CO_2GeoStorage Assessment App

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Declaration

I declare that this document is an original work of my own authorship and that it fulfils all the requirements of the Code of Conduct and Good Practices of the Universidade de Lisboa.

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 CO_2 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 CO_2 storage based on critical criteria and to reach this objective an online application (CO_2GeoStorage Assessment App) to assess the suitability of geological reservoirs for CO_2 storage was developed. The geological formation must have some specific characteristics and meet certain criteria to be suitable for storing CO_2.

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 CO_2. 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 CO_2GeoStorage Assessment App.

Keywords

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

Resumo

As alterações climáticas têm estado no topo das questões mais importante a nível mundial. Reduzir a pegada de carbono e ao mesmo tempo ter um crescimento económico sustentável é urgente e um grande desafio. Por isso, as novas tecnologias para reduzir as emissões de CO2 têm sido amplamente investigadas e desenvolvidas nas últimas décadas. Uma das estratégias possíveis é capturar as emissões na fonte e armazená-las em reservatórios geológicos. Este trabalho tem como objetivo avaliar o potencial de uma formação geológica para o armazenamento de CO2 baseado em critérios críticos e para atingir este objetivo desenvolveu-se um aplicativo online (CO2GeoStorage Assessment App). A formação geológica deve ter algumas características específicas e cumprir certos critérios para ser adequada para armazenar CO_2.

A metodologia consiste em duas partes. Primeiramente, são analisadas questões de triagem com base nos critérios eliminatórios adotados por Valer (2010). Passados os critérios eliminatórios, a segunda parte é a avaliação do ranking utilizando um método onde se valorizam critérios qualitativos com parâmetros quantitativos das características das bacias sedimentares, permitindo assim ao utilizador comparar a adequação das bacias para armazenamento geológico de CO_2. Esta avaliação utiliza quinze critérios de caracterização do local desenvolvidos por Bachu (2003) e modificados de Kaldi e Polle (2008). Duas bacias sedimentares foram escolhidas como caso de estudo para a validação do App; uma localizada no Canadá e outra localizada no Cazaquistão. O Canadá tem cinco sub-bacias e o Cazaquistão tem seis sub-bacias. Para executar esses casos de teste, foram coletados dados de trabalhos publicados. Três dos reservatórios foram eliminados na primeira fase, e os resultados do ranking das outras oito bacias foram muito positivos; os rankings foram semelhantes aos publicados validando a aplicabilidade do CO_2GeoStorage Assessment App.

Palavras-chave

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

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List of Abbreviations and Symbols

CCS - Carbon dioxide capture and storage

CO_2 – Carbon dioxide

Φ - Porosity

μ - viscosity

K – Permeability

S - Saturation

sc - Supercritical

H_2S – Hydrogen Sulphide

EOR – Enhanced oil recovery

CBM – Coal bed methane

w_i - weights

CO2CRC – Cooperative Research Centre for Greenhouse Gas Technologies

CSS - Cascading Style Sheets

HTML - HyperText Markup Language

1. Introduction

Carbon dioxide is a greenhouse gas that blocks heat in the atmosphere. Without it and other greenhouse gases, Earth would be a frozen world. This balance helps keeping Earth's temperature relatively stable. However, humans burned so much fuel, releasing an excess amount of carbon dioxide that impacted the climate of our planet, increasing its temperature.

One of the possible actions to prevent releasing this excess of CO_2 in the atmosphere is capture it and store it in proper geological formation. There are four systems for capturing CO_2 at large point sources: the capture from industrial systems, the post-combustion capture, the Oxy-fuel combustion capture, and the Pre-combustion capture. Carbon sequestration strategies are categorised into two groups: biotic and abiotic. Biotic is based on the natural process of photosynthesis and the transfer of CO_2 from the atmosphere into vegetative and aquatic pools. Abiotic require separation, capture, compression, transport, and injection of CO_2 from a power plant into a geologic reservoir (Cleveland, Cutler, 2004). This work focus on the later.

After the capture process, the CO_2 must be stored in deep, porous, and highly permeable rock with extensive covers of low porosity rocks so that the CO_2 will not be emitted into the atmosphere. Some crucial characteristics criteria are required for these geological formations. Examples of more common recommended geological storage units are Oil and gas reservoirs, Unmendable coal seams, and Deep saline formations (Bachu, 2000).

The cost of storage should be minimised counting with the transportation from the source, the environmental impact should be minimal, and the storage method should not violate any national or international laws. Underground storage of CO_2 has developed for many years due to the practice of CO_2 injection in oil fields for enhance oil recovery (Metz , et al., 2005).

1.1 Motivation

Three-quarters of global greenhouse gas emissions come from energy production. As mentioned above the CO_2 has a significant impact on global climate changes. The consequences of climate change include, among others, intense droughts, water scarcity, severe fires, rising sea levels, flooding, melting polar ice, catastrophic storms and declining biodiversity. Some communities have had to relocate due to the consequences of climate change, and in the future, the number of "climate refugees" is expected to rise. Therefore, it is a global urgency to reduce CO_2 emissions.

According to data CO_2 has increased over time, affecting more the most developed countries (Figure 1). The geographical distribution of CO_2 emission in figure 1, as energy consumption grows, CO_2 increases in the atmosphere, creating irreversible climate change. Therefore, the measures to reduce CO_2 emissions are crucial to minimise long term climate change. It also seems there is a good match between sources and opportunities. A significant number of sources are on top of or within 300 km from a site with potential for geological storage; specified studies are necessary to confirm the suitability of such a location for CO_2 storage (Metz , et al., 2005).

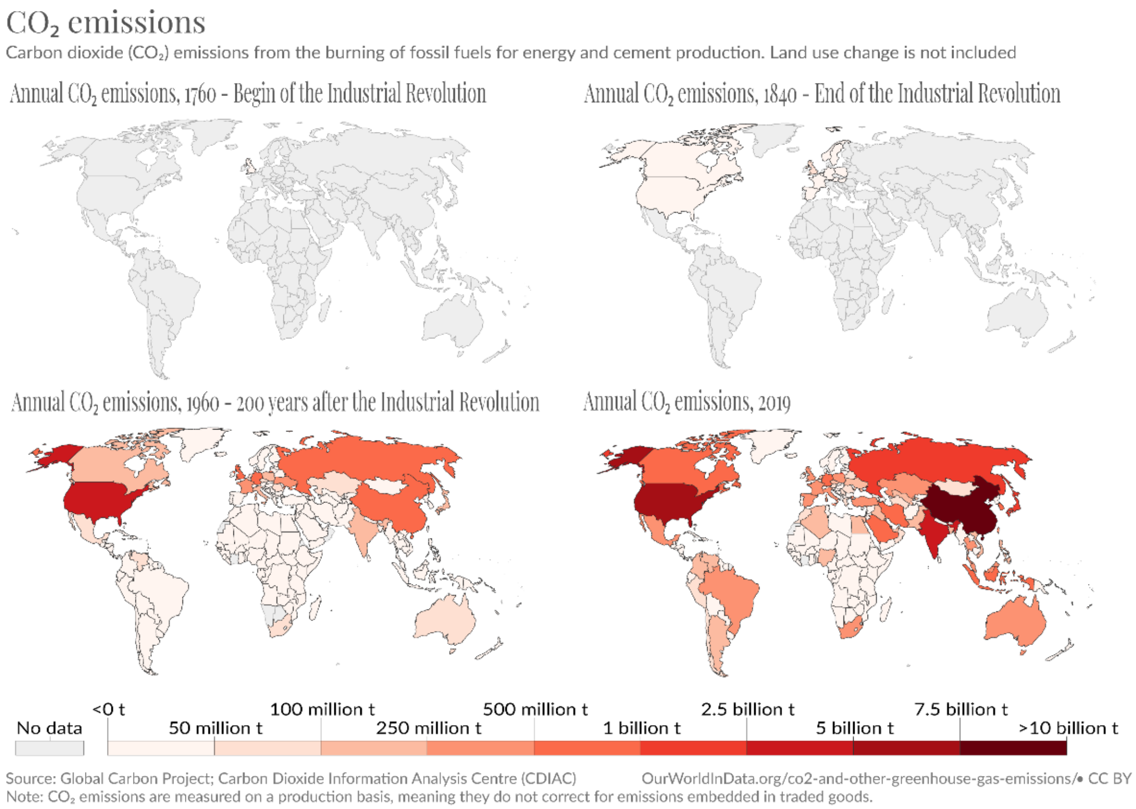

Figure 1 - CO_2 world emissions since the Begin of the Industrial Revolution until 2019 adapted from Ritchie, et al. (2020).

Since it is expected that population continues to grow and it is not desirable the slowdown of the economic development, an energy transition to low-carbon energy sources is ongoing. However, while science and technology struggles to find new alternative energies we will continue dependent no fossil fuels and therefore looking solutions to mitigate the CO_2 production excess.

The main objective of this project is to evaluate the potential of a geologic formation for CO_2 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).

1.2 Scope

The objective of this work is to attest the suitability of geologic reservoir for CO_2 storage by developing a web application that uses screening and ranking criteria that already had been studied and applied. The purpose is to join two theories of suitability criteria to allow fast decision-making. The eliminatory criteria described by Valer (2010), and the fifteen criteria described by Bachu (2003) or by Kadil and Poole (2008). To check if a reservoir is suitable for CO_2 storage requires several types of geological studies; this topic will be addressed in chapter two based on the existing literature, which will emphasise the criteria of site characterisation.

The methodology is explained in chapter three, where all phases of the assessment are described and how the modules of the App were developed. As well as a demonstration of the screen results of the App. Chapter four demonstrates the App developed by applying the data of two (2) sedimentary basins that have already been ranked, validating the results, and discussing them. In chapter five some final conclusions about the applicability of the app are drawn.

2. Literature Review

This chapter presents an overview of the main concepts and criteria underlying CO_2 storage and the specific characteristics of a geological formation required for storage.

Carbon dioxide capture and storage (CCS) in deep geological formations is one of the most promising emerging technologies for a large-scale reduction of CO_2 emissions. If CCS is fully implemented, there is a potential of capturing and storing 236 billion tons of CO_2 globally by 2050 (Stangeland, 2007).

The injection of CO_2 into subsurface geological formations was first undertaken in Texas, USA, in the 1970s, as part of enhanced oil recovery (EOR) projects and has been ongoing there and at many other locations ever since (Anon., 2020).

Research into geological storage of CO_2 as a greenhouse was done from the early 1990s, when the idea gained credibility through the work of individuals and research of some key landmark papers, namely Koide (1992), Gunter (1993), Holloway and Savage (1993), Bachu (1994), Holloway (1997).

2.1 Fluid and Rock Properties

Some of the main challenges in reservoir development are assessing reservoir-specific storage capacities due to variabilities and heterogeneities in the underlying properties and understanding the migration of CO_2 in the subsurface (Zapat, et al., 2020).

2.1.1 Rock Properties

- Porosity (Φ) is the void or pores ratio that controls the volume of fluids that can store in the rock, expressed as a percentage of the total volume of the rock.
- Permeability (K) is the porous medium's ability to transmit fluids and measure a particular material's fluid conductivity.
- The viscosity (μ) of fluid is a measure of the fluid's ability to flow.
- Saturation (S) is the per cent of a pore volume occupied by a fluid, the values of all saturation are based on pore volume and not on the gross volume of the reservoir.
- Wettability is when two immiscible fluids present in the pore space. One of the fluids will preferentially wet the rock grains and spread over the grain surfaces. The phase, which is more strongly attracted, is defined as the wetting phase. The contact angle between the fluid and the rock determines the wettability. If the contact angle is lower than 90^o, the rock is water-wet, while if the angles are larger than 90^o, the rock is oil-wet.
- Capillary pressure may be assumed as a force per unit area resulting from the interaction of surface forces and the geometry of the medium in which they exist.
- Relative permeability is unique to each fluid and indicates the movement of one in the presence of another.

2.1.2 CO_2 Properties

Carbon dioxide is soluble in water, but the level of solubility depends on the specific pressure and temperature conditions, as well as the salinity and chemistry of the water; as can see in figure 2, when the pressure and temperature increase, the solubility increase with pressure, but decreases with temperature (Bachu & Adams, 2003).

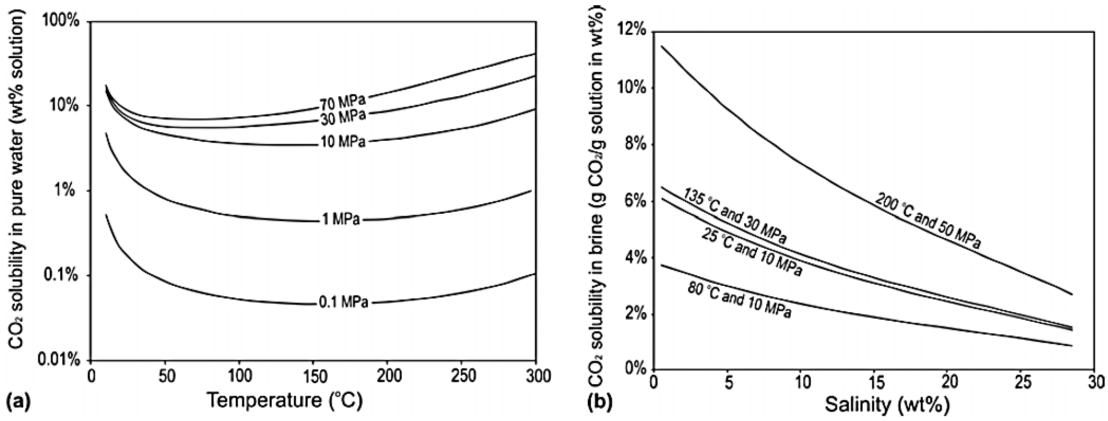

Figure 2 - Variation of CO_2 solubility in water (a) with temperature and pressure; and (b) with salinity, for various conditions of sedimentary basins (Bachu & Adms, 2003).

The critical temperature of CO_2 is 31.1ºC, and the critical pressure is 7.38 MPa, at temperatures and pressures above this critical point CO_2 exists as a supercritical fluid, as shown in figure 3, whereby it has a density similar to a liquid but exhibits gas-type viscosity behaviour (Metz , et al., 2005).

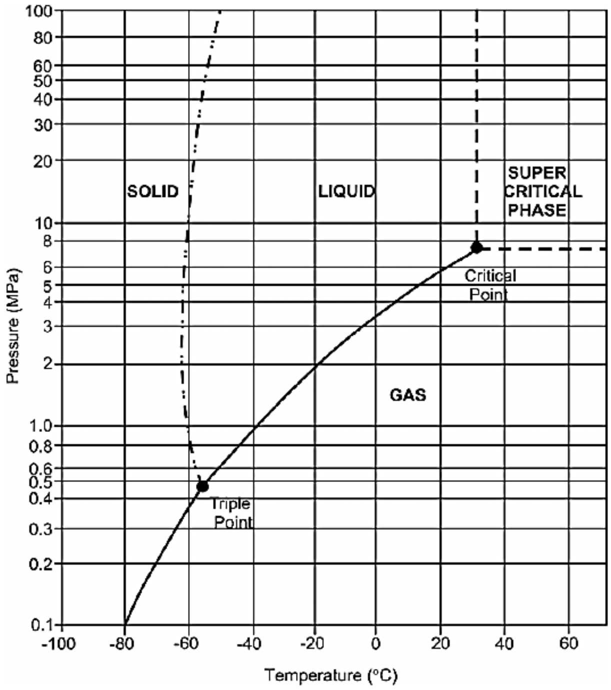

Figure 3 - Phase relationships of CO_2 as a function of pressure and temperature (Bachu,2000).

Temperature and pressure requirements for each sedimentary basin vary; however, based on average surface temperatures, geothermal and hydrostatic gradients, and an approximate minimum subsurface depth of 800m for injection of CO_2 in supercritical phase fluid for geological storage permits that a greater volume of CO_2 can be stored in pore space as shown in figure 4. Baklid also suggest that the injection of CO_2 as a dense supercritical fluid is preferable due to the complications of hydrate formation in the injection well if the CO_2 is in the gaseous or liquid state (Metz , et al., 2005).

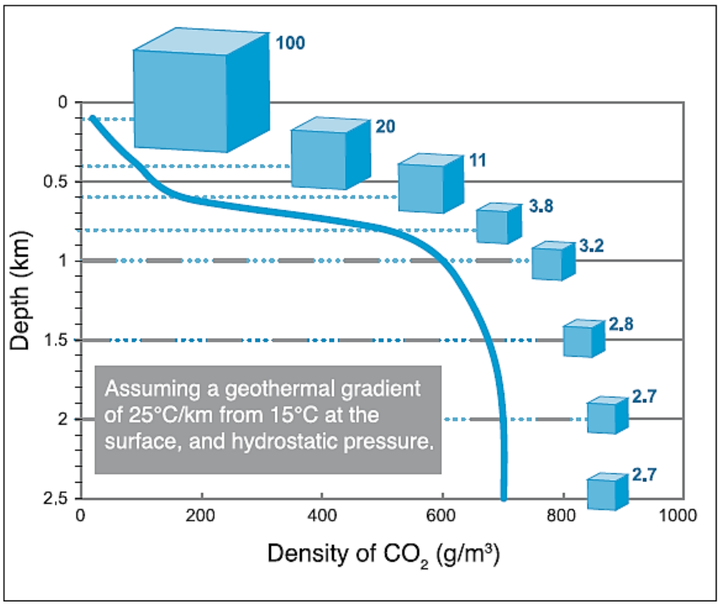

Figure 4 - Variation of CO_2 density with depth density increases rapidly at approximately 800 m depth when the CO_2 reaches a supercritical state. Cubes represent the relative volume occupied by the CO_2, and down to 800 m, this volume can be seen to decrease with depth dramatically. At depths below 1.5 km, the density and specific volume become nearly constant (Metz , et al., 2005).

2.2 Geological storage options

Carbon dioxide storage means maintaining the CO_2 secured deep underground. The continental shelf and some adjacent deep-marine basins are potential offshore storage sites. However, not all basins are suitable for CO_2 storage; some are too shallow, and rocks dominate others with low permeability or poor confining characteristics. Basins suitable for CO_2 storage have permeable rock formations saturated with extensive covers of low porosity rocks Metz, et al. (2005). The storage of CO_2 requires compression of CO_2 to allow injection by exposing the CO_2 to temperatures higher than 31.1º C and pressure greater than 73.9 bars. Here the density of CO_2 will increase with depth until about 800 metres or greater, where the injected CO_2 will be in a dense supercritical state (Newell & Ilgen, 2019).

Carbon dioxide can be stored geologically in a variety of different options as see in Figure 5. Typical geological storage sites include deep saline formations, depleted hydrocarbon reservoirs, EOR, unmendable coal seams, salt caverns, and basalt formations (Bachu, 2000).

