EDIN

CO2– EOR Screener Dashboard



S&P Global
Commodity Insights

- **Easily screen for producing reservoirs that are potential candidates for CO2 EOR schemes.**
- **Reservoir screening**
  - Identify candidate reservoirs globally that pass screening criteria
  - Generate P10, P50, P90 injection capacities
  - Rank reservoirs and assess recovery upside
- **Emission source-sink analysis**
  - Identify industrial source clusters
  - See which nearby reservoirs could be candidates



Criteria for identifying suitable oil reservoirs for miscible CO2-EOR

The CO2-EOR dashboards are intended to be used as a tool to identify depleted oil reservoirs that can be candidates for miscible CO2-EOR. An estimate of the potential recovery (P50 cumulative production distribution and curves) is provided at a given %HCPV (Hydrocarbon Pore Volume). Analytical probabilistic curves are used to describe the Recovery Factor (Rf%), the Net Utilization Factor (Uf in Mscf/STB) and the product of both (Rf x Uf) which have an impact on the potential CO2 storage (MCO2in Mt).

Table 1 contains the parameter (feature) scoring for each reservoir and fluid attribute considered for the CO2-EOR screening test. The feature score range goes from 1 to 5 where the higher the number the higher the importance of the given property.

Table 1. Scoring by reservoir parameter and its corresponding range of values

Reservoir Characteristic (Feature)	Suitable for miscible CO2-EOR		Score
	Min	Max	
Depth (ft)	1600	13365	1
Oil Gravity (°API)	22	45	5
Temperature (°F)	82	260	1
Oil Viscosity (cP)	–	6	3
Pressure (psi)	MMP	–	5
Initial pore pressure gradient (psi/ft)	–	0.74	1
Porosity (%)	3	37	1
Initial oil saturation (%)	26.5	–	1
Initial pore space oil saturation	0.05	–	1
Original oil in place (MMSTB)	12.5	–	1
Remaining oil fraction in the reservoir (%)	20	–	1
Remaining oil in the reservoir (MMSTB)	5	–	3

In this study, only reservoirs with the following fluid type and production classification (values in EDIN) are considered:

Fluid type equal to:

- "Oil"
- "Oil,gas"
- "Oil,gas,cond"
- Production type is not:
- "Prod, enhanced recov"
- "Abd,no improved recv"
- "Abd aft imprvd recov"
- "Abd aft enhncd recov"

Each reservoir is evaluated individually based on its properties. If a value falls within the range suitable for CO_2-EOR, the corresponding score from the table is assigned to it. If not, a value of zero is designated. When a value is missing from a required reservoir characteristic, the reservoir is not immediately discarded. Instead, it is assumed that the variable at hand falls within the acceptable range and the corresponding importance score is assigned to it. Finally, reservoirs with a total score of 19 or higher are considered that pass the screening criteria.

Once the parameters from Table 1 are evaluated for each reservoir, a plot is prepared where blue is assigned if the reservoir has a feature within the required range for CO2-EOR feasibility. Reservoirs are then sorted by the number of features and their importance. The resulting plot is shown in Figure 1.

Figure 1. Example of Reservoir Properties Scoring Plot for Reservoirs That Passed the Screening Test

