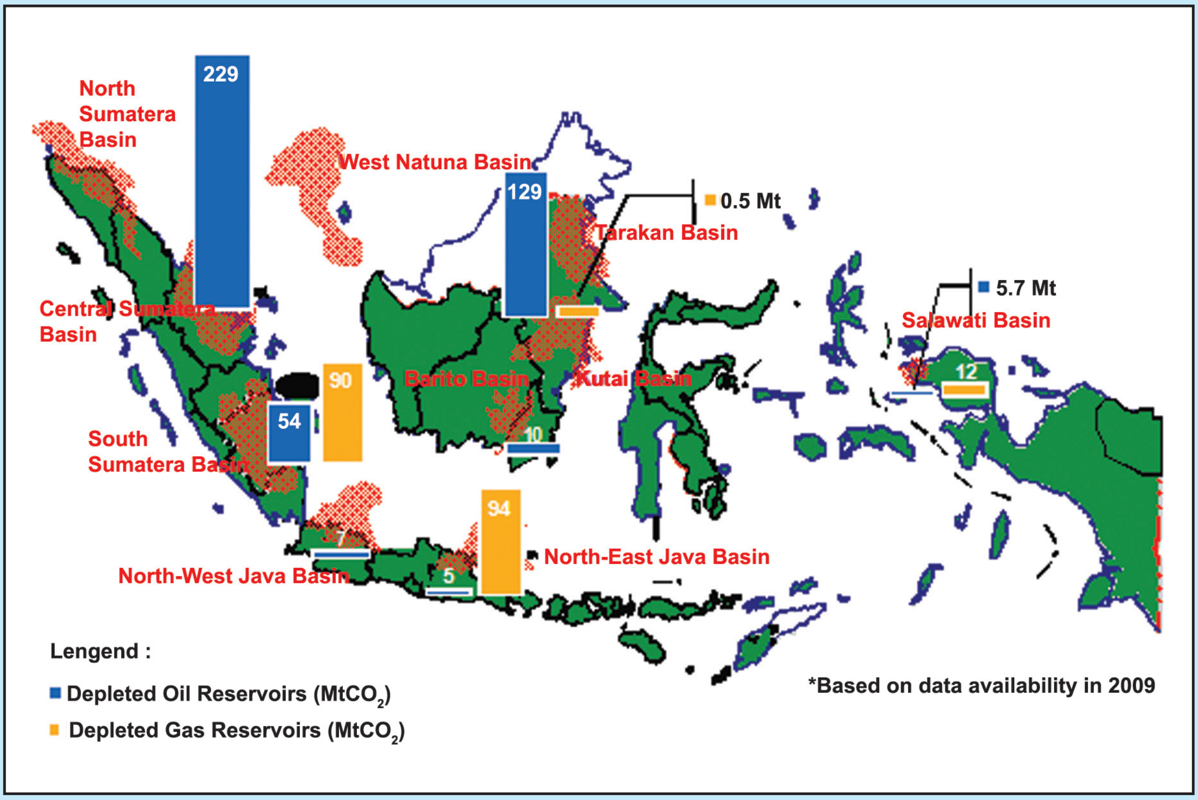

Figure 2
Map of storage capacity distribution of depleted oil and gas reservoirs in Indonesia overlaid with top 10 rank basins

that based on data availability during the assessment. The potential storage capacity might increase as data more available. The estimates resulted from this study is not conclusive where degree of geological and economic uncertainty associated with a capacity estimate is still high. However, from this estimation shows that Indonesia has huge potential of CO_2 storage in depleted oil and gas reservoirs.

VI. CONCLUSION

- From 60 identified sedimentary basins, Kutei, Tarakan and South Sumatera basins are respectively positioned in top three of the ranking system. Well known geological structure, adequate data, relatively stable geological structure and established infrastructures are the main factors make these basins have higher suitability.
- The ranking results can be then used in making decisions for future large-scale implementation of CCS Project
- The estimates showed depleted oil and gas fields in Indonesia have enormous potential for CO_2 storage. At the moment, the largest storage capacity located in Riau region and followed by South Sumatra with capacity 229 and 144 million ton of CO_2 respectively.
- The storage capacity resulted from this study is not a conclusive estimation. The potential storage capacity might increase as more data are available and potentially change current rank of largest storage capacity in each region.

NOMENCLATURE

$\rho CO_2 r$ = CO_2 density at reservoir conditions (best estimate)
URp = proven ultimate recoverable oil or gas
Seff = storage efficiency factor
$F_{i,j}$ = criteria-i and *classes*-j
$F_{i,1}$ = criteria -1 with *classes*-1
$F_{i,n}$ = criteria -i and *classes*-n;

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n = the amount of class (3, 4, or 5)
w = weight
R = general score
P = individual score
R_f = recovery factor
B_f = the formation volume factor that brings the oil volume from standard conditions to in-situ conditions
V_{iw} = volumes of injected water (applicable in the case of oil reservoirs)
V_{pw} = volumes of produced water (applicable in the case of oil reservoirs)
A, h, φ = reservoir area, thickness, and porosity
S_w = water saturation

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