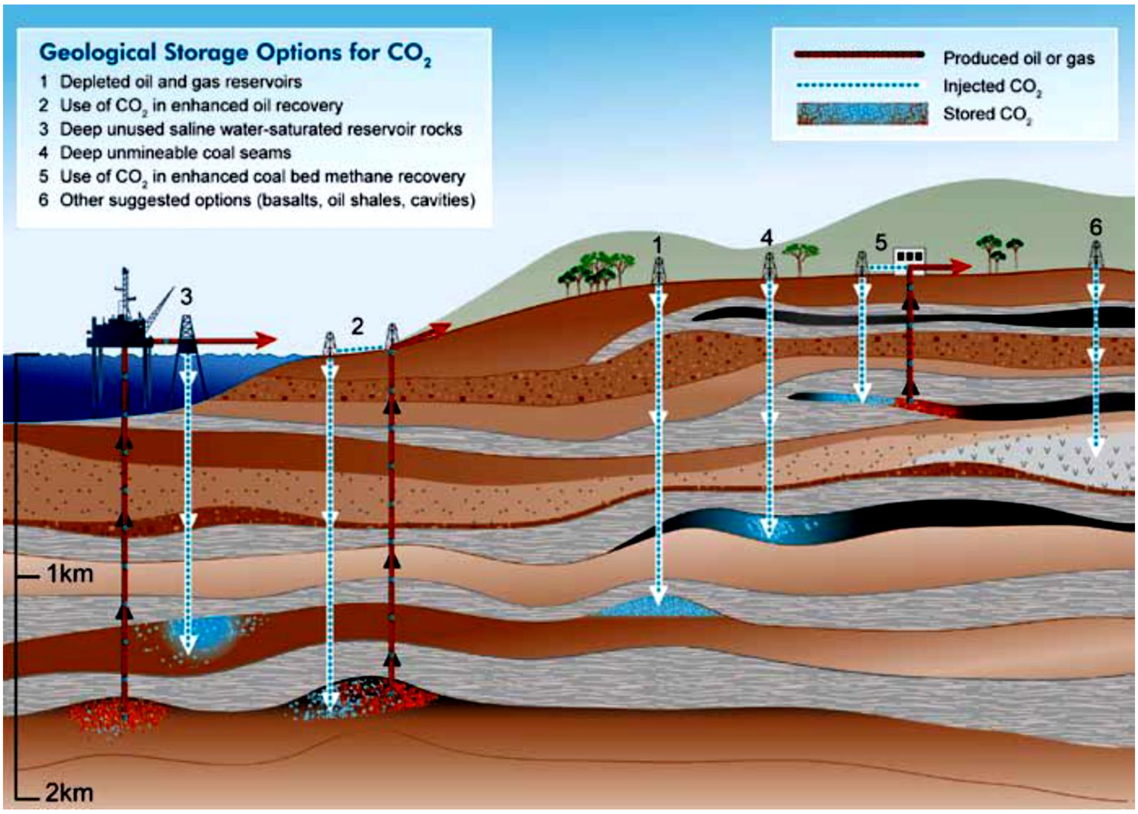

Figure 5 - Options for storing CO_2 in deep underground geological formations (Metz , et al., 2005).

2.2.1 Depleted oil and gas reservoirs

Depleted oil and gas reservoirs are prime candidates for CO_2 storage for several reasons:

1. The oil and gas initially accumulated in traps (structural and stratigraphic) did not escape (in some cases for many millions of years), demonstrating their integrity and safety.
2. Most oil and gas fields' geological structure and physical properties have extensively studied and characterized.
3. Computer models have been developed in the oil and gas industry to predict the movement, displacement behaviour and trapping of hydrocarbons.
4. Some of the infrastructure and wells already in place may be used for handling CO_2 storage operations.

Depleted fields will not be adversely affected by CO_2. However, plugging of abandoned wells in many mature fields began many decades ago when wells were filled with mud-laden fluid. Subsequently, cement plugs were required to be strategically placed within the wellbore, but not with any consideration that they may one day be relied upon to contain a reactive and potentially buoyant fluid such as CO_2. Therefore, the condition of wells penetrating the caprock must be assessed. Storage in reservoirs at depths less than approximately 800 m may be technically and economically feasible, but the low storage capacity of shallow reservoirs, where CO_2 may be in the gas phase, could be problematic (Metz , et al., 2005).

Depleted oil and gas fields injected with CO_2 can have the purpose of disposing of "acid gas," a mixture of CO_2, H_2S, and other by-products of oil and gas exploitation and refining. CO_2 represents the significant component of the acid gas most of the time, typically up to 90% of the volume injected for disposal. Acid gas injection schemes separate CO_2 and H_2S from the produced oil or gas stream, compress and carry the gases to reinject into a formation for disposal. So, acid gas injection results in less environmental impact for processing and disposing of unwanted gases. Acid gas, a variable mixture of hydrogen sulphide (H_2S) and CO_2 derived from the 'sweetening' of sour gas, is also a candidate for geological storage (Baines & Worden, 2004).

2.2.2 Use of CO_2 in enhanced oil recovery

Enhanced oil recovery (EOR) through CO_2 injection offers potential economic gain from incremental oil production. Of the original oil in place, 5–40% is usually recovered by conventional primary production. An additional 10–20% of oil in place is produced by the secondary recovery that commonly uses water injection. Various miscible agents, among them CO_2, have been used for enhanced (tertiary) oil recovery or EOR, with an incremental oil recovery of 7–23% (average 13.2%) of the original oil in place (Metz , et al., 2005).

The difference between CCS and CO_2-EOR is the end goal: CO_2-EOR produces oil in commercial quantities while storing CO_2 is a secondary benefit. The main objective of CCS is to store or sequester CO_2 with currently no defined economic drivers. The goal of CO_2- EOR is to reduce the trapped or residual oil saturation in a reservoir through mass transfer of light to intermediate hydrocarbon components. CO_2 can also reduce mobile oil saturation through pressure increase and viscosity reduction. The transfer promotes miscibility as it reduces the capillary forces responsible for trapping the oil in a reservoir. The tendency for CO_2 -EOR to promote extraction is increased with increasing pressure while decreasing temperature and when resident oils contain substantial amounts of intermediate hydrocarbon components. Late in the life of a CO_2-EOR flood, recovery becomes dominated by volumetric sweep efficiency and oil viscosity reduction. These learnings from CO_2-EOR are directly applicable to CCS because CO_2 also exhibits higher mobility than native brine in aquifers, where the mobility ratios between CO_2 and water are often around 10. Figure 6 is a schematic of CO_2-EOR. Like CCS, the injection rate in CO_2-EOR is a significant concern; the goal is to inject fluids at the highest possible rate without exceeding a bottom hole pressure that will fracture the formation. Fracturing has the potential of rapidly cycling fluids from injector to producer in CO_2-EOR and causing loss of fluid from the storage structure in CCS (Newell & Ilgen, 2019).

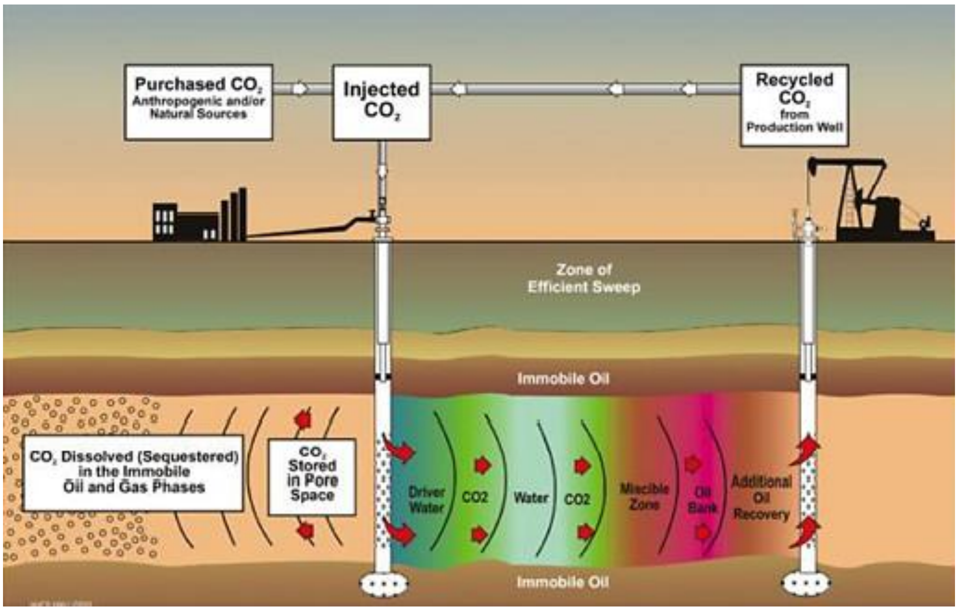

Figure 6 - Schematic of the CO_2-EOR process (Newell & Ilgen, 2019)

2.2.3 Deep Saline Formations

Saline formations are deep sedimentary rocks worldwide, making them the most significant targets for CO_2 storage (Verdon, 2012). Allows storage of CO_2 in larger volumes and a supercritical (sc) state the CO_2 is injected into about 800–1000 m below the seafloor where will be expected to persist over thousands of years until CO_2 continues predicted to dissolve into the formation brine (Metz , et al., 2005). Storage in deep saline aquifers that contain fossil, high salinity connate water that is not for industrial and agricultural use or human consumption. The high pressures encountered in deep aquifers indicate that they can withstand CO_2 injection. Some of the injected CO_2 will dissolve in the water, and the rest will form a plume that will over-ride at the top of the aquifer (Bachu, 2000). Saline aquifers are considered critical targets for CO_2 injection, given their geological, hydrodynamic, and geothermal conditions. Besides promising large storage capacities, saline aquifers are broadly distributed geographically and are more accessible to capture sites, facilitating CO_2 transport from collection to storage (Metz , et al., 2005).

2.2.4 Coal Seams

Abandoned or uneconomic coal seams, although generally imagined to be solid fuel, coal does contain some porosity in the form of fracture networks and micropores. This space is usually filled with methane created during the heating of organic matter that makes the coal. This methane is adsorbed onto the surface of the coal by electromagnetic forces. However, CO_2 has a greater affinity for coal than methane, so the introduction of CO_2 in such a system would result in the production of methane and adsorption of CO_2. However, the storage volumes available in such coal seams are not very large, and unlikely to play any significant role in global carbon storage operations (Verdon, 2012). Does the physical adsorption of the CO_2 diffuse through the pore structure of the coal, as a result, the use enhances the recovery of coal bed methane (CBM) can be cost-effective or even cost-free because the extra methane removal can compensate for the cost of the CO_2 storage operations.

2.2.5 Other options

- Natural analogues for CO_2 storage

CO_2 occurs naturally in the subsurface, often in large volumes. Several possible sources of CO_2 are often associated with igneous processes, with high-temperature metamorphism of carbonate-bearing rocks and the volatilisation of CO_2 bearing fluids. Alteration of organic matter can also produce abundant CO_2 in subsurface traps that have been in place for many thousands or even millions of years (Baines & Worden, 2004).

- Basalts

Flows and layered intrusions of basalt occur globally, with large volumes present around the world. Basalt commonly has low porosity, low permeability and low pore space continuity, and any permeability is generally associated with fractures through which CO_2 will leak unless there is a suitable caprock. Nonetheless, basalt may have some potential for mineral trapping of CO_2 because injected CO_2 may react with silicates in the basalt to form carbonate minerals (Metz , et al., 2005).

2.3 Traps mechanisms

The injected CO_2 can be immobilized typically under four different trapping mechanisms depending on the specific geological conditions (Zapat, et al., 2020):

- Structural or Stratigraphic - Trapping below an impermeable, confining layer or caprock;
- Residual CO_2 trapping - The CO_2 is retained or adhered on the surfaces of the pore spaces of the storage formation so that it becomes contained as immobile phase;
- Solubility trapping - The CO_2 is dissolved in the fluids contained in the pore spaces of the formation;
- Mineral trapping - It may be trapped by reacting with the minerals in the storage formation and caprock to produce carbonate minerals.

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):

- Structural / Stratigraphic trapping

The CO_2 is confined as a buoyant immiscible phase facilitating fluid that is not dissolved into formation water and the retention within the formation (physical trapping), restrained by the structure and the seal rock. The nature of the physical trap depends on the geometric arrangement of the reservoir and seal unit. Common structural traps include anticlinal, and typical stratigraphic traps include those created by lateral change, a depositional an unconformity.

- Residual trapping

Immobilization of the CO_2 via residual trapping occurs inside smaller pores as a function of the pore network geometry, fluid-fluid interactions, and the two-phase displacement properties of the system, including relative permeability endpoints and critical saturation. When the saturation of CO_2 falls below a certain level, it has insufficient buoyancy force to overcome the capillary entry pressures of the pore throats. CO_2 then becomes trapped in the pores by capillary pressure forces and ceases to flow.

- Solubility trapping

Solubility trapping relates to the CO_2 dissolved into the formation water where the time scale for complete dissolution is critically dependent on the vertical permeability and geometry of the top seal but is predicted to occur in hundreds to thousands of years.

- Mineral trapping

CO_2 of Mineral trapping results from the reaction of the precipitation of new carbonates minerals. This storage mechanism is the most permanent of the trapping types to immobilize CO_2. Mineral precipitation is typically long, in the order of tens to thousands of years, depending on the initial minerals present.

CO_2 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 7 (Metz , et al., 2005).

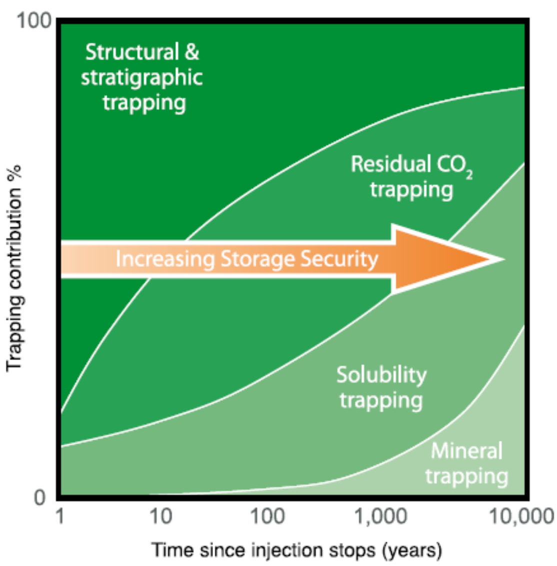

Figure 7 - Storage security depends on a combination of physical and geochemical trapping (Metz , et al., 2005).

2.4 Site criteria for CO_2 storage

Site characterisation is how data, information and knowledge are acquired and processed to provide satisfactory answers to the question: does the site meet the site selection criteria? Site characterisation is a study that needs to be done both before the site selection and after for continued monitoring. Sites should be sufficiently characterised initially to judge them based on site selection criteria, and once selected, further characterisation is needed to demonstrate site performance, including monitoring. The local characterisation is a prerequisite to a safe geological storage of CO_2, which means evaluating the storage site regarding its potential storage suitability, capacity, and security for injecting CO_2. Documentation of any storage site's characteristics will rely on data obtained directly from the reservoir. Sites for CO_2 storage vary around the globe in their quality and characteristics, and there will be instances where sites of more inferior quality will be used for storage because no other sites are available or because other sites are too far away and much more costly to develop and operate. However, the use of poorer-quality storage sites means that additional measures may have to be taken, particularly regarding safety (Valer, 2010).

2.4.1 The fifteen criteria

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

1. Basin characteristics, such as tectonism, geology, geothermal and hydrodynamic regimes (these are ''hard'' criteria because they do not change).
2. 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).
3. 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 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.

The following is a description of the fifteen (15) Criteria for assessing sedimentary basins for CO_2 geological storage (Bachu, 2003):

1. Tectonic setting - a relatively stable geological environment is essential when looking for a location to ensure no risk of CO_2 leakage. The greatest tectonic activity globally is zones of collision between plates and zones of subduction. On the other hand, cratonic zones and passive margins are zones of less tectonic activity

2. Size - the basin size and depth reflect on the achievable storage volume, as the larger the basin, the greater the chance of having a laterally extensive reservoir and seal pairs.

3. Depth - is measured from the top of the reservoir to the surface. As mentioned above the depth is directly related to the storable volume since. Therefore, it was previously considered is necessary to inject CO_2 at depths greater than 800 meters, where supercritical conditions would be met, assuming a hydrostatic pressure gradient and geothermal.

4. Geology - important geologic characteristics are the faulting intensity and reservoir sealing. Faulting intensity reflects the risk for potential leakage of CO_2. Conversely, the amount of faulting can categorize the individual basins because faults and fractures can interfere with the permeability and injection capacity of the reservoir formation and CO_2 leaks. In addition, the lithology of the basin allows us to know from the formation's characteristics if there is an excellent reservoir-sealant pair. So, the reservoir seal pair is crucial when selecting a CO_2 storage site.

5. Hydrogeology - describes the natural underground flow system and the hydrodynamic entrapment in the basin. The hydrodynamic traps can be deep and laterally extensive depending on the residence time. The less favourable type of hydrogeology is shallow, short flow systems. It does not meet the geological requirements for maintaining supercritical CO_2 and does not have a long enough residence time to immobilize the injected CO_2 by one of the trapping mechanisms. The most suitable hydrogeological conditions consist of a deep, with a sufficient injection permeability but a relatively slow flow rate.

6. Geothermal - the geothermal conditions of a sedimentary basin affect the storage volume, as the CO_2 density varies with temperature. Thus, the density is higher with lower temperatures, and it is possible to store a greater volume of CO_2 in the same rock (Bachu, 2003). However, the temperature inside the formations is dependent on the geothermal gradient and the surface temperature, which is variable throughout the year. Therefore, the basins with higher geothermal gradients tend to have lower storage capacity.

7. Hydrocarbon potential - a rock's potential to contain hydrocarbons also provides the rock's potential to be a CO_2 storage site. However, first, it is necessary to consider the impact that CO_2 storage can have on oil exploration.

8. Maturity - refers to the degree of study in the hydrocarbon exploration industry. In a basin that is already at a mature stage, it is more likely that there will be a greater number of data, and the existence of infrastructure and access to the site.

9. Coal - Coal layers also can be potential reservoirs. The great depth is no longer viable because the permeability is reduced, and depths smaller than 300m are not advisable.

10. Salt - generally, the presence of evaporites indicates that a good caprock or sealant may be present due to the impermeable properties, mainly if they occur in continuous layers, providing a safe containment of CO_2.

11. Onshore/offshore – the location of the injection point is crucial, especially from an economic point of view. It is easy to see that onshore, where there are more sources of CO_2, its storage is cheaper than having to transport it offshore.

12. Climate - affects surface temperatures that interfere with geothermal conditions and impacts the development of CO_2 injection implementation systems, considering that desert or arctic regions are much more challenging to develop than temperate regions.

13. Accessibility - the accessibility to the chosen locations is an economic condition, the easier the access to the basin the better the benefit for the project.

14. Infrastructure - the existence of infrastructure is also economic condition for the projects. Thus, regions with existing infrastructure are preferred.

15. CO_2 Source - finally, it is important to mention that the existence of CO_2 sources is another preponderant factor for a project to be economically viable because it reduces transport costs.

