The CO_2 GeoStorage Assessment

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Abstract

Climate change has been at the top of the most important issues worldwide. Reducing the carbon footprint and at the same time having sustainable economic growth is urgent and a great challenge. Therefore, new technologies to reduce CO2 emissions have been extensively investigated and developed in recent decades. One of the possible strategies is to capture emissions at source and store them in geological reservoirs. This work aims to evaluate the potential of a geologic formation for CO2 storage based on critical criteria and to reach this objective an online application (CO2GeoStorage Assessment App) to assess the suitability of geological reservoirs for CO2 storage was developed. The geological formation must have some specific characteristics and meet certain criteria to be suitable for storing CO2.

The methodology consists of two parts. First, screening questions are analyzed based on the eliminatory criteria adopted by Valer (2010). After the eliminatory criteria, the second part is the evaluation of the ranking using a method in which qualitative criteria are valued with quantitative parameters of the characteristics of the sedimentary basins, thus allowing the user to compare the suitability of the basins for geological storage of CO2. This assessment uses fifteen site characterization criteria developed by Bachu (2003) and modified by Kaldi and Polle (2008). Two sedimentary basins were chosen as a case study for the validation of the App; one located in Canada and the other located in Kazakhstan. Canada has five sub-basins and Kazakhstan has six sub-basins. To run these test cases, data from published works were collected. Three of the reservoirs were eliminated in the first phase, and the ranking results for the other eight sub-basins were very positive; the rankings were similar to those published validating the applicability of the CO2GeoStorage Assessment App.

Keywords: CO_2 Storage, CO_2 site criteria, CO_2 assessment App, CCS- Carbon dioxide capture and storage.

1. Introduction

The main objective of this project is to evaluate the potential of a geologic formation for CO2 storage based on critical criteria (eliminatory and ranking calculation) and to reach this objective an App was developed in order to contribute in the reduction the consequences of climate change. Comparing to surface mineral carbonation and ocean storage, the geological storage of CO_2 currently represents the best and likely the only short-to-medium term option for significantly reducing net carbon emissions into the atmosphere (Metz, et al., 2005).

The suitability of a specific CO_2 source for capture depends on its integrated system, volume, partial pressure, concentration, and

proximity to a proper reservoir. The CO_2 occur from a couple of sources, mainly industrial, fossil fuel combustion in the power generation and transport sectors. The industrial sectors and the power generation produce large volumes of CO_2, over 60% making them more amenable to CO_2 capture technology than small point sources as transport and residential sectors which contribute with around 30% of the global CO_2 emission (Khotalekar & Kumari, 2016).

As energy consumption continues to grow, CO_2 increases in the atmosphere, creating irreversible climate change. If carbon dioxide capture and storage (CCS) is fully implemented, there is a potential of capturing and storing 236 billion tons of CO_2 globally by 2050 (Stangeland, 2007).

The storage of CO_2 requires compression of CO_2 to allow injection by exposing the CO_2 to temperatures higher than 31.1°C and pressure greater than 73.9 bars in a supercritical state (Newell & Ilgen, 2019).

Carbon dioxide can be stored geologically in a variety of different options as see in Figure 1. Typical geological storage sites include deep saline formations, depleted hydrocarbon reservoirs, EOR, unmendable coal seams, salt caverns, and basalt formations (Bachu, 2000).