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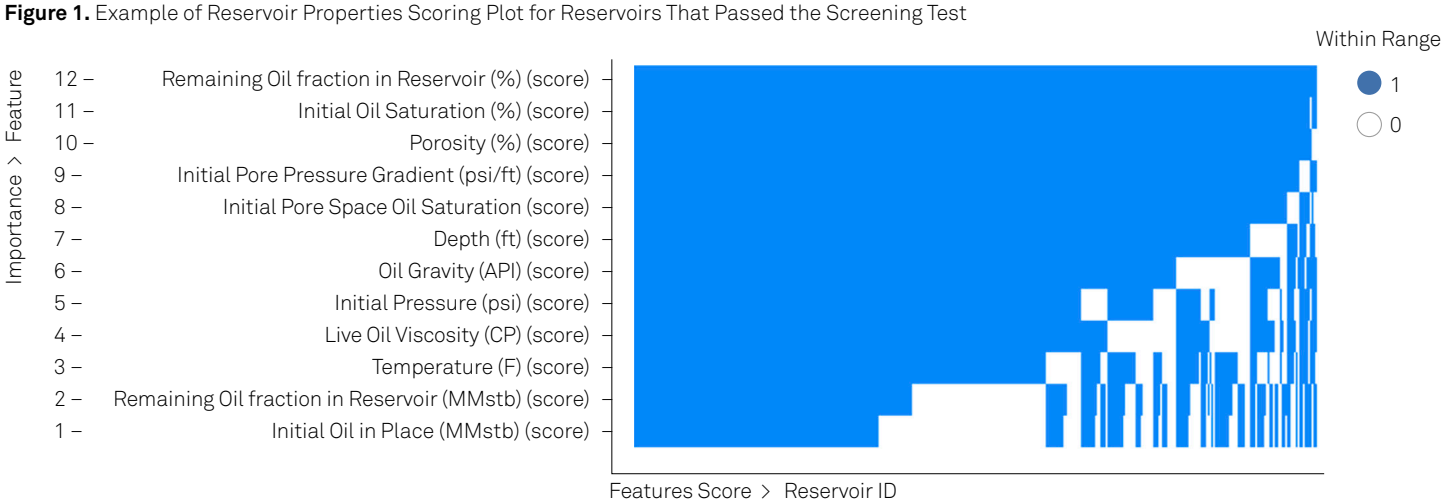
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Figure 1. Example of Reservoir Properties Scoring Plot for Reservoirs That Passed the Screening Test



From Figure 1, the reservoirs that have the most reservoir parameters within range are located on the left part of the plot. As one moves through the plot in Figure 1 from left to right, reservoirs start to have fewer parameters within range but have enough of them to pass the reservoir screening test.

A similar plot can be prepared for reservoirs that fail the reservoir screening test. Figure 2 summarizes the reservoirs that do not have enough reservoir properties within range and, therefore, have failed the screening test.

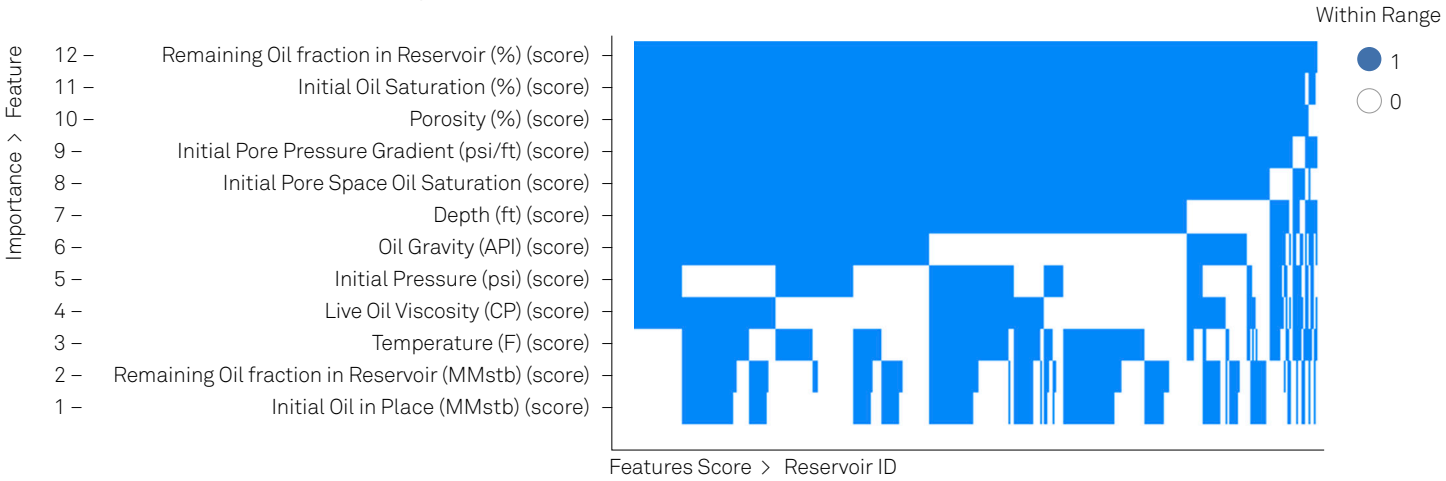


Figure 2. Example of Reservoir Properties Scoring Plot for Reservoirs That Failed the Screening Test

The CO_2 storage capacity is then calculated for every reservoir that passes the screening process. The following equations are used to calculate potential CO2 storage, additional (incremental) recovery factor and net utilization factor (Bachu, 2016):

$$M_{CO_2} = 0.00052 \times U_f \times R_f \times OOIP \quad (1)$$

$$U_f = (1/10^6)\,(V_{CO_2\ purchased}/N_p) \quad (2)$$

$$R_f = N_p / OOIP \quad (3)$$

where:

U_f	Net CO_2 utilization factor, Mscf/STB
$V_{CO_2\ purchased}$	Cumulative volume of purchased CO_2 injected, Mscf
Np	Cumulative incremental oil production, MMSTB
OOIP	Original Oil In Place, MMSTB
R_f	Incremental oil recovery factor, %
M_{CO_2}	Potential CO_2 storage, Mt

Using these expressions, a set of probabilistic plots are created at different percent hydrocarbon pore volumes (HCPV) for Rf and Uf (refer to Azzolina et al, 2015). Additionally, an Rf x Uf plot is presented to better understand how this multiplication affects the potential CO_2 storage *(as shown in Equation 1)*.

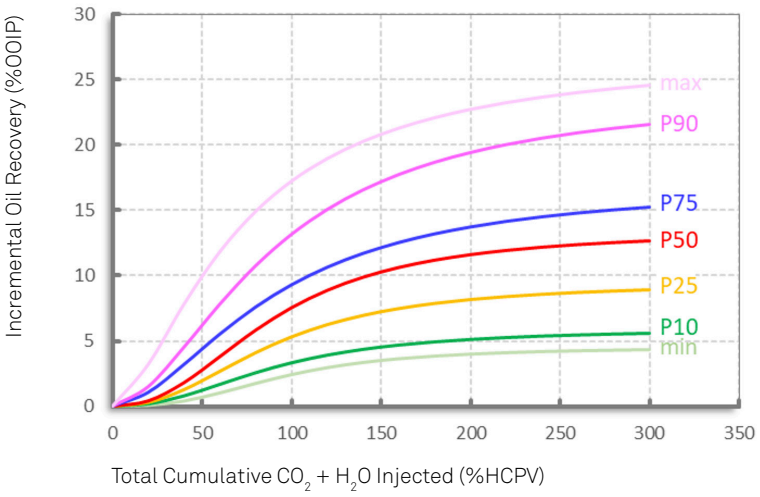


Figure 3. Incremental Oil Recovery (%OOIP) vs Total Cumulative CO_2 + H_2O Injected (%HCPV)

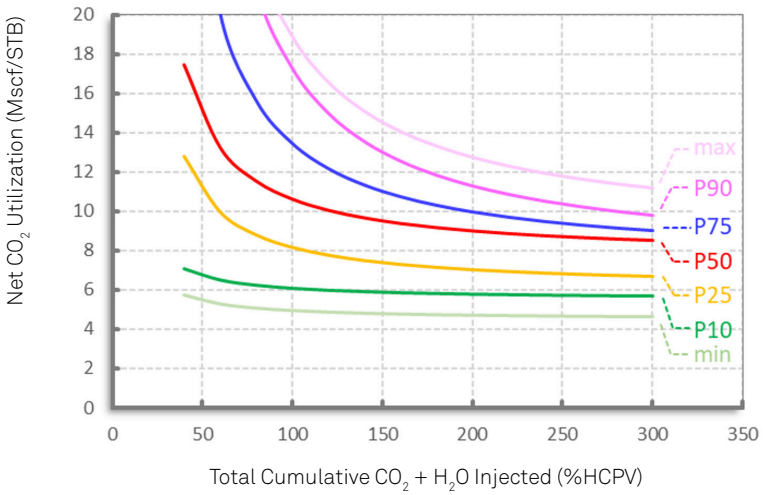


Figure 4. Net CO_2 Utilization (Mscf/STB) vs Total Cumulative CO_2 + H_2O Injected (%HCPV)