1. *Table 1 – Summary of the Criteria for assessing sedimentary basins for CO_2 geological sequestration (Bachu, 2003).*

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

For each criterion i (i=1...15) in Table 1 for evaluating basin suitability, a monotonically increasing numerical function Fi is assigned, which can be continuous or discrete, to 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, i.e., Fi,1= min (Fi) and Fi, n = max (Fi), n represents the number of classes in that criterion (n=3, 4, or 5). If the classes have relatively equal importance assigned to them, then a linear function is probably best for Fi. If an increasing value (or importance) is placed on increasingly favourable classes, geometric or exponential functions are probably better. Table 2 presents the numerical values assigned by Bachu (2003) here to the various classes for the criteria in Table 1. 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).

Table 2 - Scores and weight assigned to the criteria and classes for assessing sedimentary basins in terms of their suitability for CO_2 sequestration in geological media for Table 1 (Bachu, 2003).

	Criterion	**Score**					**Weight**
		J=1	J=2	J=3	J=4	J=5	
i=1	Tectonic setting	1	3	7	15	15	0.07
i=2	Size	1	3	5	9		0.06
i=3	Depth	1	3	5			0.07
i=4	Geology	1	3	7			0.08
i=5	Hydrogeology	1	3	7			0.08
i=6	Geothermal	1	3	7			0.10
i=7	Hydrocarbon potential	1	3	7	13	21	0.06
i=8	Maturity	1	2	4	8	10	0.08
i=9	Coal and CBM	1	2	5			0.04
i=10	Salts	1	2	3			0.01
i=11	On/Offshore	1	4	10			0.10
i=12	Climate	1	2	4	7	11	0.08
i=13	Accessibility	1	3	6	10		0.03
i=14	Infrastructure	1	3	7	10		0.05
i=15	CO_2 Sources	1	3	7	15		0.09

$$\sum_{1}^{15} w_i = 1$$

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 $F_{i,j}$. Because the function Fi has different ranges of values for each criterion, making comparisons and manipulations difficult, the individual scores $F_{i,j}$ are normalized according to (Bachu, 2003):

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

As a result of this process, each sedimentary basin k being evaluated is characterized by 15 individual scores P_i^k, such that 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. The consequence of the parameterization and normalization is that it transforms various basin characteristics, which have differing meanings and importance, into dimensionless variables that vary between 0 and 1. These can subsequently be added to produce a general score R^k, used in basin ranking, which is calculated using (Bachu, 2003):

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

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 ≈1) are most favourable, and those closer to zero (R^k ≈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.

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:

1. The very small class was added to the Size category;

2. The very shallow class was added to the Depth category;

3. The shallow offshore and onshore class was added to the On/Offshore category;

4. The coal rank category is added;

Other adaptations were made for criteria for assessing CO_2 storage in different parts of the world. The table 3 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 3 – Summary of the Criteria for assessing CO_2 storage potential of sedimentary modified from Kaldi and Poole (2008).

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

As in Bachu (2003) table 4, each i evaluates the basin suitability. Each j position is for the smallest and most great values characterize the worst and best classes in terms of suitability for criterion.

Table 4 - Scores and weight assigned to the criteria and classes for assessing sedimentary basins in terms of their suitability for CO_2 sequestration in geological media for Table 3 modified from Kaldi and Poole (2008).

	Criterion	**Score**					**Weight**
		J=1	J=2	J=3	J=4	J=5	
i=1	Tectonic setting	1	3	7	15	15	0.10
i=2	Size	1	3	5	8	10	0.06
i=3	Depth	1	2	6	10		0.10
i=4	Geology	1	4	10			0.09
i=5	Hydrogeology	1	4	10			0.10
i=6	Geothermal	1	4	10			0.08
i=7	Hydrocarbon potential	1	3	7	14	21	0.04
i=8	Salts	1	2	3			0.01
i=9	Coal and CBM	1	2	5			0.04
i=10	Maturity	1	2	4	8	10	0.08
i=11	On/Offshore	1	5	10			0.11
i=12	Climate	1	2	4	7	11	0.04
i=13	Accessibility	1	3	6	10		0.04
i=14	Infrastructure	1	3	7	10		0.05
i=15	CO_2 Sources	1	3	7	15		0.06
							$\sum_{1}^{15} w_i=1$

The calculations are made using the same method as Bachu (2003). Equation 1 calculates the individual score of each criteria, and whit equation 2 calculates the ranking of the basin in terms of its suitability for geological storage of CO_2.

2.4.2 The eliminatory criteria

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 5 presents a set of eliminatory criteria (Valer, 2010).

Table 5 - 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).

2.4.3 Geological input to site characterization

The ideal classification of geological storage sites for CO_2 requires a thorough integration of all geoscientific data. Data types of change depending on the stage of characterization. For example, regional assessment requires low-resolution, long-range data sets, such as two dimensional (2-D) seismic and stratigraphic drill holes. However, site-specific assessment requires more detailed data such as high-density 2-D or 3-D seismic, core, and many wells and logs. (Kaldi & Payenberg, 2009).

Data challenges frequently encountered when assessing geological storage sites for CO_2 because of incomplete data sets, data loss, or simple data deterioration with time. Two types of solutions can be considered to overcome the data challenges. The best but most costly solution is data acquisition. A far more cost-effective but also less accurate method of overcoming data challenges is to use outcrop and subsurface analog data sets to model the subsurface geology at the storage site. Analog data sets help provide generic quantitative data of a range of parameters paramount to a specific geological setting. They can also provide ranges and distributions of porosities and permeabilities and provide estimates on likely seal capacities. Analog data sets to characterize geological storage sites for CO_2 are currently the most affordable and accessible data sets for reservoir characterization (Kaldi & Payenberg, 2009).

2.4.4 Monitoring

In addition to the careful selection of the subsurface formation, a comprehensive monitoring system needs to be put in place to verify that the CO_2 remains underground. Monitoring of the activities of stored CO_2 includes an extensive range of established direct and remote sensing technologies, including petrophysical, geophysical, and geochemical methodologies deployed on the surface and in the borehole. These are used for repeated assessments from a reservoir, containment, wellbore integrity, near surface, and atmospheric perspective (Dodds, 2009). Geophysical monitoring involves the quantification of 3-D and seismic time-lapse imaging of the plume and its migration. Geochemical and hydrodynamic sampling ensures that the injected CO_2 has not leaked from its container, and hence verify the integrity of seals is also essential. Adding tracers to the injected CO_2, combined with sampling at surface localities, allows rapid detection of any seepage or leakage in the unlikely circumstance that this should occur (Kaldi & Payenberg, 2009).

3. 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. The CO_2GeoStorage Assessment App have the following characteristic:

- The home page is a welcome page with a brief introduction of the topic and an explanation of how the App works.
- In the CO_2GeoStorage Assessment pages, as mentioned in chapter 2, the geological storage combines several engineering processes to ensure safe and long-term storage of CO_2 from the atmosphere. There are two (2) pages to initiate de assessment where the user answers some eliminatory criteria with yes or no questions. The results of the answers may lead to a page where one of two ranking assessment method is chosen modifier from Kaldi and Gibson-Poole in the last assessment page the user selects one (1) of the classes of each fifteen (15) criteria, and each class has a specific score, and each criteria has a weight (that can be adjusted according to the basin characteristics). Then two (2) equations are calculated to assess the basin's rank.

The methodology is based on two screening pages and two assessment ranking pages. After the home page, the user will be redirected to the CO_2GeoStorage Assessment pages; three (3) steps will be taken for the entire assessment

i) 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 sequences are intermediate or excellent?
- The pressure regime is hydrostatic or sub-hydrostatic?

ii) Second assessment step

The 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 areal extent is greater than 2500 km^2?
- The hydrogeology is intermediate and regional-scale flow systems?

iii) 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 (w_i). 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 R^k 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 8 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.

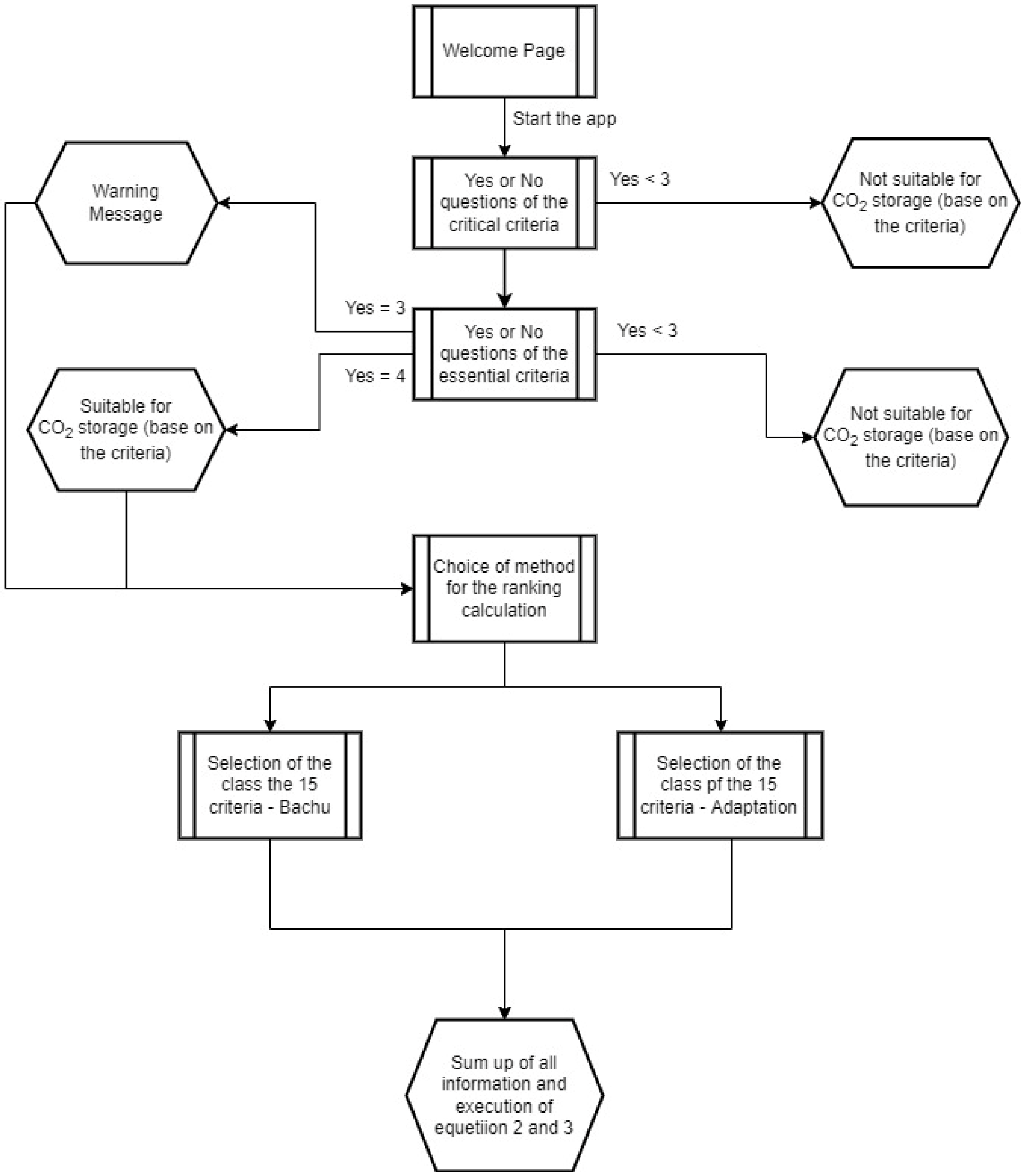

Figure 8 – Flow chart of the CO_2GeoStorage Assessment App.

3.1 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.

3.1.1 Software

3.1.1.1 Visual Studio Code

The Visual Studio Code is a code-source editor developed by Microsoft for Windows, Linux and macOS. It includes support for debugging and many functional extensions; it is possible to builtin Git versioning. Although it is free and open software, Microsoft's official download is under a proprietary license. It is an editor platform for writing different programming languages. Visual studio offers shortcuts to writing all structures of an HTML page; it is also possible to change the theme, thus changing the colour of code syntax, making it easier to identify errors and differentiate code components. This work was also installed at Visual Studio Code the Prettier, an opinionated code formatter. It enforces a consistent style by parsing code and re-printing it with its own rules that take the maximum line length into account, wrapping code when necessary. (https://marketplace.visualstudio.com/items?itemName=esbenp.prettier-vscode)

3.1.1.2 GitHub and Hosting

GitHub is the version control software that saves and stores the changes of the code- source over time, overwriting previous versions. It is used on the browser and as a desktop application. To get started is necessary to create a repository, and after that file with the code is saved inside, it is necessary to commit and push every time to save a new change on the code. And it is free for one user (https://github.com/git-guides)

Hosting provides a place on a webserver to store all files and is responsible for delivering the website files as soon as a browser requests by typing the domain name. For this work, was used Netlify as a hosting platform for the project. Can be connected the code with the GitHub account, so every time the user saves a change in code and pushes, the web page is automatically updated. (https://www.netlify.com)

3.1.2. 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.

The HTML is written inside of the <body> using the following components "<>": "h", "p", "label", "ul", "li", "div", "br", "hr", "img", "a", "button", "form", "select", "option", "input", and the attribute "class".

All pages have similar components of HTML and CSS. The HTML components, by default, can be customized using CSS elements. For example, the Inside of the <head> the <style> can be inserted by writing the name of the component with full stop (.) or the attribute between "{}": background, background-color, color, border, padding, border-radius, max-width, display, box-shadow, transition, box-shadow, line-heigh, cursor, text-align, font-family, font-size, text-decoration. All pages also have a link to Bootstrap (quickly design and customize responsive mobile-first sites with Bootstrap, the world's most popular front-end opensource toolkit) which facilities the configuration of the components.

The JavaScript can be written on the <head> or <body> in this application it is written on the <body> using <script> first the function is command "()" and between "{}" the following elements are called: let, prompt, alert, querySelector, addEventListener, var, if, else, return, getElementByld.

3.1.2.1. Home Page

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, for example: "h1", "p", "h2", "div","br", "a" to make a summary of the topic and describe the steps for the assessment and "button" to redirect to next page. The figures 9 shows part of the HTML code.

```
<ul>
  <li>
    Structural or Stratigraphic - Trapping below an impermeable, confining layer or caprock;
  </li>
  <li>
    Residual CO2 trapping - The CO2 is retained or adhered on the surfaces of the
     pore spaces of the storage formation so that it becomes contained as immobile phase;
  </li>
  <li>
    Solubility trapping - The CO2 is dissolved in the fluids contained in the pore spaces
     of the formation;
  </li>
  <li>
    Mineral trapping - It may be trapped by reacting with the minerals in the storage
    formation and caprock to produce carbonate minerals.
  </li>
</ul>
    </p>
    <br />
   <img
  src="https://live.staticflickr.com/65535/51974224852_671c212a78_b.jpg"
  width="300"
  alt="Storage security depends on a combination of physical and geochemical trapping. (IPCC,2005)"
/>
<p class ="leg">Storage security depends on a combination of physical and geochemical trapping. </p>
<br />
```

Figure 9 - Part of the HTML code of the Homepage.

The part of code in the figure 9 above shows how the textual list was introduced in the code; it initiates with "<ul>" and inside it each "<li>" represents one (1) item of the list. This configuration was used to describe the four different trapping exact mechanisms according to the specific geological conditions, which are structural or stratigraphic, residual CO_2 trapping, solubility trapping and mineral trapping. An image that shows the trapping mechanisms on the website by being searched "scr", then the image size was determined using "width", the "alt" describes the image in case of an error, and it cracks. The "
" breaks the line because the component "<img />" by default does not break the line as om the paragraph "<p>".

The figure 10 shows the CSS code for the home page that was used to configure the layout of the page such as “margin”, “padding”, “border-radius”, “max-width”, “background”, “text-algin”, “font-size” along others.

```
<style>
 .mar {
  margin: 12px 42px;
  padding: 15px;
  border-radius:35px;
  max-width: 5000px;
  border: 2px solid #dadde1;
 }
 body{
  background: (135deg, #fdfcfb 0%, #e2d1c3 100%);
 }
 h1 {
  text-align: center;
  margin: 25px auto;
 }
h2 {
  text-align: center;
 }
 p{
  margin: 10px 40px;
  text-align: justify;
  font-family: 'Montserrat', sans-serif;
  font-size: large;
 }
 ul {
  margin: 10px 50px;
  text-align: justify;
  font-family: 'Montserrat', sans-serif;
 }
 img {
  margin: 0 auto;
  display: block;
 }
 button {
  margin: 0 auto;
  display: block;
  box-shadow: grey;
  transition: all 500ms linear;
  box-shadow: 4px 4px 2px gray;
  line-height: 100%;
  padding: 20px;
  border: 4px solid grey;
  border-radius: 20px;
 }
 button:hover {
  cursor: pointer;
  background-color: #82858f;
  color: white;
 }
 a {
  text-decoration:none;
 }
 .leg {
text-align: center;
font-size: medium;
 }
</style>
</head>
```

Figure 10 - The CSS code for the Homepage.

The JavaScript, as mentioned before, is what permits the interaction with the user to allow the user to get to the next page; it requests the user to write his name and then it shows a welcome message with the user's name. Then redirected to the next page where the CO_2GeoStorage Assessment starts. This part of the code can be seen in figure 11.

```
<script>
function Co2() {
  let name = prompt("What is your name?");
    alert("Welcome " + name);
    window.location.href = "https://legendary-nougat-49ac68.netlify.app";

}
let GeoStorage = document.querySelector("button");
GeoStorage.addEventListener("click", Co2);
</script>

</body>
```

Figure 11 – The JavaScript code for the Homepage.

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

3.1.2.2. Critical and essential criteria page

These two pages are very similar in terms of programming. They present more HTML components such as the “<from>” right at the beginning of the page to be able to have control over the submitted answers. There is the “<input>” with attributes like “type”, “id”, “name”, “value” and “checked” to permit to interact with each question so that the submitted answers are read correctly when the button is clicked. Finally, the “<label>” allows the attribute “for” to identify the answer to the question. The following figure 12 shows part of the code used in these pages.

```
<form action="#" method="post" onsubmit="return VerificaEssential()">
 <p>
  The seismicity (basin tectonic setting) is very low to moderate
  (foreland, passive margin and cratonic basins)?
 </p>
 <p>
  <input
   type="radio"
   id="question-4-yes"
   name="question-4"
   value="1"
   checked="checked"
  />
  <label for="question-4-yes">Yes</label>
  <br />
  <input type="radio" id="question-4-no" name="question-4" value="0" />
  <label for="question-4-no">No</label>
  <br />
 </p>
```

Figure 12 - Part of the HTML code of the critical and essential criteria page.

Figure 12 above illustrate the code. As elucidated before in the app methodology, the critical and essential criteria are eliminatory questions adopted using table 5 (Valer, 2010). The question is a textual inserted between the “<p>” and “</p>”. It is vital to describe each of the input attributes. The "type" is the radio button that allows the user to choose one of the answers (Yes or No). Each answer has a “value”, if the answer is Yes the value is one (1) and if the answer is No the value is zero (0). The "checked" uses by default so that all the questions are checked, and the user does not proceed without having all the answers chosen. The “id” is unique for each value. And the “name” is used to identify each question.