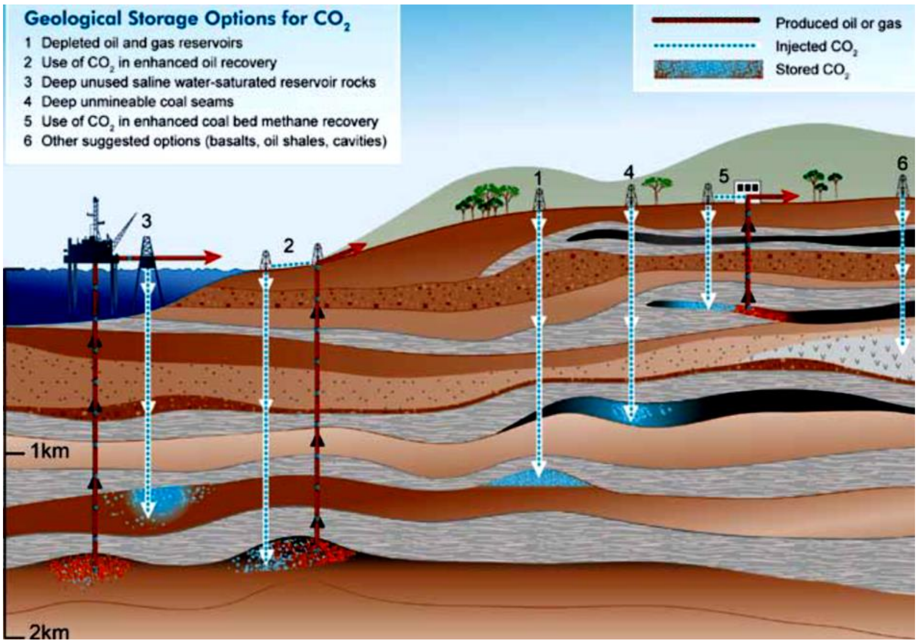

Figure 1- Options for storing CO_2 in deep underground geological formations (Metz, et al., 2005)

Carbon dioxide becomes less mobile over time due to multiple trapping mechanisms, further lowering the prospect of leakage, which builds confidence in the geological security of carbon dioxide storage, as shown in Figure 2 (Metz, et al., 2005).

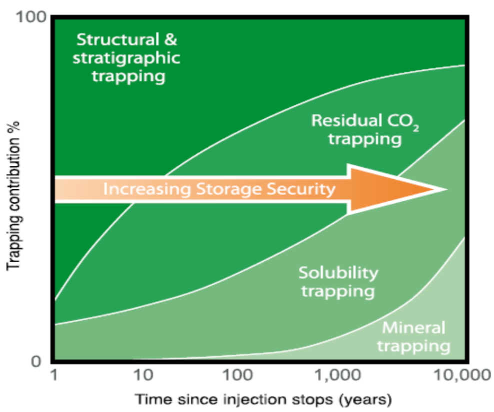

Figure 2 - Storage security depends on a combination of physical and geochemical trapping. (Metz, et al., 2005)

The initial storage mechanism will dominant be physical trapping with increasing time and migration, more CO_2 is trapped residual in the pore space or is dissolved in the formation water, and finally, mineral trapping may occur by precipitation of carbonate minerals after geochemical reaction, permanently trapping the CO_2 and increasing the storage security (Poole, 2009).

1.2. Site Criteria

A series of suitability criteria were previously developed Bachu, which can be broadly classified into:

- Basin characteristics, such as tectonism, geology, geothermal and hydrodynamic regimes (these are ''hard'' criteria because they do not change).

- Basin resources (hydrocarbons, coal, salt), maturity and infrastructure (these ''semi-hard'' or ''semi-soft'' criteria because they may change with discoveries, technological advances or economic development).
- Societal, such as level of development, economy, political structure and stability, public education, and attitude (these are ''soft'' criteria because they can rapidly change or vary from one region to another).

An overall ranking score would take these and other criteria into account to arrive at a quantitative evaluation regarding a basin's suitability for CO_2 sequestration.

Table 1 and Table 2 presents a set of 15 criteria for assessing and ranking sedimentary basins in terms of their suitability for CO_2 sequestration or storage. The list can be expanded further if more criteria are developed. Three to five classes have been defined in each category listed from the least favourable to the most favourable for CO_2 sequestration or storage (Bachu, 2003). However, if CO_2 geological sequestration or storage are to be implemented on a large scale, then there is need for a systematic, quantitative analysis of sedimentary basins in terms of their suitability.

For each criterion i (i=1...15) in these tables describe a value placed on the specific class j for that criterion. The smallest and most outstanding values of this function characterize the worst and best class in terms of suitability for that criterion, the is the Fi,1= min and Fi, n = max (Fi), n represents the number of classes in that criterion (n=3, or 5). The weights (w_i) can be changed or adapted to changing conditions and priorities, where w_i are weighting that satisfies the condition, of the total weight is equal to one (1).