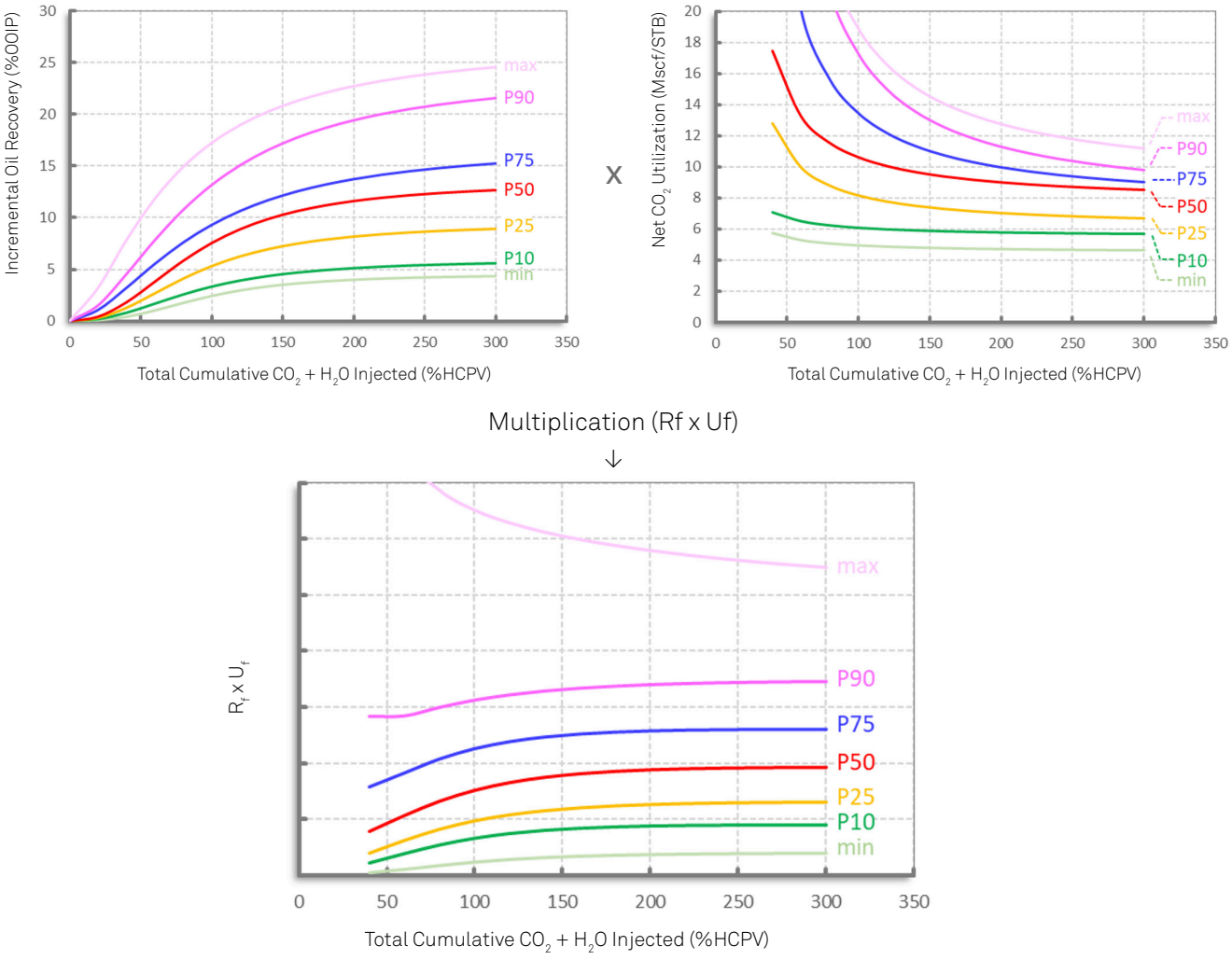


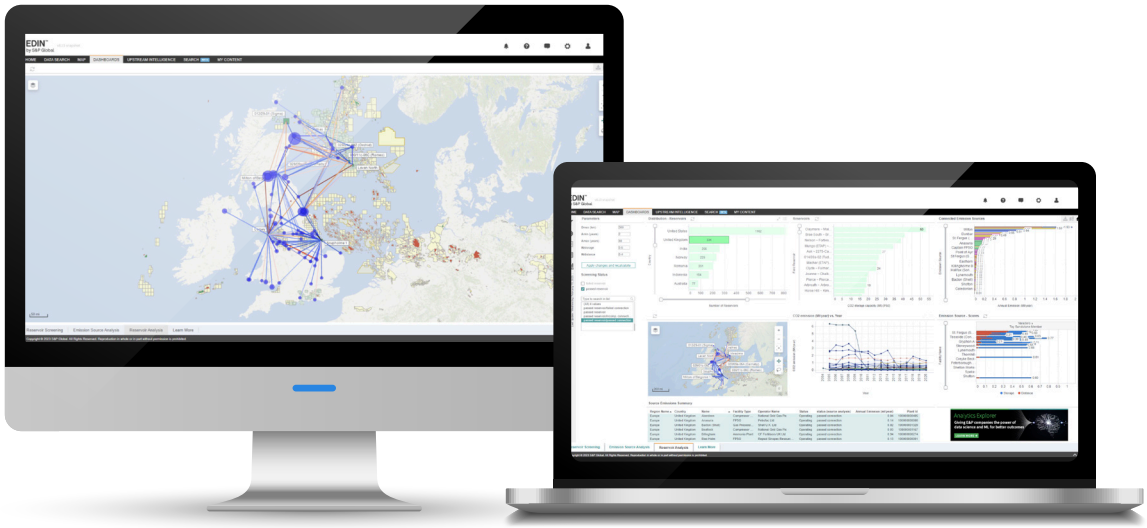
Figure 5. R_f x U_f vs Total Cumulative CO_2 + H_2O Injected (%HCPV)