The JavaScript only differs on the two (2) pages in the number of conditional functions they have, as seen in the flowchart in Figure 8. The critical criteria have two (2) conditionals, while the essential criteria have three (3) conditionals. The figure 13 below shows the JavaScript code of the essential criteria page.

```
function VerificaEssential() {
  var seismicity = parseInt(
    document.querySelector('input[name="question-4"]:checked').value
  );
  var fracturing = parseInt(
    document.querySelector('input[name="question-5"]:checked').value
  );
  var areal = parseInt(
    document.querySelector('input[name="question-6"]:checked').value
  );
  var intermed = parseInt(
    document.querySelector('input[name="question-7"]:checked').value
  );
  var soma = seismicity + fracturing + areal + intermed;
  if (soma == 4) {
    alert("So next setp is the calculation the basin ranking");
    window.location.href = "https://deluxe-fairy-aeecf6.netlify.app/";
  } else {
    if (soma == 3) {
      alert(
        "One of these  essential criteria is not being met, but all the others are, such a basin may still be consider
      );
      window.location.href = "https://deluxe-fairy-aeecf6.netlify.app/";
    } else {
      alert(
        "More than one of the essential suitability criteria is not being met, then that basin or region should not b
```

Figure 13 - The JavaScript code for the critical and essential criteria page.

Conditional Function

As observed in the figure 13 above, this part of the code represents the function where the number of Yes determines the conditionals using “if”. In the first conditional, if all four (4) questions are answered Yes the user is redirected to the last assessment page. The second condition if only three (3) questions are answered Yes a pop-up window displays a message “One of the essential criteria is not being met but, all the others are so, the basin may still be considered for CO_2 storage” redirect to the last assessment page. The third conditional if less than three (3) questions are answered Yes a pop-up window displays a message saying, “More than one of the eliminatory criteria is not being met, so that basin should not be considered for CO_2 storage” and assessments end here.

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

3.1.2.3. The 15 criteria assessing and ranking page

First of all is necessary to choose which, assessment ranking will be used, there are two option the criteria modified from Bachu;Kaldi and Gibson-Poole. Then it leads the last assessment page composes an important part of App, the most complex part of the code. 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>”. In addition, the “<input/>” is inserted to give the weight for each criterion. The attributes for this page are the following “name”, “id”, “value”,” type”, “step”, “max”, “min”. The figure 14 below shows part of the code.

```
<hr />
<form action="#" method="post" onsubmit="return Calcula()">
<p>
 Tectonic setting
 <br />
 <select name="tectonicSetting" id="tectonicSetting">
  <option value=1>Very high</option>
  <option value=3>High
  </option>
  <option value=7>
   Intermediate
  </option>
  <option value=15>Low</option>
  <option value=15>Very low</option>
 </select>
</p>
<p>
 Size
 <br />
 <select name="Size" id="Size">
  <option value=1>Very Small</option>
  <option value=3>Smal</option>
  <option value=5>Medium</option>
  <option value=8>Large</option>
  <option value=10>Very Large</option>
 </select>
 </p>
```

Figure 14 - Part of the HTML code of the 15 criteria assessing and ranking page.

Furthermore, the figure 14 shows that the attribute “value” in the “<option>” represents the score “J”. The “min” and “max” attributes define the maximum and minimum values of the weights. Finally, the “step” determines the number of decimals for the values.

Notwithstanding the foregoing JavaScript in this page has a crucial function of the App because involves the execution of the two equation that leads to the ranking of the sedimentary basin, as demonstrated in the figure 15.

```
//equation 2
var p1= (tectonicSetting -1) / (15-1);
var p2= (Size -1) / (10-1);
var p3= (Depth -1) / (10-1);
var p4= (Geology -1) / (10-1);
var p5= (Hydrogeology -1) / (10-1);
var p6= (Geothermal -1) / (10-1);
var p7= (hydrocarbonPotential -1) / (21-1);
var p8= (Maturity -1) / (10-1);
var p9= (coalAndCBM -1) / (5-1);
var p10= (Salts -1) / (3-1);
var p11= (OnOffshore -1) / (15-1);
var p12= (Climate -1) / (10-1);
var p13= (Accessibility -1) / (10-1);
var p14= (Infrastructure -1) / (10-1);
var p15= (CO2Sources -1) / (15-1);
//equation 3
var Rk = 0.1 * p1 + 0.06 * p2 + 0.1 * p3 + 0.09 * p4 + 0.1 * p5 + 0.08 * p6 + 0.04 * p7 + 0.08 * p8 + 0.04 * p9 + 0.01 * p10
alert("The basin ranking is "+Rk+" . When results closer to 1 are most favourable, and those closer to 0 are less favourable. F
```

Figure 15 – Part of the JavaScript of the 15 criteria assessing and ranking page.

Equation Function

Equation 1 has the objective of finding the value of the P for each criterion for that; the variable P was created, and the value of each Pi was found using the scores "J" of the same criterion. Pi is determined by the score “J” of the class chosen minus the minimum score “J” (which is one (1)) divided by the maximum score “J” minus the minimum score “J” (which is one (1)), all scores related to the same criterion. Thereby, equation 3 uses the results of equation 1 and the weight “i” of each criterion to get the R^k ranking of the sedimentary basin. Finally, a pop-up window is displayed showing the ranking result.

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

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

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

3.2 Section of the App

This section presents part of the website as the result of the App development, which consists of the four (4) pages described above. The website can be accessed from this link

https://bespoke-wisp-e92dba.netlify.app

3.2.1 Welcome interface

The Figure 16 is shown the section of the home page where there is an interaction with the user. By pressing the button “The CO_2GeoStorage Assessment”, the user's name is asked, and then it welcomes the user and goes to the next page.

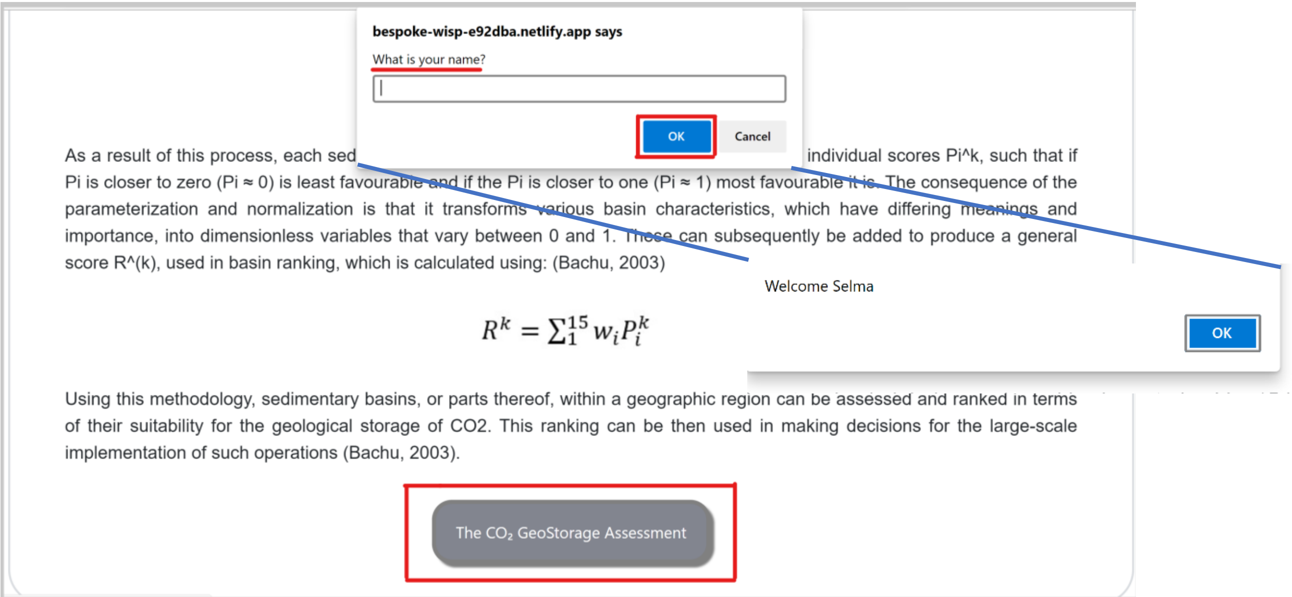

Figure 16 - The CO_2GeoStorage Assessment Homepage.

3.2.2 Screen Results: Eliminatory criteria

3.2.2.1 Critical criteria

When selecting the critical criteria to process to the next step of the assessment, it is indispensable to answer positively to all questions. Thus, the figure 17 below show what happens when one question is answered No. It means that the sedimentary basin does not meet the critical criteria, so no further analysis needs to be made.

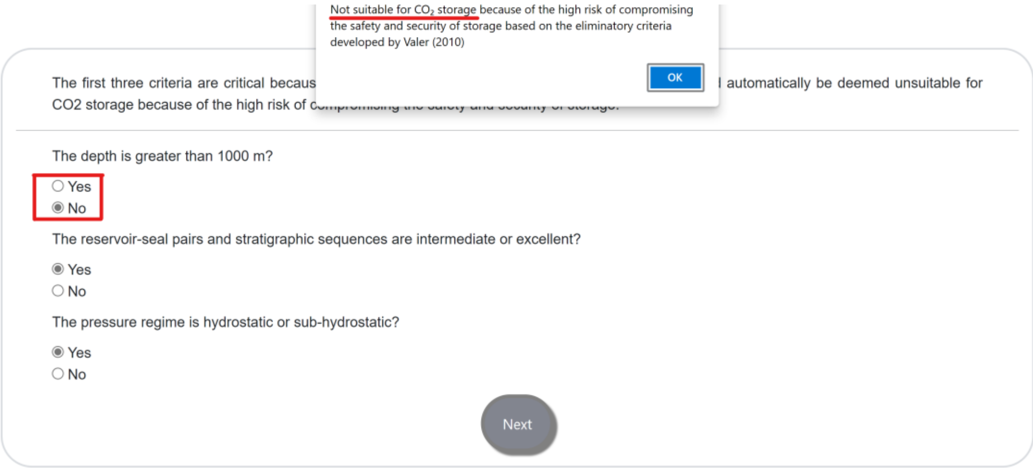

Figure 17 - The CO_2GeoStorage Assessment Critical Criteria Page.

3.2.2.2 Essential criteria

Contrary to the critical criteria on the essential criteria assessment page, despite the one (1) question being answered negatively, the sedimentary basin can still be considered for CO_2 storage. Then it displays a message to warming that one of the essential criteria has not been met, as seen in the figure 18 below and proceeds to the next page.

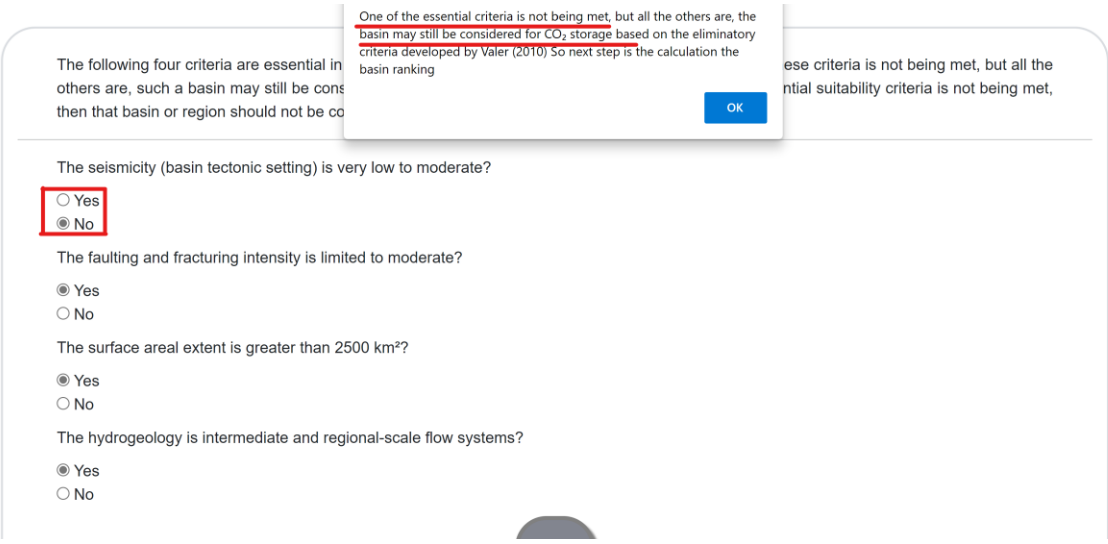

Figure 18 - The CO_2GeoStorage Assessment Essential Criteria Page – one (1) No.

In the case of two (2) negative answers of the essential criteria, it does not proceed to next page because the sedimentary basin does not meet the essential criteria, so no further analysis needs to be made as showed in the figure 19 below.

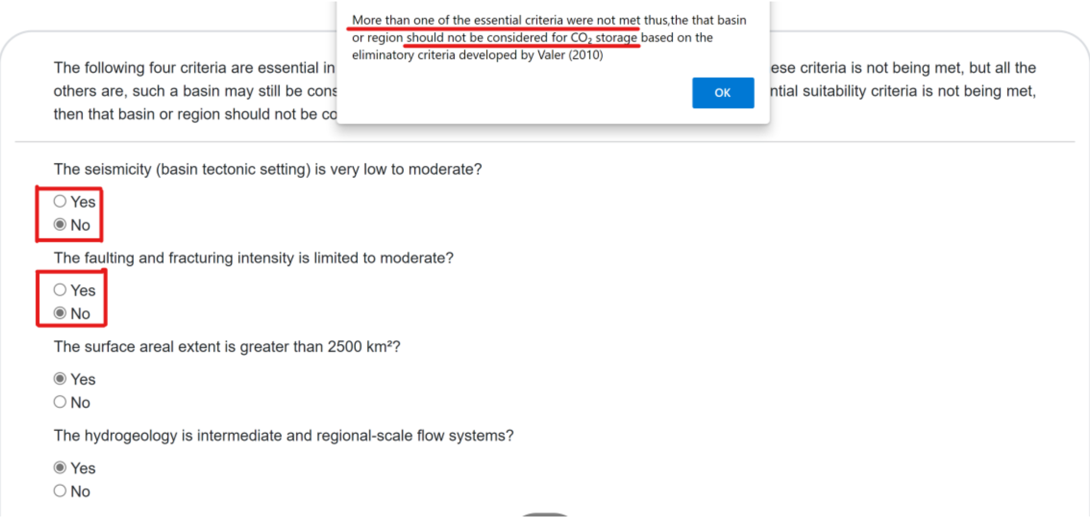

Figure 19 - The CO_2GeoStorage Assessment Essential Criteria Page – two (2) No´s.

3.2.3 Selection of one of ranking assessment

This page has an explanation of the two set of the fifteen criteria where the user might choose which criteria will apply. The criteria developed by Bachu or the modified criteria from Kaldi and Poole. As show in the figures 20 and the figure 21 there is a button to press which will lead to ranking assessment page.

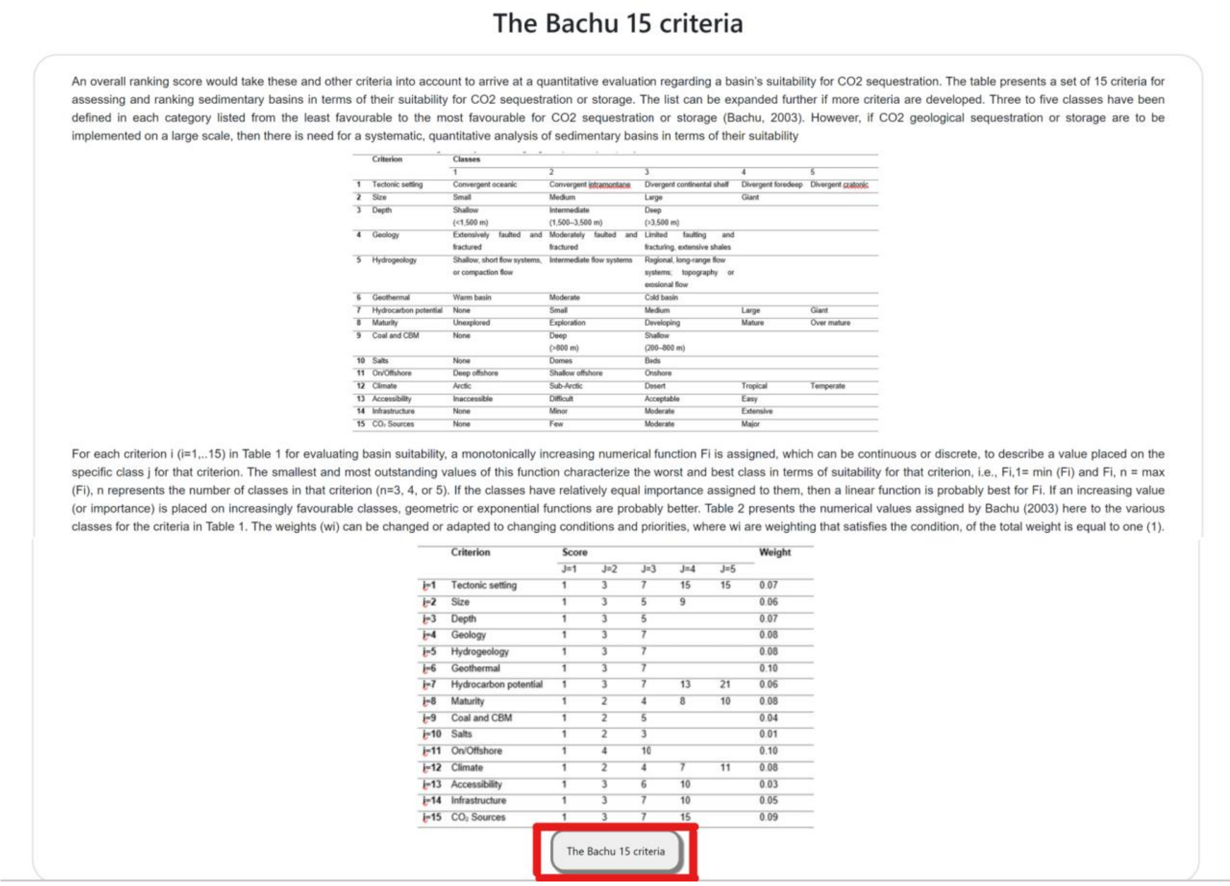

Figure 20 - The CO_2GeoStorage Assessment Selection of The Bachu 15 Criteria for the Ranking.

In 2008, the Cooperative Research Centre for Greenhouse Gas Technologies (CO2CRC) in Australia produced a report on methods for estimating CO2 storage capacity and storage site selection and characterisation. Kaldi and Gibson-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 CO2; some numerical values were modified, refined or added.

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

As in Bachu (2003) table , each i evaluates the basin suitability. Each j position is for the smallest and most great values characterize the worst and best classes in terms of suitability for criterion

	Criterion	Score					Weight
		J=1	J=2	J=3	J=4	J=5	
i=1	Tectonic setting	1	3	7	15	15	0.10
i=2	Size	1	3	5	8	10	0.06
i=3	Depth	1	2	6	10		0.10
i=4	Geology	1	4	10			0.09
i=5	Hydrogeology	1	4	10			0.10
i=6	Geothermal	1	4	10			0.08
i=7	Hydrocarbon potential	1	3	7	14	21	0.04
i=8	Salts	1	2	3			0.01
i=9	Coal and CBM	1	2	5			0.04
i=10	Maturity	1	2	4	8	10	0.08
i=11	On/Offshore	1	5	10			0.11
i=12	Climate	1	2	4	7	11	0.04
i=13	Accessibility	1	3	6	10		0.04
i=14	Infrastructure	1	3	7	10		0.05
i=15	CO_2 Sources	1	3	7	15		0.06

$\sum_1^{15} w_i = 1$

The Modified 15 criteria

Figure 21 - The CO_2GeoStorage Assessment Selection of The Modified 15 Criteria from Kaldi and Poole for the Ranking.