Tablet 1 - Criteria for assessing sedimentary basins for CO_2 geological sequestration with the scores. (Bachu, 2003)

	Criterion	**Classes (Score "J")**					**Weight ("w_i")**
		J=1	J=2	J=3	J=4	J=5	
i=1	Tectonic setting	Convergent oceanic **(1)**	Convergent intramontane **(3)**	Divergent continental shelf **(7)**	Divergent foredeep **(15)**	Divergent cratonic **(15)**	0.07
i=2	Size	Small **(1)**	Medium **(3)**	Large **(5)**	Giant **(9)**		0.06
i=3	Depth	Shallow (<1,500 m) **(1)**	Intermediate (1,500–3,500 m) **(3)**	Deep (>3,500 m) **(5)**			0.08
i=4	Geology	Extensively faulted and fractured **(1)**	Moderately faulted and fractured **(3)**	Limited faulting and fracturing, extensive shales **(7)**			0.08
i=5	Hydrogeology	Shallow, short flow systems, or compaction flow **(1)**	Intermediate flow systems **(3)**	Regional, long-range flow systems; topography or erosional flow **(7)**			0.08
i=6	Geothermal	Warm basin **(1)**	Moderate **(3)**	Cold basin **(7)**			0.10
i=7	Hydrocarbon potential	None **(1)**	Small **(3)**	Medium **(7)**	Large **(13)**	Giant **(21)**	0.06
i=8	Maturity	Unexplored **(1)**	Exploration **(2)**	Developing **(4)**	Mature **(8)**	Over mature **(10)**	0.08
i=9	Coal and CBM	None **(1)**	Deep (>800 m) **(2)**	Shallow (200–800 m) **(5)**			0.04
i=10	Salts	None **(1)**	Domes **(2)**	Beds **(3)**			0.01
i=11	On/Offshore	Deep offshore **(1)**	Shallow offshore **(4)**	Onshore **(10)**			0.10
i=12	Climate	Arctic **(1)**	Sub-Arctic **(2)**	Desert **(4)**	Tropical **(7)**	Temperate **(11)**	0.08
i=13	Accessibility	Inaccessible **(1)**	Difficult **(3)**	Acceptable **(6)**	Easy **(10)**		0.03
i=14	Infrastructure	None **(1)**	Minor **(3)**	Moderate **(7)**	Extensive **(10)**		0.05
i=15	CO_2 Sources	None **(1)**	Few **(3)**	Moderate **(7)**	Major **(15)**		0.09

In 2008, the Cooperative Research Centre for Greenhouse Gas Technologies (CO2CRC) in Australia produced a report on methods for estimating CO_2 storage capacity and storage site selection and characterisation. Kaldi and Poole (2008) created a new table adapted for the Bachu (2003); the adapted table indicates a significant difference between the criteria for basin-scale assessment in terms of suitability for CO_2; some numerical values were modified, refined or added. Only in the following cases the Kaldi and Poole (2008) introduce some changes: the very small class was added to the Size category and Depth category; The shallow offshore and onshore class was added on the On/Offshore category. Other adaptations were made for criteria for assessing CO_2 storage in different parts of the world. The table 2 represents the modified table from Kaldi and Poole (2008), which also will be used in this work, with all the data necessary for the calculation of the ranking.

Table 2 - Criteria for assessing CO_2 storage potential of sedimentary modified from (Kaldi and Gibson-Poole) with the scores

	Criterion	Classes (Score "J")					Weight ("w_i")
		J=1	J=2	J=3	J=4	J=5	
i=1	Seismic - Tectonic setting	Very high **(1)**	High **(3)**	Intermediate **(7)**	Low **(15)**	Very low **(15)**	**0.10**
i=2	Size (Km^2)	Very small (<1,000 km^2) **(1)**	Small (1,000-5,000 km^2) **(3)**	Medium (5,000-25,000 km^2) **(5)**	Large (25,000-50,000 km^2) **(8)**	Very large (>50,000 km^2) **(10)**	**0.06**
i=3	Depth	Very shallow (<300 m) **(1)**	Shallow (300-800 m) **(2)**	Deep (>3,500 m) **(6)**	Intermediate (800-3,500 m) **(10)**		**0.10**
i=4	Deformation – Faults & Fractures	Extensive **(1)**	Moderate **(4)**	Limited **(10)**			**0.09**
i=5	Reservoir Seal Pairs	Poor **(1)**	Intermediate **(4)**	Excellent **(10)**			**0.10**
i=6	Geothermal	Warm basin (>40° C/km) **(1)**	Moderate (30-40° C/km) **(4)**	Cold basin (<30° C/km) **(10)**			**0.08**
i=7	Hydrocarbon potential	None **(1)**	Small **(3)**	Medium **(7)**	Large **(14)**	Giant **(21)**	**0.04**
i=8	Salts	None **(1)**	Domes **(2)**	Beds **(3)**			**0.01**
i=9	Coal and CBM	None **(1)**	Deep (>800 m) **(2)**	Shallow (200–800 m) **(5)**			**0.04**
i=10	Maturity	Unexplored **(1)**	Exploration **(2)**	Developing **(4)**	Mature **(8)**	Super mature **(10)**	**0.08**
i=11	On/Offshore	Deep offshore **(1)**	Shallow offshore **(5)**	Shallow offshore and onshore **(10)**	Onshore		**0.11**
i=12	Climate	Arctic **(1)**	Sub-Arctic **(2)**	Desert **(4)**	Tropical **(7)**	Temperate **(11)**	**0.04**
i=13	Accessibility	Inaccessible **(1)**	Difficult **(3)**	Acceptable **(6)**	Easy **(10)**		**0.04**
i=14	Infrastructure	None **(1)**	Minor **(3)**	Moderate **(7)**	Extensive **(10)**		**0.05**
i=15	CO_2 Sources	None **(1)**	Few **(3)**	Moderate **(7)**	Significant **(15)**	Many	**0.06**