All probability curves are shown for completeness but, for the purposes of this analysis, only P50 curves are considered.

Linking Emission Sources and Reservoirs

To have a better understanding of the relationship between a CO_2 emitter (emission source) and the storage capacity of a reservoir (to act as CO_2 sink), one can analyze each pair of source-sink nodes starting from the perspective of each of them.

Emission Source Analysis



Starting from the point of view of the emitter, the estimation of the time (years) required for a particular emission source to reach the maximum storage capacity (in Mt) of an oil reservoir (for an EOR scheme) is expressed using the following equation:

$$A_{ER} = M^{R}_{CO_2} / q_E \tag{4}$$

Therefore, the higher A_{ER} the better the capacity to store more CO2 underground over time.

For an impartial comparison, three normalized parameters are used. The normalized capacity index for each reservoir is calculated using the minimum and maximum with reference to each country by:

$$C^{N}_{ER} = (A_{ER} - A_E^{min}) / (A_E^{max} - A_E^{min}) \tag{5}$$

Similarly, the normalized distance between the emitter and the oil reservoir is calculated by:

$$L^{N}_{ER} = (L_E^{max} - L_{ER}) / (L_E^{max} - L_E^{min}) \tag{6}$$

And finally, the normalized depth of the oil reservoir is expressed by:

$$D^{N}_{ER} = (D_R^{max} - D_{ER}) / (D_R^{max} - L_R^{min}) \tag{7}$$

Distance and depth can be used as a proxy economic parameter to consider when connecting an emitter to a prospect reservoir. For example, the deeper the reservoir the more investment will be required to achieve the necessary compression capabilities and facility sizing.

During calculations, it is possible to give more weight to a parameter by using the weighting factors: $W_{storage}$, $W_{distance}$ and W_{depth}. The summation of these weighting factors should add up to one. The use of these factors provides the flexibility to cover diverse combination of scenarios when one of the parameters (storage, distance, or depth) is more important than the others.

Nomenclature

A	Ratio of potential storage of an oil reservoir with respect to the size of the CO_2 emitter
C	Reservoir capacity
D	Depth
L	Distance
M	Potential storage
q	Annual emission
W	Weighting factor

Superscripts

R Reservoir
N Normalized
max Maximum value within a country
min Minimum value within a country

Subscripts

E Emission source
R Reservoir
ER Linked emission source and reservoir
CO_2 Carbon dioxide

Reservoir Analysis

From the reservoir analysis perspective, the normalized factors can be estimated similarly. The difference is that A_ER is now used to estimate how long it will take to reach the maximum storage capacity of an oil reservoir.

$$A_{ER} = M^{R}_{CO_2} / q_E \tag{8}$$

$$C^{N}_{ER} = (A^{max}_{E} - A_{ER}) / (A^{max}_{E} - A^{min}_{E}) \tag{9}$$

$$L^{N}_{ER} = (L^{max}_{E} - L_{ER}) / (L^{max}_{E} - L^{min}_{E}) \tag{10}$$

In this case, two weighting factors can be used to accommodate different scenarios where storage is more important than distance and vice versa: Wstorage and Wdistance. The summation of these factors should add up to one.