3.2.4 Screen results: Ranking assessment

In this section of the App is where data of the basin characterization is selected according to the fifteen (15) criteria described on the table 1 (Bachu, 2003) or the modified table 3 Kaldi and Poole (2008) according to the method chosen. Hence, the equations' functions are executed, and the result is shown in display pop-up window.

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 (1) and as expected, the ranking result was zero (0) as seen in figure 22.

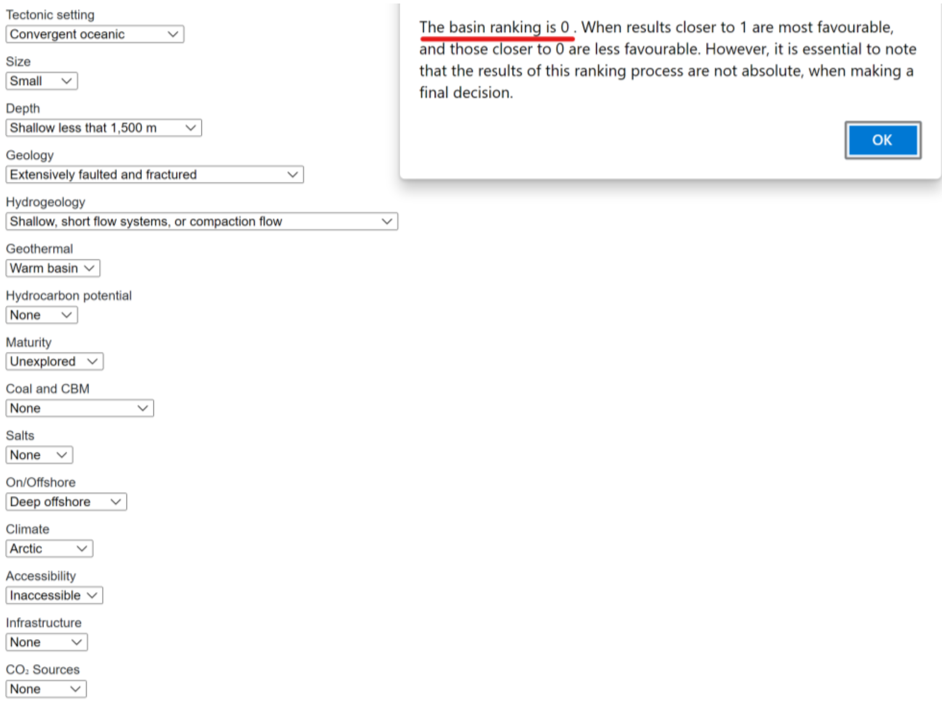

Figure 22 - The CO_2GeoStorage Assessment Ranking Extreme Tests for zero (0).

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) as seen in figure 23.

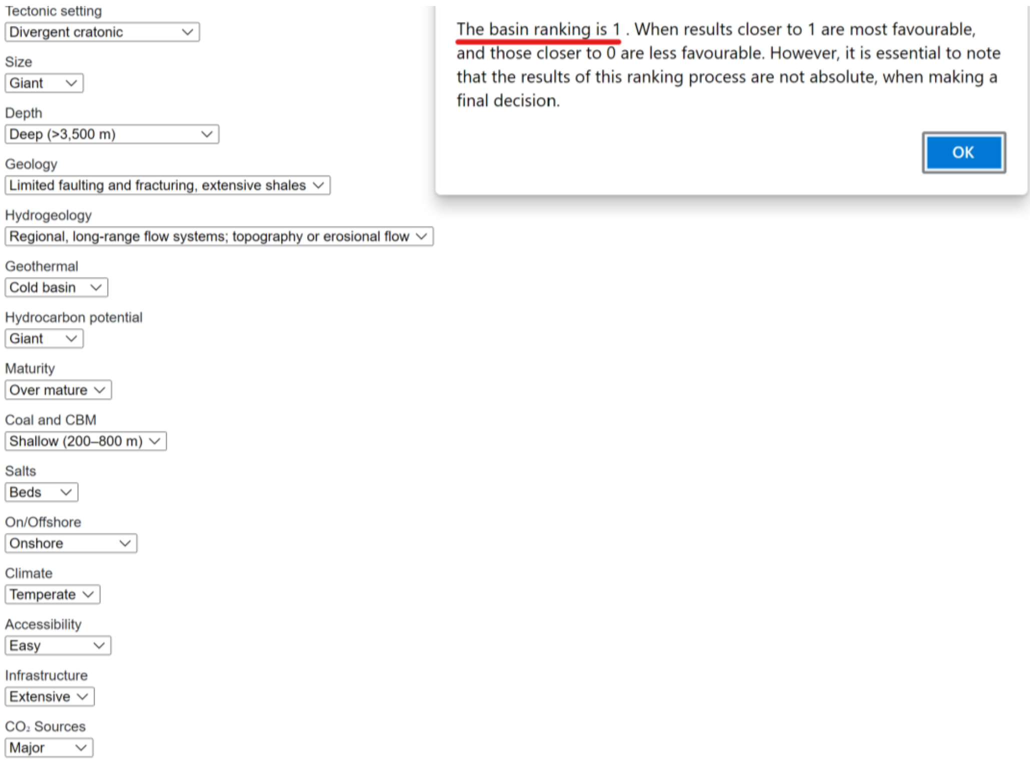

Figure 23 - The CO_2GeoStorage Assessment Ranking Extreme Tests for one (1).

4.Result and Discussion

To analyze 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 Geo_2Storege Assessment App.

Research into CCS technology began in Europe, the United States and Canada. Currently, dozens of CCS projects are active or planned around the world. The Table was adapted from the 2020 Global Status of CSS report and presented some commercial facilities worldwide.

Table 6 - CSS commercial facilities in operation (adapted of the report do Global Status of CSS de 2020)

Facility Title	Country	Since	Industry	Storage Type
Terrell Natural Gas Processing Plant	United States	1972	Natural gas processing	Enhanced Oil Recovery
Enid Fertilizer	United States	1982	Fertiliser production	Enhanced Oil Recovery
Sleipner CO_2 Storage	Norway	1996	Natural gas processing	Geological Storage
Sinopec Zhongyuan Carbon Capture Utilisation and Storage	China	2006	Chemical production	Enhanced Oil Recovery
Century Plant	United States	2010	Natural gas processing	Enhanced Oil Recovery & Geological Storage
Petrobras Santos Basin Pre-Salt Oil Field CCS	Brazil	2013	Natural gas processing	Enhanced Oil Recovery
Quest	Canada	2015	Hydrogen Production Oil sands upgrading	Geological Storage
Abu Dhabi CCS	United Arab Emirates	2016	Iron and steel production	Enhanced Oil Recovery
Gorgon Carbon Dioxide Injection	Australia	2019	Natural gas processing	Geological Storage
Qatar LNG CCS	Qatar	2019	Natural gas processing	Geological Storage

Table 6 demonstrates that many of the projects already developed are only focused on the two types of storage, the Enhanced Oil Recovery (EOR) or Dedicated Geological Storage, without exposing the Geological Storage type. Observing the table data also indicates that the industry that provides the most CO_2 is natural gas processing.

Sleipner project was the pioneer with the central objective of CO_2 storage (conditioned by the Norwegian government's carbon tax). Its tarted injecting CO_2 in 1996 into a saline aquifer about 800m below the seabed.

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 analyze 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.

4.1. Province of Québec Basin, Canada

The Province of Québec in Canada is divided into two geological regions: the Canadian Shield to the north and the Appalachian Mountain belt. The Canadian Shield comprises the Precambrian igneous, volcanic and metamorphic rocks, which makes the region not suitable for CO_2 geological storage. 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, as shown in the figure 24. Each sub-basin will be geological and practical described below. (Malo & Bedard, 2012)

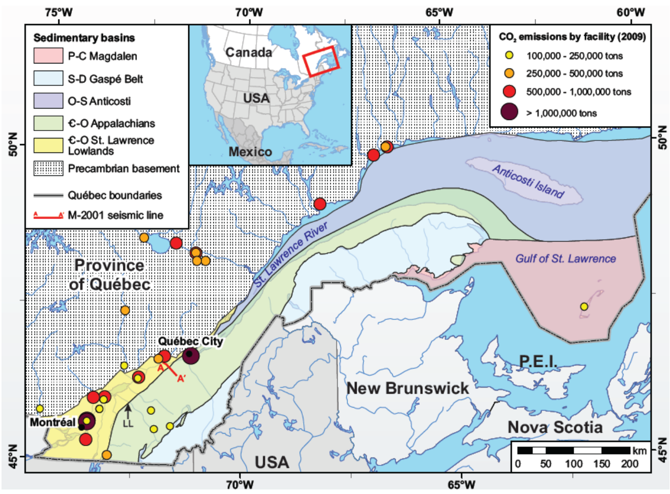

Figure 24 - Appalachian Mountain Belt, Province of Québec Basin, Canada (Malo & Bedard, 2012)

4.1.1 St. Lawrence platform sub-basin

The St. Lawrence platform is split into two: the Anticosti sub-basin to the northeast, in the Gulf of St. Lawrence, and the St. Lawrence Lowlands sub-basin, to the southwest between Montréal and Quebec City. (Malo & Bedard, 2012)

The St. Lawrence Lowlands sub-basin, some of the geological characteristics of the sub-basin clearly indicates the criteria and the class described. An area that extends over approximately 20,000 km2 marked in the figure 24 by the yellow colour, With concentrated data about seismic and well; Oil and gas exploration is currently active for shale gas; The bottom hole temperature data indicate a sub-basin geothermal gradient of about 20°C/km; Deformation intensity varies from very low to intermediate towards the Logan's Line where rocks of the platform are imbricated in thrust slices; The base of the Utica Shale is found at depths of 500 to more than 4,000 meters, deepening from the St. Lawrence River toward the southeast in the sub-basin. All practical characteristics are favourable for CO_2 geological storage mostly because the sub-basin has several large CO_2 emitters located directly in the sub-basin, between Montréal and Quebec City (CO_2 Source). (Malo & Bedard, 2012)

The Anticosti sub-basin has an extends area about 90,000 km^2 marked in the figure 24 by the lilac colour; It is only affected by sedimentary normal faults, and the intensity of deformation is low; The depth is between 400 and more than 2300 meters from north to south on Anticosti Island; Seismic data indicate that sedimentary units cropping out on Anticosti Island are continuous southwards in the Gulf of St. Lawrence, but there are no offshore wells; geothermal gradient is about 20°C/km. There is active hydrocarbon exploration on Anticosti Island. Hence, the geologically prospective for CO_2 storage, but infrastructure on the island is poor, accessibility is difficult due to its offshore setting, and the closest large CO_2 emitters are located at more than 200 km on the north shore of the St. Lawrence River. (Malo & Bedard, 2012)

4.1.2 The Appalachian sub-basin

The Appalachian sub-basin, also known as the Taconian sub-basin, has an extends area of approximately 50,000 km2 marked in the figure 24 by the light green colour; The rocks are highly folded and faulted; although the reservoir-seal pairs are present there is few seismic and well data are available to constrain their depth and geometry. The sub-basin is practically unexplored for hydrocarbon; Most of the wells in the sub-basin were targeting reservoir rocks of the St. Lawrence platform sub-basin; There is no data for temperature and depth; the geothermal gradient is estimated as cold according to the geothermal map of North America and the temperatures of the adjacent basins. The accessibility is easy, and the infrastructures are extensive, but very few large CO_2 emitters are in the sub-basin. (Malo & Bedard, 2012)

4.1.3 The Gaspé Belt sub-basin

The Gaspé Belt sub-basin, also known as the Acadian sub-basin, has extends area about 35,000 km2 in Québec marked in the figure 24 by the light blue colour; The deformation and metamorphism are high to moderate but increase significantly southwards in the sub-basin. Although the southern part of the Gaspé Peninsula is still unexplored for oil and gas; as result of the complex geology and lack of data, the CO_2 storage prospect of these parts of the Gaspé Belt sub-basin is shallow. Oil and gas exploration is better developed in the northern part of the sub-basin, where the intensity of deformation is moderate to low. Data from wells and seismic lines are available; the well temperature data indicate a geothermal gradient of about 20°C/km. The accessibility is easy, and the infrastructures are extensive, but no large CO_2 emitters are nearby. The northeaster part of the Gaspé Belt sub-basin in the Gaspé Peninsula is geologically prospective for CO_2 storage. (Malo & Bedard, 2012)

4.1.4 The Magdalen

The Magdalen sub-basin has extended area approximately 40,000 km2 in Québec, mainly offshore in the Gulf of St. Lawrence marked in the figure 24 by the pink colour and is affected by extensional and strike-slip faults; The sub-basin rocks including evaporite beds and domes as well as coal measures. Therefore, salt domes have been the focus of oil and gas exploration. However, the maturity of exploration is still low, there is a lack of data; the geothermal gradient is counted as cold according to the geothermal map of North America and the temperatures of the other basins. Geologically the Maritimes sub-basin is potential for CO_2 storage, but practical aspects are not favourable for example the accessibility and infrastructure of the offshore potential CO_2 storage sites do not exist. (Malo & Bedard, 2012)

The table 7 below shows the fifteen (15) criteria modified from Bachu; Kaldi and Gibson-Poole and the correspondent class of the five (5) Québec basins characterized above. The rank for each sub-basin presented in the published paper is displayed on the last row of the table 7.

Table 7 – Appalachian Mountain Basin – Québec, 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

4.1.5 Canadian case results and discussion

The data about the Québec sub-basins Canada (Malo & Bedard, 2012) characteristics were inserted at the CO_2 GeoStorage Assessment App. At the screening phase, where critical criteria are tested, the Taconian and the Acadian sub-basins did not meet one of the requirements to pass the eliminatory criteria. Both present a poor reservoir seal pair. Taconian sub-basin also did not met another critical criterion because data about the depth was not found. Consequently, as predated the App automatically alerted that the sub-basins were unsuitable for CO_2 storage because of the high risk of compromising the safety and security by the critical criteria by (Valer, 2010). As previously referred a poor reservoir seal pair increase the risk of CO_2 leakage. Figure 25 illustrates the assessment of Acadian sub-basin.

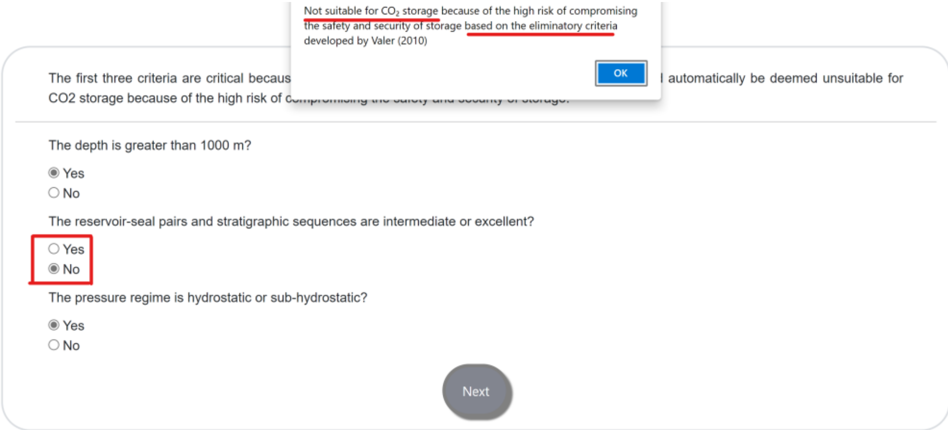

Figure 25 – The CO_2 GeoStorage Assessment – The Acadian and Maritimes Sub-Basins

Apart from the two sub-basins mentioned above, the other three Québec sub-basins, the Lowlands, the Anticosti and the Maritimes met the screening assessment requirements of the critical and essential criteria (eliminatory criteria). All of them presented intermediate depth, excellent reservoir seal pairs, low seismicity, limited faulting, medium to very large size and cold geothermal. Thus, the App allows to pass to the ranking assessment page where the qualitative characteristics are quantified by the definition of scores and weighted according the criteria to assess the rank. The CO_2 GeoStorage Assessment App results for the three sub-basins were consistent with the published ones (Malo & Bedard, 2012) presented on the table 7

Figure 26 shows the Lowland sub-basin results which had the best rank 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.

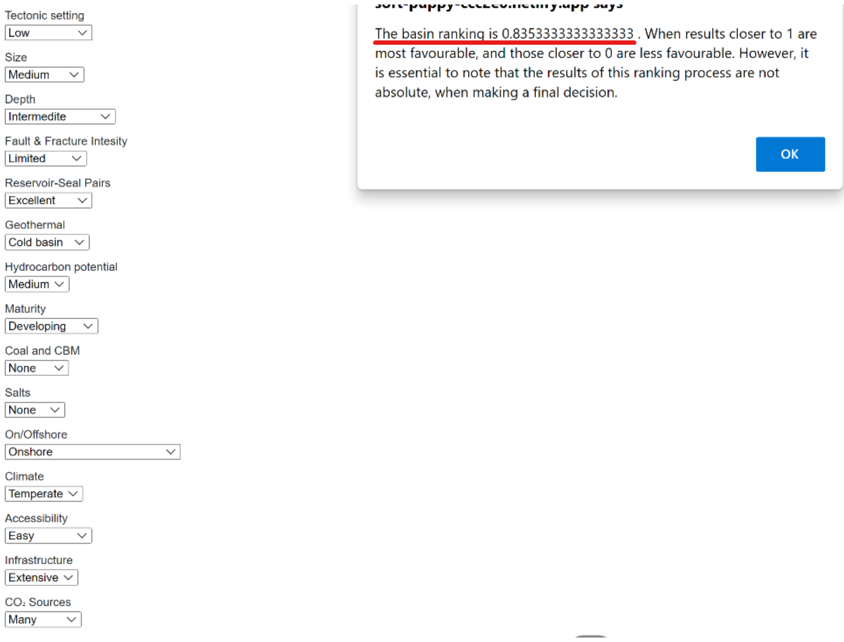

Figure 26 – The CO_2 GeoStorage Assessment – The Lowland Sub-Basin rank

The Anticosti sub-basin presents the second-best rank mainly because is the biggest of the three and is located at shallow offshore and onshore, but the accessibility is difficult and has few sources of CO_2. Figure 27 shows the Antocosti sub-basin rank.