For any sedimentary basin k evaluated regarding its general suitability for CO_2 sequestration or storage, the corresponding class j for each criterion is identified, resulting in a corresponding score $F_{i,j}$. *As a result of this process, each sedimentary basin k being evaluated is characterized by 15 individual scores* P_i^k,

$$P_i^k = \frac{F_{i,j} - F_{i,1}}{F_{i,n} - F_{i,1}} \qquad \text{(equation 1)}$$

These can subsequently be added to produce a general score R^k, used in basin ranking, which is calculated using:

$$R^k = \sum_1^{15} w_i P_i^k \qquad \text{(equation 2)}$$

Using this methodology, sedimentary basins, or parts thereof, within a geographic region can be assessed and ranked in terms of their suitability for the geological storage of CO_2 (Bachu, 2003).

When results of the ranking closer to one ($R^k \approx 1$) are most favourable, and those closer to zero ($R^k \approx 0$) are less favourable for CO_2 storage. However, it is essential to note that the results of this ranking process are not absolute when making a final decision.

The eliminatory criteria developed by Valer (2010) form the site screening, a sedimentary basin or region that does not pass these criteria should not be considered for CO_2 storage. Table 3 presents a set of eliminatory criteria (Valer, 2010)

Table 3 - Eliminatory suitability criteria for assessing sedimentary basins for CO_2 geological storage. (Valer, 2010)

	Criterion	Not suitable	Suitable
1	Depth	Less than 1000 m	Greater than 1000 m, with storage units deeper than 800 m
2	Reservoir-seal pairs and stratigraphic sequences	Poor	Intermediate and excellent, at least one major extensive regional-scale competent seal
3	Pressure regime	Over-pressured	Hydrostatic or sub-hydrostatic
4	Seismicity (basin tectonic setting)	High and very high (subduction zones; syn-rift and strike- slip basins)	Very low to moderate (foreland, passive margin and cratonic basins)
5	Faulting and fracturing intensity	Extensive	Limited to moderate
6	Surface areal extent	Less than 2500 km^2	Greater than 2500 km^2
7	Hydrogeology	Shallow, short flow systems, or compaction flow	Intermediate and regional-scale flow systems; topography and erosional flow
8	'Legal' accessibility	Forbidden	Possible

The first three criteria are critical because the reservoir or part thereof that does not satisfy all these should automatically be deemed unsuitable for CO_2 storage because of the high risk of compromising the safety and security of storage. The following four criteria are essential in the sense that there may be exceptional cases where one of these criteria is not being met, but all the others are, such a basin may still be considered for CO_2 storage. However, if more than one of the essential suitability criteria is not being met, then that basin or region should not be considered for CO_2 storage. Finally, the last criterion is also critical, but, unlike the others, it is not a physical characteristic of the basin but rather a designation resulting from a legislative or regulatory action that may change in the future (Valer, 2010).

2. Methodology

Nowadays, the criteria developed by Bachu (2003) have been adopted around the world to fit the reality of different regions and characteristics of the sedimentary basin, as explained in the literature review. This work proposes the development of an App with a user interface where users can select the criteria based in geological data. The data combines both approaches, the eliminatory suitability criteria Valer (2010) and the fifteen (15) criteria selection from Bachu (2003) or modifier from Kaldi and Poole (2008) for assessing sedimentary basins for CO_2 geological storage. Once data have been compiled on characteristics of the sedimentary basin, they can be compared, contrasted, and ranked.