Nomenclature

A Ratio of potential storage of an oil reservoir with respect to the size of the C02 emitter
C Reservoir capacity
L Distance
M Potential storage
q Annual emission
W Weighting factor

Superscripts

R Reservoir
N Normalized
max Maximum value within a country
min Minimum value within a country

Subscripts

E Emission source
ER Linked emission source and reservoir
CO_2 Carbon dioxide

Imputation of missing values/calculating required parameters (Bachu, 2016)

The following expressions are used to estimate missing reservoir parameters whenever possible.

$$L_{ER}^{N} = (L_E^{max} - L_{ER})/(L_E^{max} - L_E^{min}) \quad (10)$$

$$T = 0.0164 \times d + 32 \quad (11)$$

$$p_i = 0.45 \times d \quad (12)$$

$$\text{Initial Pore Pressure Gradient} = p_i / d \quad (13)$$

$$R_s = c_1 \times \gamma_g \times p^{c_2} \times e^{c_3(\gamma_o/(T+460))} \quad (14)$$

$p = p_i$
$\gamma_g = 0.6$
$\gamma_o \leq 30 \Rightarrow c_1, c_2, c_3 = 0.0362, 1.0937, 25.7240$
$\gamma_o > 30 \Rightarrow c_1, c_2, c_3 = 0.0178, 1.1870, 23.9310$

$$\mu_{od} = (3.141 \times 10^{10}) / T^{3.444} \; [\log(\gamma_o)]^{10.313 \times \log(T) - 36.447} \quad (15)$$

$$\mu_{ob} = A(\mu_{od})^B$$
$$A = 10.715 \times (R_s + 100)^{-0.515} \quad (16)$$
$$B = 5.44 \times (R_s + 150)^{-0.338}$$

$$MMP = -329.558 + (33056.106 \times \gamma_o^{-0.87} \times 1.005^T) - 18724.806 \times \gamma_o^{-0.87} \quad (17)$$

$$S_{oi} = 100 - S_{wi} \quad (18)$$

$$\text{Initial Pore Space Oil Saturation} = 10^{-4} \times S_{oi} \times \phi \quad (19)$$

$$\text{Remaining Oil Fraction in the Reservoir (\%)} = 100 - \text{Oil Recovery Factor} \quad (20)$$

$$\text{Remaining Oil in the Reservoir (MMstb)} = 0.01 \times \text{Remaining Oil Fraction in the Reservoir (\%)} \times OOIP \quad (21)$$

where:

T Temperature, °F

d Depth, *ft*

p_i Intial Reservoir Pressure, *psi*

γ_o API Gravity

γ_g Gas specific Gravity

R_s Solution Gas Oil Rato, *scf/stb*

μ_{od} Dead Oil Viscosity, *cp*

μ_{ob} Live Oil Viscosity, *cp*

MMP Minimum Miscibility Pressure, *psi*

S_{wi} Initial Water Saturaton, *%*

S_{oi} Initial Oil Saturation, *%*

ϕ Porosity, *%*

$OOIP$ Original Oil In Place, *MMSTB*

Further considerations

The following are considerations of this study and scenarios that are not covered by the currently implemented methodology:

- There is no differentiation between offshore and onshore assets. Similarly, at the present time, topography is not considered
- Only emission sources with reported values after 2019 were used
- The average of the last three years of emissions is used as a proxy for expected future emission volumes
- Only emission sources with an emission rate greater than 0.01 Mt/Year were considered
- This methodology cannot be used to evaluate additional production or storage in gas reservoirs
- It takes no account of existing pipeline infrastructure.
- It does not assess the quality of existing boreholes.
- It eliminates reservoirs in fields that do not meet minimum reservoir criteria (see table)
- It eliminates reservoirs that could not be sourced from existing emissions hubs
- Where data is missing, it imputes values (see the "Parameter Description" document for details)

References

Bachu, Stefan: "Identification of oil reservoirs suitable for CO2-EOR and CO2 storage (CCUS) using reserves databases, with application to Alberta, Canada.", *International Journal of Greenhouse Gas Control* 44 (2016), 152-165.

Azzolina, N.A., **Nackles, D.V.**, **Gorecki, C.D.**, **Peck, W.D.**, **Ayash, S.C.**, **Melzer, S.L.**,**Chatterjee, S.**: "CO_2 storage associated with CO2 enhanced oil recovery: a statistical analysis of historical operations.", *International Journal of Greenhouse Gas Control* 37 (2015), 384–397.

Angarita, Edgar Eduardo Yáñez, et al.: "Rapid screening and probabilistic estimation of the potential for CO_2-EOR and associated geological CO2 storage in Colombian petroleum basins.", *Petroleum Geoscience* 28.1 (2022), petgeo 2020-110.

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