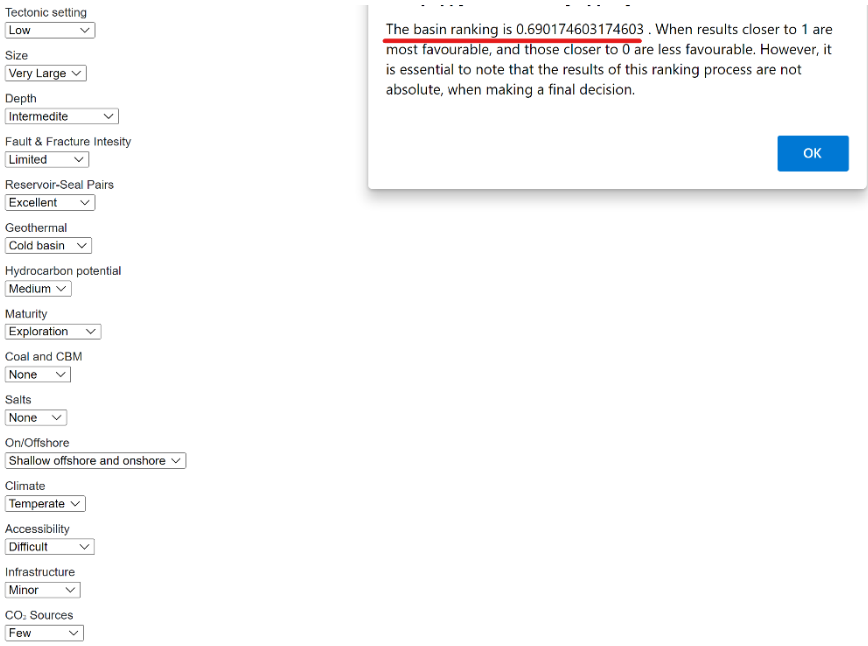

Figure 27 – The CO_2 GeoStorage Assessment – The Anticosti Sub-Basin rank

The rank of the Magdalen sub-basin has a small difference with Anticosti sub-basin despite the size of the sub-basin is less than half the Anticosti sub-basin. In fact, this sub-basin is only one of the three cases that presents coal depth and salt beds, and have a large hydrocarbon potential. However, it is located in shallow offshore, it has difficult accessibility and few close CO_2 sources, as shown in the figure 28.

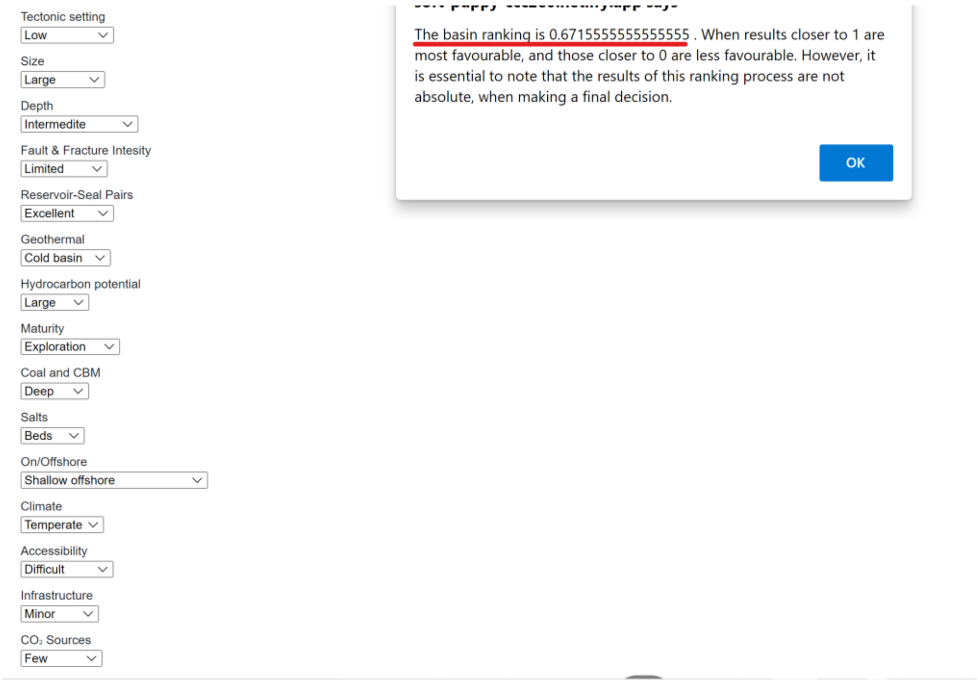

Figure 28 – The CO_2 GeoStorage Assessment – The Magdalen Sub-Basin rank

4.2. Kazakhstan sedimentary basins

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. The territory of Kazakhstan has 15 sedimentary basins (KazEnergy 2015); six of them 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 Precaspian, Mangyshlak, South Turgay, Ustyurt, Chu-Sarysu, and Zaysan sub-basins are described below.

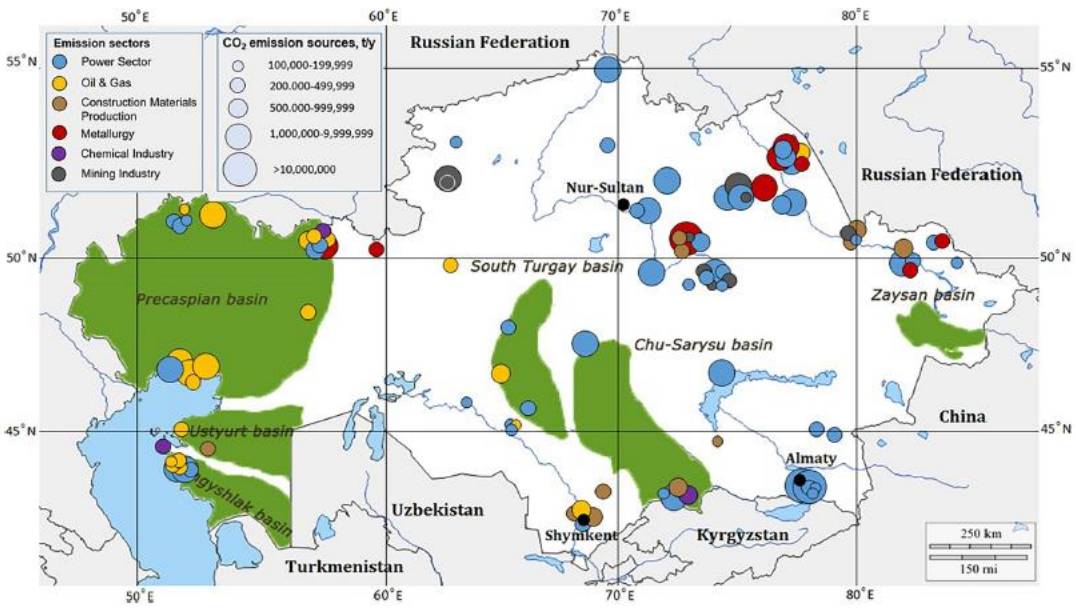

Figure 29 – Kazakhstan sedimentary basins (Abuov, et al., 2020)

4.2.1 The Precaspian sub-basin

The Precaspian sub-basin is one of the biggest in the world, with an area of 500 000 km2 where three-quarters lie in Kazakhstan, and the rest lies in Russian territory. The depth reaches more than 20 km in central parts. Sediments in the sub-basin are divided by a large salt bed of Kungurian (lower Permian) evaporites. Kungurian salts are highly deformed into salt domes throughout the entire territory of the sub-basin and reach the present-day surface in some places. (Abuov, et al., 2020)The sub-basin is tectonically stable after Cadomian orogeny in Early Cambrian, and therefore it was able to hold huge hydrocarbon accumulations. Faults are found throughout the entire territory of the sub-basin and are especially more intense on the south and east sides. The regional seal is provided by the Kungurian salt that covers the entire sub-basin area except for narrow salt zones in the south and east of the sub-basin. The sub-basin margins have depths between 1700 and 4400 m which holds a large hydrocarbon accumulation of the sub-basin, while the central part of the presalt is located at a depth of more than 7 – 10 Km, which means high drilling coast. The large porous volume found in carbonates of Precaspian sub-basin margins presents a significant potential for CO_2 storage. The porosity is higher than 20 %, and permeability varies from 30 mD to several hundred millidarcies. The geothermal gradient in is approximately 10− 20 ºC/km in the east and 20− 30 ºC/km towards the western margin, both are a good indication for CO_2 storage but in the southeastern part of the sub-basin has been documented sub-basin 45− 48 ºC/km, which could be unfavorable for CO_2 storage. It has resisted twenty-seven major CO_2 sources with annual CO_2 emissions of more than 100,000 t are, located within 300 km of the Precaspian Sub-Basin, with annual total CO_2 emissions of 21,331 kt.

4.2.2 The Mangyshlak sub-basin

The Mangyshlak sub-basin is an eastern part of the Middle Caspian Sea. It has an area of 75,000 km2 split between onshore (35,000 km2) and offshore (40,000 km2). Faulting is present in some sections of sub-basin of Middle Jurassic to contemporary sediments and has only a few faults. The intensity of folding is much less in the western part of the sub-basin. Principal reservoirs of the Mangyshlak Sub-Basin occur in Lower and Middle Jurassic sandstones interbedded with mudstones and shales. The central parts of the sub-basin have a seal thickness of 500-700 m and the southern and northern margins has a seal thickness of 100 m. The seal is highly effective because it holds more than 300 m of the oil column in a thin region with less than 100 m thickness. The porosity is between 14-23% and permeability is few to 1200 mD. Geothermal gradient varies between 38 – 41º C/km which, provides moderate conditions for storage safety but, it can be alleviated by the good quality of seals. The sub-basin has ten stationary CO_2 sources. (Abuov, et al., 2020)

4.2.3 The South Turgay sub-basin

The South Torgay Sub-Basin is located on the Turan platform. It has an area if proximately 80 000 km^2. The southwestern part of the sub-basin is a regional strike-slip Karatau-Talas-Fergana (KTF) fault, which is an important tectonic element that affected the origin of several reservoir systems. Fault activities stopped during Lower Cretaceous and therefore Cretaceous to present-day sediments were not affected by faults. The seal qualities of the Lower and Middle Jurassic are believed to be effective, and the seal integrity of the Upper Jurassic has not yet been verified despite the thick sandstone reservoir system found there. The porosity is between 10-20% and permeability exceed 1000 mD at shallow depth. (Abuov, et al., 2020)

4.2.4 The Ustyurt sub-basin

The triangular-shaped North Ustyurt is situated on the northern part of the Ustyurt Plateau and covers an area more than 145,000 km^2 in Kazakhstan. It is mainly located onshore but some parts extend to the offshore of the Caspian and Aral Sea. Geophysical data from a few wells showed that the heterogeneous basement consists of Precambrian massifs and deformed Caledonian fold belts. Sedimentation depth is in the range of 5.5–11 km. The sub-basin has not been subjected to severe faulting, and 5 km of sediments have accumulated since then part of the sub-basin have good reservoir properties (permeability tens to hundreds of mD and porosity of 22–29 %) and a regional seal of Aptian shales (Ulmishek, 2001c). Reservoirs occur in a wide range of strata that vary between 250 m and 1300 m. The reservoirs at suitable depths for supercritical CO_2 reside. The Ustyurt sub-basin was categorized as a cold basin from estimated geothermal gradient. Seismic survey efforts in the Soviet Union revealed a significant number of Middle Jurassic structural traps throughout the basin that are not yet drilled, and the potential of reservoir-seal pairs from this sequence thus remains speculative. (Abuov, et al., 2020)

4.2.5 The Chu-Sarysu sub-basin

The Chu-Sarysu Sub-Basin is the second-largest sedimentary sub-basin in Kazakhstan, with an NW–SE trending direction and covering an area of 160,000 km^2, located in the center of the basin, and their give structural traps. The sub-basin reveals a series of faults that intruded present day sediments and indicates recent seismic activities. Reservoir fluids are mostly trapped at the depth range of 1,100 – 2,400 m. Reservoir porosity is in the range of 3.0–21.6 %, and permeability is in the range of 1–46 mD. Clastic reservoir horizons are found in Permian age but their potential is limited due to depths below 800 m. Estimated sub-basin thermal gradient is 27.4 ◦C/km, which indicates that Chu-Sarysu is a cold basin, a favorable option for storing supercritical CO_2. (Abuov, et al., 2020)

4.2.6 The Zaysan sub-basin

The Zaysan Sub-Basin covers an area of 5000 km2 in the East Kazakhstan region. The sub-basin is flanked by the Saur-Tarbagatay Mountains and the Altai-Kalby mountains from the south and north margins, respectively (Blackbourn, 2013). The Mid-Carboniferous closure of the Zaysan ocean (one of the Palaeo-Asian oceans) induced convergence between the Kazakhstan and Siberia continental blocks that led to the creation of the Irtysh sinistral shear zone where the Zaysan Sub-Basin was developed (Delvaux et al., 2013; Windley et al., 2007). The sub-basin fills consist of continental Upper Cretaceous to Cenozoic deposits over 1700 m thick with containment, and reservoir horizons were reported in the Paleozoic basement (Blackbourn, 2013). The sub-basin's occurrence in the convergent strike-slip zone of two continental blocks made it a subject of numerous complex deformation events inherited from the episodes of the Central Asian Orogenic Belt (CAOB). The sub-basin is tectonically unstable, and faulting exists in all sediment horizons. On April 14, 1990, the Irtysh earthquake occurred along the transpressional northern margin where it was over thrusted by the Altai range (Delvaux et al., 2013). Extensive faults, along with unstable geology, pose a significant risk for the upward leakage of injected CO_2, and the sub-basin resources cannot provide a large capacity for geological CO_2 storage. The young development stage of the oil and gas industry and remotely located stationary CO_2 sources also downgrade the feasibility aspect (Abuov, et al., 2020).

Table 8 - Kazakhstan Sedimentary Basins (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
R^k **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)

4.2.7 Kazakhstan case results and discussion

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 two of the requirements to pass the eliminatory criteria (Valer, 2010). The Zaysan sub-basin is tectonically unstable and extensively faulted, and it is considered to be oceanic convergent. The figure 30 illustrates the assessment of Zaysan sub-basin.

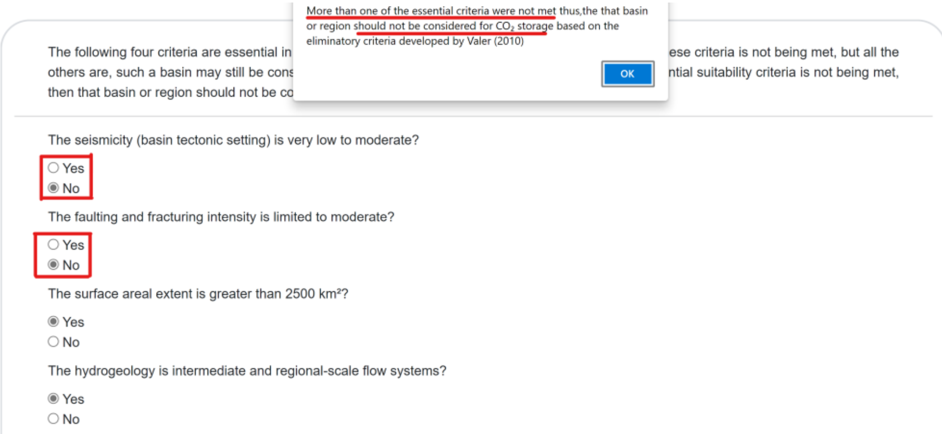

Figure 30 – The CO_2 GeoStorage Assessment – The Zaysan Sub-Basin

Whereas the other five sub-basins present good characteristics to pass the screening of the eliminatory criteria, such as located in less seismic area, deep depth of the sub-basins and giant size. Hence, the App allows to pass to the ranking assessment page, applying the data at the CO_2 GeoStorage Assessment App, the results of the rank for the five sub-basins were consistent with the ones published by (Abuov, et al., 2020) and presented on the table 8.

Precaspian is by far the one with the best rank because it is one of the largest sub-basins of the world with an area of 500 000 km^2 along with favorable geological characteristics for CO_2 storage such as the presence of saltbeds as well as a temperate climate, onshore location, satisfactorily accessible, extensive infrastructures and close to major CO_2 sources. The ranking of Precaspian sub-basin is showed in the figure 31.

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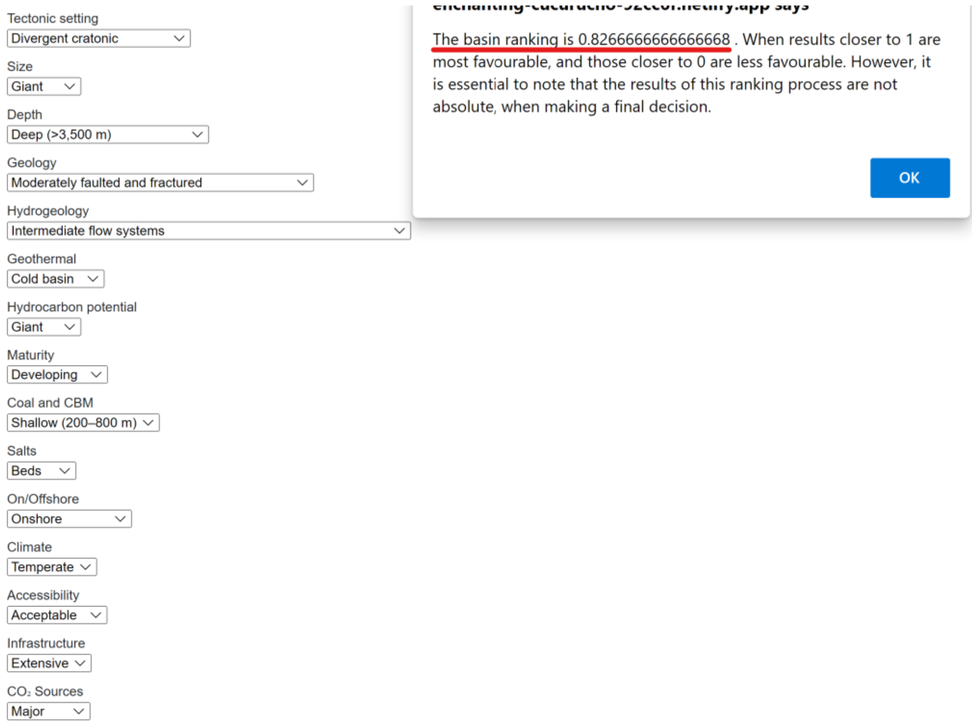

Figure 31 – The CO_2 GeoStorage Assessment – The Precaspian Sub-Basin rank

Mangyshlak sub-basin presents the second-best rank 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. Figure 32 shows the Mangyshlak sub-basin rank.