The CO_2GeoStorage Assessment is an App was developed using the software Visual Studio Code, GitHub and Hosting, and the following programming languages HTML, CSS and JavaScript. The procedure used in the App is a sequencing of the elimination criteria Valer (2010) divided into two (2) assessment page and last page is assessment ranking calculation Bachu, 2003 or Kaldi and Poole.

First assessment step

The first step consists of a series of Yes or No questions about the critical criteria described in table 5 (Valer, 2010). All three (3) questions must be answered positively so that it can proceed to the next step contrarily, the program displays a pop-up message saying that the sedimentary basin is not suitable for CO_2 storage according to the eliminatory criteria, and the assessment will end at the first step. The following questions are related to the study area:

- The depth is greater than 1000 m?
- The reservoir-seal pairs and stratigraphic are intermediate or excellent?
- The pressure regime is hydrostatic or sub-hydrostatic?

Second assessment step

he second step is also Yes or No questions of the essential criteria described in table 5 (Valer, 2010). Depending on the number of positive answers, the program has different approaches. The program leads the next step if all four (4) questions are answered positively. Suppose only three (3) questions are answered positively; in that case, the program displays a pop-up message saying that although one (1) of the essential criteria were met, it is possible to continue and go to the next step. In case of two (2) negative answers, the program displays a pop-up message saying that the sedimentary basin is not suitable for CO_2 storage according to the eliminatory criteria, and the assessment will end at the second step. The four (4) questions will be the following:

- The seismicity (basin tectonic setting) is very low to moderate?
- The faulting and fracturing intensity is limited to moderate?
- The surface is greater than 2500 km^2?
- The hydrogeology is intermediate flow?

Third assessment step

After choosing one or two ranking assessment methods the Bachu or the modified Kaldi and Poole, the third step involves the selection of one (1) class of each fifteen (15) criteria described on the table1 (Bachu, 2003) or table 3 (the motived Kaldi and Poole, 2008), Then using the values described in table 2 (Bachu, 2003) or table 4 (the modified from Kaldi and Poole, 2008),which indicates that each class has a specific score (J) and each criterion (i) has a weight (wi). Hence, equation 1 results from these selections, where 15 individual scores characterize evaluation. For example, if Pi is closer to zero (Pi ≈ 0) is least favourable, and if the Pi is closer to one (Pi ≈ 1), most favourable it is. To finalize the assessment, a basin ranking score R^k is calculated using equation 2, which uses the results of equation 1 and weights (w_i) equally if Rk is closer to zero (R^k ≈ 0) is least favourable, and if the R^k is closer to one (R^k ≈ 1), most favourable it is. These fifteen (15) Criteria for assessing sedimentary basins for CO_2 geological storage sequestration were described in the literature review.

Figure 3 below represents the flow chart of the App. The six (6) rectangular represent the pages, the home page, critical criteria assessment page, essential criteria assessment page, the page to choose between the two ranking assessment and fifteen (15) criteria ranking assessment page. The five (5) hexagons represent the pop-up windows. Two of them indicate that the basin is not suitable for CO_2 storage based on eliminatory criteria; one is a warning message to alert that although one essential criterion was not met, the basin still be considered for CO_2 storage; and other indicates that all the eliminatory criteria were met, next step is the ranking assessment; and the last is the result of basin ranking based on equation 1 and 2.

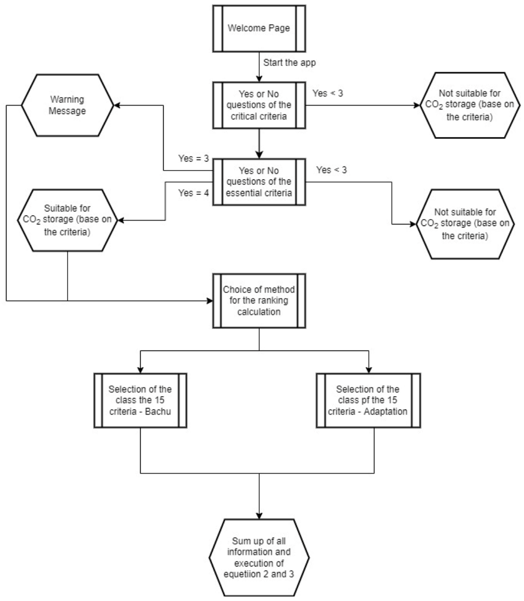

Figure 3 - Flow chart of the CO_2 GeoStorage Assessment App

2.1. App Development

In order to develop the application described above, the programming language referred to in the literature review was used to code. Moreover, software to edit the code and another to save the code version and host will be explained below.

2.1.1 Website development

The website was developed using the following programming languages HTML, CSS and JavaScript which are considered frontend languages, because they define the architecture of the pages and determine the visual aspects of the website, that can be seen and experienced by the user. The HTML to write all that be seen on the pages. The CSS has functionality to configure the style of the page on the screen. While JavaScript helps develop the interaction with the user; it also has backend language that sums up the answers to fulfil the conditional function, executes the equations' function, and pops up messages and buttons to press to get the next step and submit the answers.

Home Page

The HTML of the home page is the simplest of the four pages. It was the only page where the image was inserted, and list of elements to introduce the text, the CSS code for the home page that was used to configure the layout of all of the pages, and the JavaScript, as mentioned before, is what permits the interaction with the user to allow the user to get to the next page.

The all code of the page can be found on this link: https://github.com/selmachanga/homepage/tree/328f0b9b3ffc7f72e771cf3077d6da5edc535986

Critical and Essential Criteria Page

The HTML for these pages are very similar in terms of programming, present more components such as the “<from>” right at the beginning of the page to be able to have control over the submitted answers. The JavaScript only differs on the two (2) pages in the number of conditional functions they have, as seen in the flowchart Figure 3.

The all codes of the page can be found on these links:

https://github.com/selmachanga/CriticalCriteria/commit/6dcbc39e2563f0e036f4429689661a5d46ad7779

https://github.com/selmachanga/EssentialCriteria/commit/771e837f8cce5af99dbbde0e960d16b71d594938

The 15 Criteria Assessing and Ranking Page

First of all is necessary to choose which, criteria assessment ranking will be used, there are two option the one described on table 1 by (Bachu 2003) and another one described on table 3 by (Kaldi and Gibson-Poole 2008). Then it leads the last assessment page that composes an important part of App, the most complex part of the code. The HTML to begin, it needs to manage the control of the classes chosen for each of the 15 criteria; for that, the component “<from>” is inserted right at the beginning of the page. Then the component “<select>” is used to present a menu of options, in which each class is represented by the element “<option>”.

The JavaScript in this page has a crucial function of the App because involves the execution of the two equations that leads to the ranking of the sedimentary basin. Extreme tests were done to attest the efficiency of the equations for the ranking assessment. Firstly, all criteria were selected in the first class, which is the least favourable scenario where the score “j” equals one (0) and as expected, the ranking result was zero (0). Secondly, all criteria were selected in the last class, which indicates the most favourable scenario where the score “j” equals as the higher value and as expected, the ranking result was one (1).

The all codes of the page can be found on these links:

https://github.com/selmachanga/Choiceofmethodfortherankingcalculation/commit/3b9be52f1e87d93eda3a778d4da832a16f46ec6d

https://github.com/selmachanga/15criteriabachu1/commit/59185d593e3b6d3b8beea29d6d9590793033af3d

https://github.com/selmachanga/15criteriaadptada/commit/b37fe43d149c40ed46ae6016a1688674f4e6f7cc

3. Result and Discussion

The website can be accessed from this link: https://bespoke-wisp-e92dba.netlify.app

To analyse the capability of the App developed in this work, two (2) sedimentary basins were chosen for test cases, where ranking assessments have already been applied, and the information of the site characterisation data is available. It is noteworthy that it was challenging to find published papers with all the necessary data to attend all the criteria phases for the CO_2 Geo2Storege Assessment App.

The fields chosen for this research are the Québec basin in Canada (Malo & Bedard, 2012) and Kazakhstan sedimentary basins (Abuov, et al., 2020).

The CO_2GeoStorage Assessment App has two distinct parts, the screening phase, where the eliminatory criteria are applied (which is also divided in critical and essential criteria) and the ranking assessment phase, where the equation 1 and equation 2 are applied. Most of the published papers found were focused on the ranking assessment. However, this work may eliminate some basins before the ranking assessment phase because it takes into consideration the eliminator criteria first. In other words, if it does not pass the qualitative characteristics, it is considered unsuitable for CO_2 storage and there is no need to analyse quantitatively.