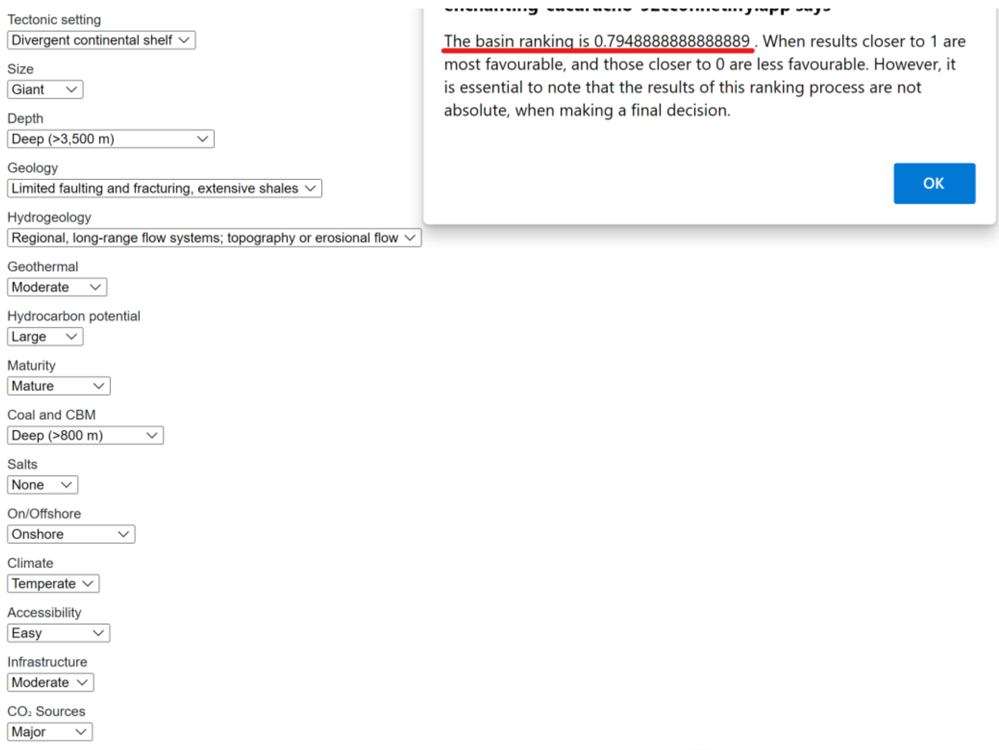

Figure 32 – The CO_2 GeoStorage Assessment – The Mangyshlak Sub-Basin rank

South Torgay sub-basin presents the third best rank. 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. Figure 33 shows the South Torgay sub-basin rank.

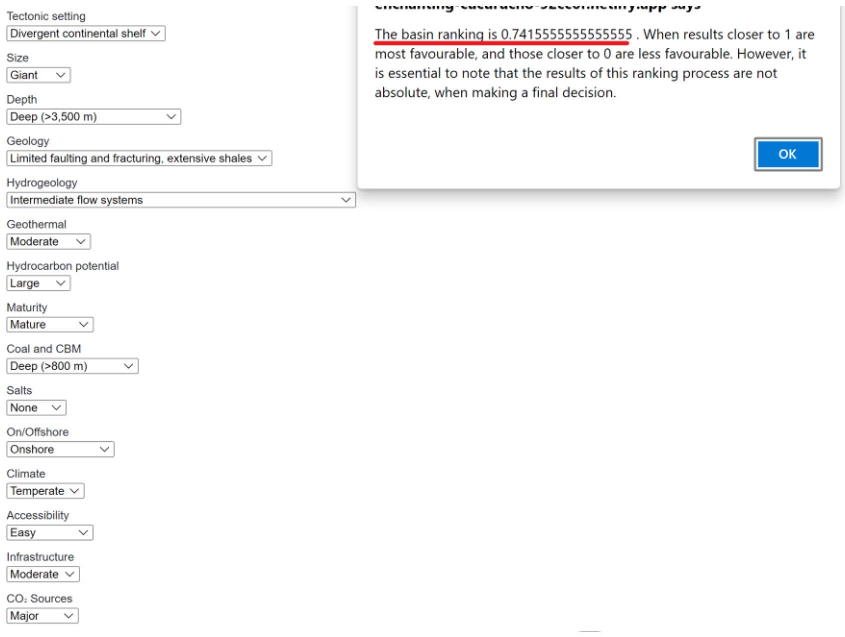

Figure 33 – The CO_2 GeoStorage Assessment – The South Torgay Sub-Basin rank

Ustyurt sub-basin 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. As illustrate in the figure 34.

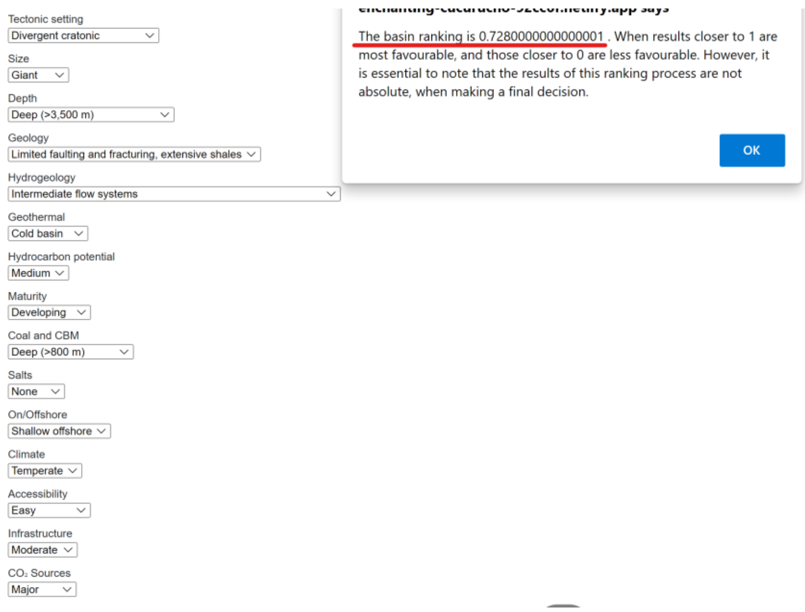

Figure 34 – The CO_2 GeoStorage Assessment – The Ustyurt Sub-Basin rank

Chu-Sarysa sub-basin has the smallest ranking mainly 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. Figure 35 shows the Chu-Sarysa sub-basin rank.

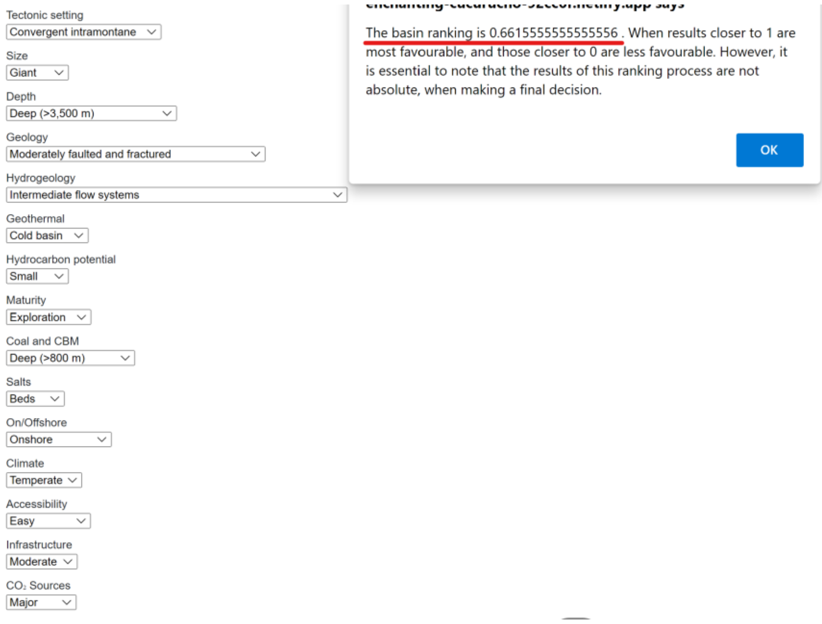

Figure 35 - The CO_2 GeoStorage Assessment – The Chu-Sarysa Sub-Basin rank

5. Conclusions and Recommendations

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 sub-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.

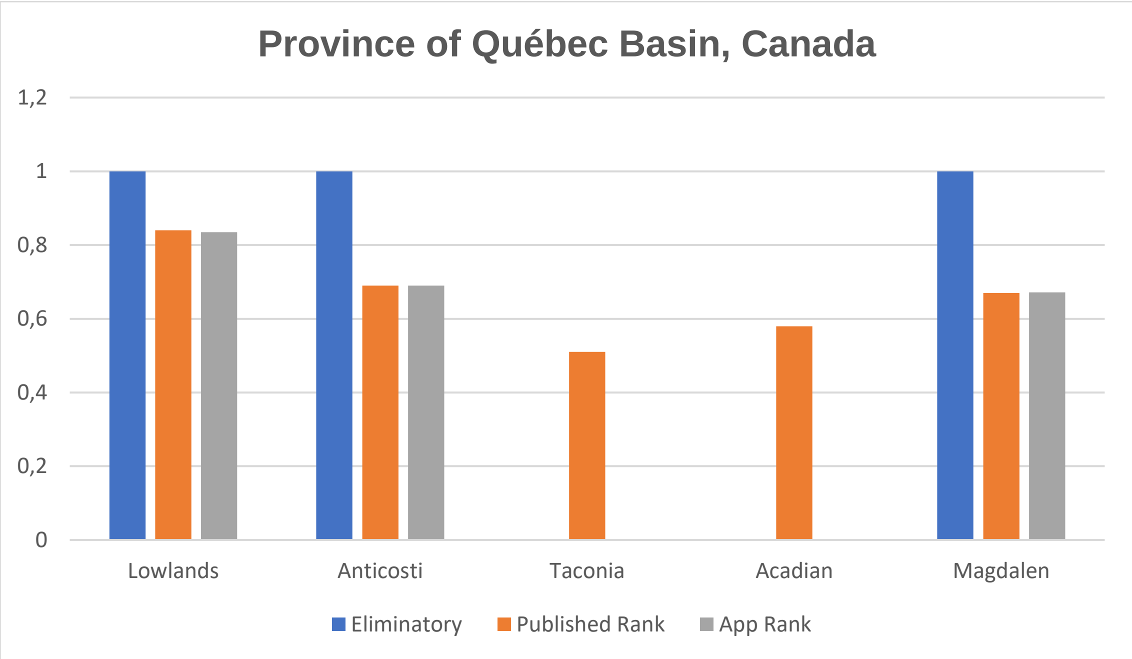

Figure 36 - Comparation between the results of the published paper and App – Québec Basin

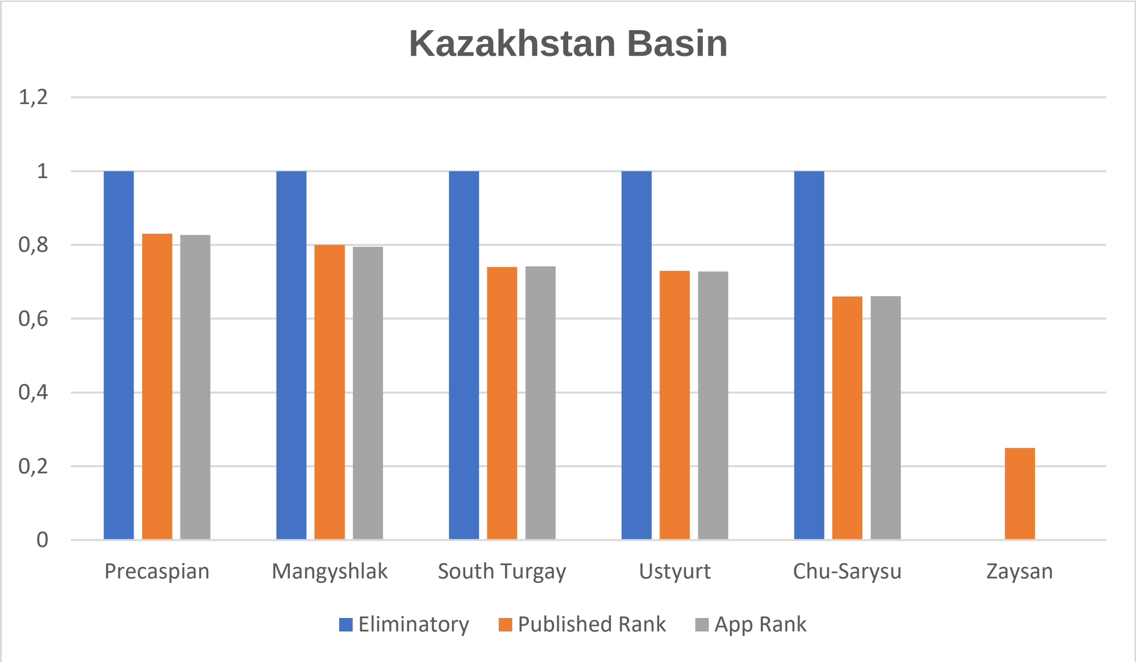

Figure 37 -Comparation between the results of the published paper and App – Kazakhstan Basi

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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Appendix A

The Critical Criteria Code

```
<!DOCTYPE html>
<html lang="en">
  <head>
    <meta charset="UTF-8" />
    <meta http-equiv="X-UA-Compatible" content="IE=edge" />
    <meta name="viewport" content="width= <device-width>, initial-scale=1.0" />
    <title>Critical criteria</title>
    <link
      href="https://cdn.jsdelivr.net/npm/bootstrap@5.1.3/dist/css/bootstrap.min.css"
      rel="stylesheet"
      integrity="sha384-1BmE4kWBq78iYhFldvKuhfTAU6auU8tT94WrHftjDbrCEXSU1oBoqyl2QvZ6jIW3"
      crossorigin="anonymous"
    />
    <style>
      h1 {
        text-align: center;
      }
      .mar {
        margin: 12px 42px;
        padding: 15px;
        border-radius: 35px;
        max-width: 5000px;
        border: 2px solid #dadde1;
      }
      p {
        margin: 10px 40px;
        text-align: justify;
        font-family: "Montserrat", sans-serif;
      }
      button {
        margin: 0 auto;
        display: block;
        box-shadow: grey;
        transition: all 500ms linear;
        box-shadow: 4px 4px 2px gray;
        line-height: 100%;
        padding: 20px;
        border: 4px solid grey;
        border-radius: 40px;
      }
      button:hover {
        cursor: pointer;
        background-color: #82858f;
        color: white;
      }
      a {
        text-decoration: none;
      }
    </style>
  </head>
  <body>
    <h1>Critical criteria</h1>
    <br />
    <div class="mar">
      <p>
        The first three criteria are critical because a basin or part thereof
        that does not satisfy all these should automatically be deemed
        unsuitable for CO2 storage because of the high risk of compromising the
```

```
      safety and security of storage.
    </p>
    <hr />
    <p>The depth is greater than 1000 m?</p>
    <form action="#" method="post" onsubmit="return VerificaCritico()">
      <p>
        <input
          type="radio"
          id="question-1-yes"
          name="question-1"
          value="1"
          checked="checked"
        />
        <label for="question-1-yes">Yes</label>
        <br />
        <input type="radio" id="question-1-no" name="question-1" value="0" />
        <label for="question-1-no">No</label>
        <br />
      </p>
      <p>
        The reservoir-seal pairs and stratigraphic sequences are intermediate
        or excellent?
      </p>
      <p>
        <input
          type="radio"
          id="question-2-yes"
          name="question-2"
          value="1"
          checked="checked"
        />
        <label for="question-2-yes">Yes</label>
        <br />
        <input type="radio" id="question-2-no" name="question-2" value="0" />
        <label for="question-2-no">No</label>
        <br />
      </p>
      <p>The pressure regime is hydrostatic or sub-hydrostatic?</p>
      <p>
        <input
          type="radio"
          id="question-3-yes"
          name="question-3"
          value="1"
          checked="checked"
        />
        <label for="question-3-yes">Yes</label>
        <br />
        <input type="radio" id="question-3-no" name="question-3" value="0" />
        <label for="question-3-no">No</label>
        <br />
      </p>

      <a href="https://bucolic-quokka-bac877.netlify.app/">
        <button type="submit">Next</button></a
      >
    </form>
  </div>
  <script>
    function VerificaCritico() {
      var depth = parseInt(
        document.querySelector('input[name="question-1"]:checked').value
```

```
        );
        var seal = parseInt(
          document.querySelector('input[name="question-2"]:checked').value
        );
        var pressure = parseInt(
          document.querySelector('input[name="question-3"]:checked').value
        );
        var soma = depth + seal + pressure;
        if (soma == 3) {
          window.location.href = "https://bucolic-quokka-bac877.netlify.app/";
        } else {
          alert(
            "Not suitable for CO₂ storage because of the high risk of compromising the safety and security of storage based on the eliminatory criteria developed by Valer (2010)"
          );
        }
        return false;
      }
    </script>
  </body>
</html>
```

The Essential Criteria Code

```
<!DOCTYPE html>
<html lang="en">
  <head>
    <script src="https://unpkg.com/axios/dist/axios.min.js"></script>
    <meta charset="UTF-8" />
    <meta http-equiv="X-UA-Compatible" content="IE=edge" />
    <meta name="viewport" content="width=<device-width>, initial-scale=1.0" />
    <title>Essential criteria</title>
    <link
      href="https://cdn.jsdelivr.net/npm/bootstrap@5.1.3/dist/css/bootstrap.min.css"
      rel="stylesheet"
      integrity="sha384-1BmE4kWBq78iYhFldvKuhfTAU6auU8tT94WrHftjDbrCEXSU1oBoqyl2QvZ6jIW3"
      crossorigin="anonymous"
    />
    <style>
      h1 {
        text-align: center;
      }
      .mar {
        margin: 12px 42px;
        padding: 15px;
        border-radius: 35px;
        max-width: 5000px;
        border: 2px solid #dadde1;
      }
      p {
        margin: 10px 40px;
        text-align: justify;
        font-family: "Montserrat", sans-serif;
      }
      button {
        margin: 0 auto;
        display: block;
        box-shadow: grey;
        transition: all 500ms linear;
        box-shadow: 4px 4px 2px gray;
        line-height: 100%;
```

```
      padding: 20px;
      border: 4px solid grey;
      border-radius: 40px;
    }
    button:hover {
      cursor: pointer;
      background-color: #82858f;
      color: white;
    }
    a {
      text-decoration: none;
    }
  </style>
</head>
<body>
  <h1>Essential criteria</h1>
  <div class="mar">
    <p>
      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 CO2 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 CO2
      storage.
    </p>
    <hr />
    <form action="#" method="post" onsubmit="return VerificaEssential()">
      <p>The seismicity (basin tectonic setting) is very low to moderate?</p>
      <p>
        <input
          type="radio"
          id="question-4-yes"
          name="question-4"
          value="1"
          checked="checked"
        />
        <label for="question-4-yes">Yes</label>
        <br />
        <input type="radio" id="question-4-no" name="question-4" value="0" />
        <label for="question-4-no">No</label>
        <br />
      </p>
      <p>The faulting and fracturing intensity is limited to moderate?</p>
      <p>
        <input
          type="radio"
          id="question-5-yes"
          name="question-5"
          value="1"
          checked="checked"
        />
        <label for="question-5-yes">Yes</label>
        <br />
        <input type="radio" id="question-5-no" name="question-5" value="0" />
        <label for="question-5-no">No</label>
        <br />
      </p>
      <p>The surface areal extent is greater than 2500 km²?</p>
      <p>
        <input
          type="radio"
          id="question-6-yes"
```

```
            name="question-6"
            value="1"
            checked="checked"
          />
          <label for="question-6-yes">Yes</label>
          <br />
          <input type="radio" id="question-6-no" name="question-6" value="0" />
          <label for="question-6-no">No</label>
          <br />
        </p>
        <p>The hydrogeology is intermediate and regional-scale flow systems?</p>
        <p>
          <input
            type="radio"
            id="question-7-yes"
            name="question-7"
            value="1"
            checked="checked"
          />
          <label for="question-7-yes">Yes</label>
          <br />
          <input type="radio" id="question-7-no" name="question-7" value="0" />
          <label for="question-7-no">No</label>
          <br />
        </p>

        <a href="https://reliable-bunny-83d6ce.netlify.app/">
          <button type="submit">Next</button></a
        >
      </form>
    </div>
    <script>
      function VerificaEssential() {
        var seismicity = parseInt(
          document.querySelector('input[name="question-4"]:checked').value
        );
        var fracturing = parseInt(
          document.querySelector('input[name="question-5"]:checked').value
        );
        var areal = parseInt(
          document.querySelector('input[name="question-6"]:checked').value
        );
        var intermed = parseInt(
          document.querySelector('input[name="question-7"]:checked').value
        );
        var soma = seismicity + fracturing + areal + intermed;
        if (soma == 4) {
          alert("So next step is the calculation the basin ranking");
          window.location.href = "https://reliable-bunny-83d6ce.netlify.app/";
        } else {
          if (soma == 3) {
            alert(
              "One of the essential criteria is not being met, but all the others are, the
basin may still be considered for CO₂ storage based on the eliminatory criteria developed
by Valer (2010) So next step is the calculation the basin ranking"
            );
            window.location.href = "https://reliable-bunny-83d6ce.netlify.app/";
          } else {
            alert(
              "More than one of the essential criteria were not met thus,the that basin or
region should not be considered for CO₂ storage based on the eliminatory criteria
developed by Valer (2010)"
```

```
          );
        }
      }
      return false;
    }
  </script>
</body>
</html>
```