Additionally, the results before and after using the CO_2GeoStorage Assessment App are presented showing the ranking assessment and the percentage of matching. Also, the information regarding the characterization of each basin can be found in this chapter.

3.1. Province of Québec Basin, Canada

The Appalachian Mountain belt comprises Palaeozoic sedimentary rocks that can be split into four sub-basins: the St. Lawrence platform, the Appalachian sub-basin, the Gaspé Belt sub-basin, and the Magdalen sub-basin. The St. Lawrence platform is split into two: the Anticosti and the St. Lawrence Lowlands. (Malo & Bedard, 2012). After applying the data about the site characterization of the six sub-basins into the App the following results were gotten:

- The Taconian and the Acadian sub-basins did not meet one of the requirements to pass the eliminatory criteria. Both presented a poor reservoir seal pair. There was also did not found data about depth of Taconian depth.
- The other three sub-basin passed the eliminatory criteria, all of them presented intermediate depth, excellent reservoir seal pairs, low seismicity, limited faulting, medium to very large size and cold geothermal.
- The Lowland sub-basin results which had the best rank (0.84) because not only has suitable geological properties but also has a temperate climate, easy accessibility and infrastructures, with the advantage of being located onshore and close to many CO_2 sources.
- The Anticosti sub-basin presents the second-best rank (0.69) mainly because is biggest of the three and is located at shallow offshore and onshore, but the accessibility is difficult and has few sources of CO_2.
- The rank (0.67) of the Magdalen sub-basin has a small difference with Anticosti sub-basin mainly despite the size that is less than half the Anticosti sub-basin. In fact, this sub-basin is only one of three cases that presents coal depth and salt beds, and have a large hydrocarbon potential but, it has a shallow offshore, difficult accessibility and few CO_2 sources.

The data about the Québec basin in the table 4 were applied at the CO_2 GeoStorage Assessment App and compared with the one on the published paper (Malo & Bedard, 2012).

Table 4 – Québec basin, Canada (Malo & Bedard, 2012)

Criterion	Classes for each basin				
	Lowlands	Anticosti	Taconian	Acadian	Magdalen
Tectonic setting	Low	Low	Low	Low	Low
Size	Medium	Very large	Very large	Large	Large
Depth	Intermediate	Intermediate		Intermediate	Intermediate
Deformation	Limited	Limited	Extensive	Extensive	Limited
Reservoir Seal Pairs	Excellent	Excellent	Poor	Poor	Excellent
Geothermal	Cold basin	Cold basin	Cold basin	Cold basin	Cold basin
Hydrocarbon potential	Medium	Medium	None	Small	Large
Salts	None	None	None	None	Beds
Coal and CBM	None	None	None	None	Deep
Maturity	Developing	Exploration	Exploration	Exploration	Exploration
On/Offshore	Onshore	Shallow offshore and onshore	Onshore	Onshore	Shallow offshore
Climate	Temperate	Temperate	Temperate	Temperate	Temperate
Accessibility	Easy	Difficult	Easy	Easy	Difficult
Infrastructure	Extensive	Minor	Extensive	Extensive	Minor
CO_2 Sources	Many	Few	Moderate	None	Few
R^k of the published paper	0.84	0.69	0.51	0.58	0.67
R^k of the CO_2 GeoStorage Assessment App	0.835	0.690	Unsuitable by the critical criteria (Valer, 2010)	Unsuitable by the critical criteria (Valer, 2010)	0.672

3.2. Kazakhstan sedimentary basin

Kazakhstan is the ninth largest country in the world and has the twelfth oil and gas reserves in the world. That is an indication of the country´s huge potential for CO_2 storage. Six sedimentary sub-basins were selected for the study published in (Abuov, et al., 2020). The six selected sub-basins have different ages, geological characteristics, fossil fuel potentials, affinity to CO_2 sources, and different levels of development in existing infrastructures. The six Kazakhstan sub-basin were tested at the CO_2 GeoStorage Assessment App:

- The Zaysan sub-basin was the only one eliminated at the first phase because it did not meet tow of the requirement to pass the eliminatory criteria by Valer (2010); is a tectonically un-stable and extensively faulted it is considered to be oceanic convergent.
- Whereas the other five sub-basins present good characteristics to pass the screening of the eliminatory.
- Precaspian is one with the best rank (0.83) because it is one of the largest sub-basins of the world with an area of 500 000 km2 along with favorable geological characteristics of CO_2 storages such as the presence saltbeds, as well as a temperate climate, onshore location, satisfactorily accessible, extensive infrastructures and close to major CO_2 sources.
- Mangyshlak sub-basin presents the second-best rank (0.80) of the 6 cases analyzed and comparing with the Precaspian sub-basin, does not have saltbeds, and it has a moderate infrastructure and a moderate geothermal gradient. The major advantage is the easy accessibility to an aquifer with long flow system.
- South Torgay sub-basin presents the third best rank (0.74). It does not have saltbeds but presents a tectonic setting of divergent continental shelf, intermediate flow of aquifer, a moderate infrastructure and moderate geothermal gradient, and an easy accessibility.
- Ustyurt sub-basin has a rank (0.73) has a small difference compared to the South Torgay sub-basin because it has a medium hydrocarbon potential, a medium industrial maturity, and a divergent cratonic tectonic setting but, on other side it has an easy accessibility and a cold geothermal gradient.
- Chu-Sarysa sub-basin has the small rank (0.66) because the tectonic setting is a convergent intramontane and it presents a moderate infrastructure, an intermediate flow aquifer, and a moderately faulted and fractured geology. The advantage of this sub-basin is the cold geothermal gradient, an easy accessibility and a saltbed.

The data about the Kazakhstan sedimentary basin in the table 5 were applied at the CO_2 GeoStorage Assessment App and compared with the one on the published paper (Abuov, et al., 2020).

Table 5 - Kazakhstan Sedimentary Basin (Abuov, et al., 2020)

Criteria	Classes for each basin					
	Precaspian	Mangyshlak	South Torgay	Ustyurt	Chu-Sarysu	Zaysan
Tectonic setting	Divergent cratonic	Divergent continental shelfh	Divergent continental shelf	Divergent cratonic	Convergent intramontane	Convergent oceanic
Size	Giant	Giant	Giant	Giant	Giant	Medium
Depth	Deep	Deep	Deep	Deep	Deep	Intermediate
Geology	Moderately faulted	Limited faulting	Limited faulting	Limited faulting	Moderately faulted	Extensively faulted
Hydrogeology	Intermediate flow	long-range flow	Intermediate flow	Intermediate flow	Intermediate flow	Intermediate flow
Geothermal	Cold	Moderate	Moderate	Cold	Cold	Warm
Hydrocarbon potential	Giant	Large	Large	Medium	Small	Small
Salts	Beds	None	None	None	Beds	None
Coal and CBM	Shallow	Deep	Deep	Deep	Deep	Deep
Maturity	Developing	Mature	Mature	Developing	Exploration	Exploration
On/Offshore	Onshore	Onshore	Onshore	Shallow offshore	Onshore	Onshore
Climate	Temperate	Temperate	Temperate	Temperate	Temperate	Sub-Arctic
Accessibility	Acceptable	Easy	Easy	Easy	Easy	Easy
Infrastructure	Extensive	Moderate	Moderate	Moderate	Moderate	Moderate
CO_2 Sources	Major	Major	Major	Major	Major	None
Rk of the published paper	0.83	0.80	0.74	0.73	0.66	0.25
R^k of the CO_2 GeoStorage Assessment App	0.827	0.795	0.742	0.728	0.662	Unsuitable by essential criteria (Valer, 2010)

4. Conclusion

Undoubtedly, action to combat climate change caused by gas emissions is the world's number one priority. Geological reservoir for CO_2 storage is one of solutions that could help cutting down the levels of CO_2 emission released to the atmosphere. In this work an online app helps the decision-making process about the potential suitability for geological reservoir CO_2 storage was developed.

It was proposed a two stages methodology: a screening phase and a ranking phase. In the screening phase some basins may be preliminary eliminated before going to the ranking phase because they have characteristics that compromise the safety and security of the CO_2

storage. Two regional basins were chosen to attest the suitability of the App. A few test cases were used to validate the results of the app and it were consistently verified by published data. For some of the reservoirs data to fulfil the eliminatory criteria was not found and for this reason were not used in the validation process.

In the future, the App can be improved to be flexible and allow the user to change the scores and the weights of each criterion to express the importance of classes for any given criteria.

As a recommendation, the App can be used in the future to assess other sedimentary basins that have not yet been evaluated. Other factors that are not evaluated by this must remain in consideration, such as the storage capacity, economic viability, political stability, and others.

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