The Bachu 15 Code

```
<!DOCTYPE html
<html lang="en">
  <head>
    <meta charset="UTF-8" />
    <meta http-equiv="X-UA-Compatible" content="IE=edge" />
    <meta name="viewport" content="width=<device-width>, initial-scale=1.0" />
    <title>15 Criteria for CO2 storage</title>
    <link
      href="https://cdn.jsdelivr.net/npm/bootstrap@5.1.3/dist/css/bootstrap.min.css"
      rel="stylesheet"
      integrity="sha384-1BmE4kWBq78iYhFldvKuhfTAU6auU8tT94WrHftjDbrCEXSU1oBoqyl2QvZ6jIW3"
      crossorigin="anonymous"
    />
    <style>
      h1 {
        text-align: center;
      }
      .mar {
        margin: 12px 42px;
        padding: 15px;
        border-radius: 35px;
        max-width: 5000px;
        border: 2px solid #dadde1;
      }
      p {
        margin: 10px 40px;
        text-align: justify;
        font-family: "Montserrat", sans-serif;
      }
      button {
        margin: 0 auto;
        display: block;
        box-shadow: grey;
        transition: all 500ms linear;
        box-shadow: 4px 4px 2px gray;
        line-height: 100%;
        padding: 20px;
        border: 4px solid grey;
        border-radius: 40px;
      }
      button:hover {
        cursor: pointer;
        background-color: #82858f;
        color: white;
      }
      a {
        text-decoration: none;
      }
    </style>

  </head>
```

```html
<body>
  <h1>
    The Bachu 15 criteria
  </h1>
  <div class="mar">
    <p>
      An overall ranking score would take these and other criteria into
      account to arrive at a quantitative evaluation regarding a basin's
      suitability for CO2 sequestration.Three to five classes have been
      defined in each category listed from the least favourable to the most
      favourable for CO2 sequestration or storage (Bachu, 2003). However, if
      CO2 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
    </p>
    <p>......</p>
    <hr />
    <form action="#" method="post" onsubmit="return Calcula()">
    <p>
      Tectonic setting
      <br />
      <select name="tectonicSetting" id="tectonicSetting">
        <option value=1>Convergent oceanic</option>
        <option value=3>
          Convergent intramontane
        </option>
        <option value=7>
          Divergent continental shelf
        </option>
        <option value=15>Divergent foredeep</option>
        <option value="15">Divergent cratonic</option>
      </select>
    </p>
    <p>
      Size
      <br />
      <select name="Size" id="Size">
        <option value=1>Small</option>
        <option value=3>Medium</option>
        <option value=5>Large</option>
        <option value="9">Giant</option>
      </select>
    </p>
    <p>
      Depth
      <br />
      <select name="Depth" id="Depth">
        <option value=1>Shallow less that 1,500 m</option>
        <option value=3>Intermediate (1,500-3,500 m)</option>
        <option value="5">Deep (>3,500 m)</option>
      </select>
    </p>
    <p>
      Geology
      <br />
      <select name="Geology" id="Geology">
        <option value=1>Extensively faulted and fractured</option>
        <option value=3>Moderately faulted and fractured</option>
        <option value="7">
          Limited faulting and fracturing, extensive shales
        </option>
      </select>
```

```
</p>
<p>
  Hydrogeology
  <br />
  <select name="Hydrogeology" id="Hydrogeology">
    <option value=1>
      Shallow, short flow systems, or compaction flow
    </option>
    <option value=3>Intermediate flow systems</option>
    <option value="7">
      Regional, long-range flow systems; topography or erosional flow
    </option>
  </select>
</p>
<p>
  Geothermal
  <br />
  <select name="Geothermal" id="Geothermal">
    <option value=1>Warm basin</option>
    <option value=3>Moderate</option>
    <option value="7">Cold basin</option>
  </select>
</p>
<p>
  Hydrocarbon potential
  <br />
  <select name="hydrocarbonPotential" id="hydrocarbonPotential">
    <option value=1>None</option>
    <option value=3>Small</option>
    <option value=7>Medium</option>
    <option value=13>Large</option>
    <option value="21">Giant</option>
  </select>
</p>
<p>
  Maturity
  <br />
  <select name="Maturity" id="Maturity">
    <option value=1>Unexplored</option>
    <option value=2>Exploration</option>
    <option value=4>Developing</option>
    <option value=8>Mature</option>
    <option value="10">Over mature</option>
  </select>
</p>
<p>
  Coal and CBM
  <br />
  <select name="coalAndCBM" id="coalAndCBM">
    <option value=1>None</option>
    <option value=2>Deep (>800 m)</option>
    <option value="5">Shallow (200-800 m)</option>
  </select>
</p>
<p>
  Salts
  <br />
  <select name="Salts" id="Salts">
    <option value=1>None</option>
    <option value=2>Domes</option>
    <option value="3">Beds</option>
  </select>
```

```
    </p>
    <p>
      On/Offshore
      <br />
      <select name="On/Offshore" id="On/Offshore">
        <option value=1>Deep offshore</option>
        <option value=4>Shallow offshore</option>
        <option value="10">Onshore</option>
      </select>
    </p>
    <p>
      Climate
      <br />
      <select name="Climate" id="Climate">
        <option value=1>Arctic</option>
        <option value=2>Sub-Arctic</option>
        <option value=4>Desert</option>
        <option value=7>Tropical</option>
        <option value="11">Temperate</option>
      </select>
    </p>
    <p>
      Accessibility
      <br />
      <select name="Accessibility" id="Accessibility">
        <option value=1>Inaccessible</option>
        <option value=3>Difficult</option>
        <option value=6>Acceptable</option>
        <option value="10">Easy</option>
      </select>
    </p>
    <p>
      Infrastructure
      <br />
      <select name="Infrastructure" id="Infrastructure">
        <option value=1>None</option>
        <option value=3>Minor</option>
        <option value=7>Moderate</option>
        <option value="10">Extensive</option>
      </select>
    </p>
    <p>
      CO₂ Sources
      <br />
      <select name="CO2Sources" id="CO2Sources">
        <option value=1>None</option>
        <option value=3>Few</option>
        <option value=7>Moderate</option>
        <option value="15">Major</option>
      </select>
    </p>
    <a href="">
      <button type="submit">Next</button></a
    >

  </div>
  <script>
    function Calcula() {

      var tectonicSetting = parseInt(document.getElementById('tectonicSetting').value);
      var Size = parseInt(document.getElementById('Size').value);
      var Depth =  parseInt(document.getElementById('Depth').value);
```

```
        var Geology =  parseInt(document.getElementById('Geology').value);
        var Hydrogeology =  parseInt(document.getElementById('Hydrogeology').value);
        var Geothermal =  parseInt(document.getElementById('Geothermal').value);
        var hydrocarbonPotential
=  parseInt(document.getElementById('hydrocarbonPotential').value);
        var Maturity =  parseInt(document.getElementById('Maturity').value);
        var coalAndCBM =  parseInt(document.getElementById('coalAndCBM').value);
        var Salts =  parseInt(document.getElementById('Salts').value);
        var OnOffshore =  parseInt(document.getElementById('On/Offshore').value);
        var Climate =  parseInt(document.getElementById('Climate').value);
        var Accessibility =  parseInt(document.getElementById('Accessibility').value);
        var Infrastructure =  parseInt(document.getElementById('Infrastructure').value);
        var CO2Sources =  parseInt(document.getElementById('CO2Sources').value);

        //equation 1
        var p1= (tectonicSetting -1) / (15-1);
        var p2= (Size -1) / (9-1);
        var p3= (Depth -1) / (5-1);
        var p4= (Geology -1) / (7-1);
        var p5= (Hydrogeology -1) / (7-1);
        var p6= (Geothermal -1) / (7-1);
        var p7= (hydrocarbonPotential -1) / (21-1);
        var p8= (Maturity -1) / (10-1);
        var p9= (coalAndCBM -1) / (5-1);
        var p10= (Salts -1) / (3-1);
        var p11= (OnOffshore -1) / (10-1);
        var p12= (Climate -1) / (11-1);
        var p13= (Accessibility -1) / (10-1);
        var p14= (Infrastructure -1) / (10-1);
        var p15= (CO2Sources -1) / (15-1);
        //equation 2
        var Rk =(0.07 * p1) + (0.06 * p2) + (0.07 * p3) + (0.08 * p4) + (0.08 * p5) + (0.1
* p6) + (0.06* p7) + (0.08 * p8) + (0.04 * p9) + (0.01 * p10) + (0.1 * p11) + (0.08 * p12)
+( 0.03 * p13) + (0.05 * p14) +(0.09 * p15);
        alert("The basin ranking is "+Rk+" . When results closer to 1 are most favourable,
and those closer to 0 are less favourable. However, it is essential to note that the
results of this ranking process are not absolute, when making a final decision.");

        return false;
        }
    </script>

  </body>
</html>
```

The Modified 15 Code

```
<!DOCTYPE html>
<html lang="en">
  <head>
    <meta charset="UTF-8" />
    <meta http-equiv="X-UA-Compatible" content="IE=edge" />
    <meta name="viewport" content="width=<device-width>, initial-scale=1.0" />
    <title>15 Criteria for CO2 storage</title>
    <link
      href="https://cdn.jsdelivr.net/npm/bootstrap@5.1.3/dist/css/bootstrap.min.css"
      rel="stylesheet"
      integrity="sha384-1BmE4kWBq78iYhFldvKuhfTAU6auU8tT94WrHftjDbrCEXSU1oBoqyl2QvZ6jIW3"
      crossorigin="anonymous"
    />
    <style>
      h1 {
```

```
        text-align: center;
      }
      .mar {
        margin: 12px 42px;
        padding: 15px;
        border-radius: 35px;
        max-width: 5000px;
        border: 2px solid #dadde1;
      }
      p {
        margin: 10px 40px;
        text-align: justify;
        font-family: "Montserrat", sans-serif;
      }
      button {
        margin: 0 auto;
        display: block;
        box-shadow: grey;
        transition: all 500ms linear;
        box-shadow: 4px 4px 2px gray;
        line-height: 100%;
        padding: 20px;
        border: 4px solid grey;
        border-radius: 40px;
      }
      button:hover {
        cursor: pointer;
        background-color: #82858f;
        color: white;
      }
      a {
        text-decoration: none;
      }
    </style>

  </head>
  <body>
    <h1>
The Modified 15 criteria from  Kaldi and Gibson-Poole
    </h1>
    <div class="mar">
      <p>
        An overall ranking score would take these and other criteria into
        account to arrive at a quantitative evaluation regarding a basin's
        suitability for CO2 sequestration.Three to five classes have been
        defined in each category listed from the least favourable to the most
        favourable for CO2 sequestration or storage (Bachu, 2003). However, if
        CO2 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
      </p>
      <hr />
      <form action="#" method="post" onsubmit="return Calcula()">
      <p>
        Tectonic setting
        <br />
        <select name="tectonicSetting" id="tectonicSetting">
          <option value=1>Very high</option>
          <option value=3>High
          </option>
          <option value=7>
            Intermediate
```

```
    </option>
    <option value=15>Low</option>
    <option value=15>Very low</option>
  </select>
</p>
<p>
  Size
  <br />
  <select name="Size" id="Size">
    <option value=1>Very Small</option>
    <option value=3>Smal</option>
    <option value=5>Medium</option>
    <option value=8>Large</option>
    <option value=10>Very Large</option>
  </select>
   </p>
<p>
  Depth
  <br />
  <select name="Depth" id="Depth">
    <option value=1>Very Shallow</option>
    <option value=2>Shallow</option>
    <option value=6>Deep (>3,500 m)</option>
    <option value=10>Intermedite</option>
  </select>
</p>
<p>
  Fault & Fracture Intesity
  <br />
  <select name="Geology" id="Geology">
    <option value=1>Extensively </option>
    <option value=4>Moderate</option>
    <option value=10>
      Limited
    </option>
  </select>
</p>
<p>
  Reservoir-Seal Pairs
  <br />
  <select name="Hydrogeology" id="Hydrogeology">
    <option value=1>
      Poor
    </option>
    <option value=4>Intermediate</option>
    <option value=10>Excellent
    </option>
  </select>
 </p>
<p>
  Geothermal
  <br />
  <select name="Geothermal" id="Geothermal">
    <option value=1>Warm basin</option>
    <option value=4>Moderate</option>
    <option value=10>Cold basin</option>
  </select>
 </p>
<p>
  Hydrocarbon potential
  <br />
  <select name="hydrocarbonPotential" id="hydrocarbonPotential">
```

```
      <option value=1>None</option>
      <option value=3>Small</option>
      <option value=7>Medium</option>
      <option value=14>Large</option>
      <option value=21>Giant</option>
    </select>
  </p>
<p>
    Maturity
    <br />
    <select name="Maturity" id="Maturity">
      <option value=1>Unexplored</option>
      <option value=2>Exploration</option>
      <option value=4>Developing</option>
      <option value=8>Mature</option>
      <option value=10>Super mature</option>
    </select>
</p>
<p>
    Coal and CBM
    <br />
    <select name="coalAndCBM" id="coalAndCBM">
      <option value=1>None</option>
      <option value=2>Deep </option>
      <option value=5>Shallow </option>
    </select>
</p>
<p>
    Salts
    <br />
    <select name="Salts" id="Salts">
      <option value=1>None</option>
      <option value=2>Domes</option>
      <option value=3>Beds</option>
    </select>
  </p>
<p>
    On/Offshore
    <br />
    <select name="On/Offshore" id="On/Offshore">
      <option value=1>Deep offshore</option>
      <option value=5>Shallow offshore</option>
      <option value=10>Shallow offshore and onshore</option>
      <option value=15>Onshore</option>
    </select>
</p>
<p>
    Climate
    <br />
    <select name="Climate" id="Climate">
      <option value=1>Arctic</option>
      <option value=2>Sub-Arctic</option>
      <option value=4>Desert</option>
      <option value=7>Tropical</option>
      <option value=10>Temperate</option>
    </select>
</p>
<p>
    Accessibility
    <br />
    <select name="Accessibility" id="Accessibility">
      <option value=1>Inaccessible</option>
```

```
          <option value=3>Difficult</option>
          <option value=6>Acceptable</option>
          <option value=10>Easy</option>
        </select>
      </p>
      <p>
        Infrastructure
        <br />
        <select name="Infrastructure" id="Infrastructure">
          <option value=1>None</option>
          <option value=3>Minor</option>
          <option value=7>Moderate</option>
          <option value=10>Extensive</option>
        </select>
      </p>
      <p>
        CO₂ Sources
        <br />
        <select name="CO2Sources" id="CO2Sources">
          <option value=1>None</option>
          <option value=3>Few</option>
          <option value=7>Moderate</option>
          <option value=11>Significant</option>
          <option value=15>Many</option>
        </select>
      </p>
      <a href="">
        <button type="submit">Next</button></a
      >

    </div>
    <script>
      function Calcula() {

        var tectonicSetting = parseInt(document.getElementById('tectonicSetting').value);
        var Size = parseInt(document.getElementById('Size').value);
        var Depth =  parseInt(document.getElementById('Depth').value);
        var Geology =  parseInt(document.getElementById('Geology').value);
        var Hydrogeology =  parseInt(document.getElementById('Hydrogeology').value);
        var Geothermal =  parseInt(document.getElementById('Geothermal').value);
        var hydrocarbonPotential
=  parseInt(document.getElementById('hydrocarbonPotential').value);
        var Maturity =  parseInt(document.getElementById('Maturity').value);
        var coalAndCBM =  parseInt(document.getElementById('coalAndCBM').value);
        var Salts =  parseInt(document.getElementById('Salts').value);
        var OnOffshore =  parseInt(document.getElementById('On/Offshore').value);
        var Climate =  parseInt(document.getElementById('Climate').value);
        var Accessibility =  parseInt(document.getElementById('Accessibility').value);
        var Infrastructure =  parseInt(document.getElementById('Infrastructure').value);
        var CO2Sources =  parseInt(document.getElementById('CO2Sources').value);
        //equation 1
        var p1= (tectonicSetting -1) / (15-1);
        var p2= (Size -1) / (10-1);
        var p3= (Depth -1) / (10-1);
        var p4= (Geology -1) / (10-1);
        var p5= (Hydrogeology -1) / (10-1);
        var p6= (Geothermal -1) / (10-1);
        var p7= (hydrocarbonPotential -1) / (21-1);
        var p8= (Maturity -1) / (10-1);
        var p9= (coalAndCBM -1) / (5-1);
        var p10= (Salts -1) / (3-1);
        var p11= (OnOffshore -1) / (15-1);
```

```
        var p12= (Climate -1) / (10-1);
        var p13= (Accessibility -1) / (10-1);
        var p14= (Infrastructure -1) / (10-1);
        var p15= (CO2Sources -1) / (15-1);
        //equation 2
        var Rk = 0.1 * p1 + 0.06 * p2 + 0.1 * p3 + 0.09 * p4 + 0.1 * p5 + 0.08 * p6 + 0.04
* p7 + 0.08 * p8 + 0.04 * p9 + 0.01 * p10 + 0.11 * p11 + 0.04 * p12 + 0.04 * p13 + 0.05 *
p14 +0.06 * p15;
        alert("The basin ranking is "+Rk+" . When results closer to 1 are most favourable,
and those closer to 0 are less favourable. However, it is essential to note that the
results of this ranking process are not absolute, when making a final decision.");

        return false;
        }
    </script>

  </body>
</html>
```