



An Automated Python Script-Based Platform for CCS Screening Feasibility of Subsurface Geological Formations

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Abstract

Carbon sequestration in subsurface geological formations has massive potential for emission reduction of greenhouse gases in the coming decades. To accurately identify a geological prospect for carbon dioxide CO₂ storage requires a play-based exploration scenario analogous to hydrocarbon exploration. The process requires a multi-faceted approach incorporating geological, geophysical, and well-engineering datasets for CO₂ storage screening potential of a depleted oil and gas reservoir and/or saline aquifers. An automated Python script-based user interface (UI) is developed for identifying necessary data sources when planning CO₂ storage screening of any geological sites in a minimum amount of time. UI takes multiple varied file inputs (.las, .csv, .pdf, .txt, .xlsx, .sgy) and searches them for the necessary data which is required for CO₂ storage screening potential such as porosity, lithology, permeability, temperature, pore pressure, etc. It further generates a detailed report of the geological site in terms of data priority listing and feasibility of CO₂ screening program. The application is proven to be efficient in reducing time and cost during the early planning phase of the storage site selection program. It is tested on a small amount of data from Ichthys field, Browse Basin, Western Australia for CO₂ storage screening and has enormous scope to improve further.

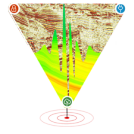
Introduction

Atmospheric carbon dioxide CO₂ levels are at an all-time high at around 37Gt and it is steadily increasing (IEA, 2022). With the continual use and dependence on fossil fuels to meet energy demand, this number has been predicted to increase. To honour the Paris

Climate Agreement 2015, it was decided to keep global temperature rise below 2^oC pre-industrial level. To achieve this, the concept of carbon capture and storage (CCS) is one potential approach ^{[1][2][3]} while the conversion of captured CO₂ into usable chemicals and products is another alternate method. As hydrocarbons are extracted from the subsurface reservoirs, the pore spaces of geological formations acquire the capacity to store CO₂ and can be utilized by injecting CO₂ into these formations ^[4].

Assessing the overall suitability to accurately classify a location for carbon storage requires a multi-faceted approach to analyzing the depositional environment, geological markers, basin formation history, and rock types. While there are the aforementioned factors that are considered for CCS site screening for geological carbon sequestration, a major factor is CO₂ containment which guarantees the long-term storage of CO₂ and prevents the escape of CO₂ into the atmosphere ^[5]. In that regard, seal quality analysis using high-quality subsurface data is of utmost importance.

The analysis of fault seal or top seal begins with evaluating the petrophysical data in a particular subsurface formation. This evaluation is enhanced by accompanying data obtained from well logs (gamma ray, sonic, porosity, and density), and drill cuttings in that region with seismic data (2D, 3D) to identify various formations ^[6]. Due to economic constraints and tool specifications, various logging tools are run in reservoir zones only (excluding the overburden sections), which is not ideal for top seal analysis. While there have been many studies on how to recover or generate missing petrophysical data using machine learning algorithms ^{[7][8]}, it is very important to categorize petrophysical data for CCS screening



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purposes. There have been considerable strides in the research and development of well log database management to properly categorize well data and carry out its quality control for purposes- such as CCS screening and reservoir characterization ^{[9][10]}.

Standing against this backdrop, we sensed the significance and need for an easy and quick-to-implement application that can indicate if a given geological formation is feasible for carbon sequestration and generate a detailed report on that area based on input data files. For this purpose, PyQt was chosen among various other frameworks, because of its extensive documentation, mature and powerful features, cross-platform compatibility, data visualization capabilities, and the flexibility of using other Python libraries in building a user-friendly and time-saving application ^[11]. The application is designed to accept data files with the most commonly used extensions in petrophysical analysis (.las, .xlsx, .csv, .txt, and .pdf), seismic data (.pdf, .txt and .sgy), geological data (.xlsx, .csv, .txt) and well engineering data (.csv, .txt, and .las) as inputs. On uploading multiple such data files of a particular geological site, the Python code runs and searches for necessary data and parameters from the files. It then displays those data headers representing different physical parameters and further concludes what other parameters can be estimated from the ones already present. For example, if gamma-ray (GR) log is available in the .las files, then volume of shale can be estimated. This is one simple instance. Many such complex estimations are done while the code runs, and a detailed report of that geological site is generated. The focal point of the application lies in its time-saving properties, where the user does not need to manually check for essential information from each file. Such a development will reduce time and cost-effectiveness for future subsurface storage screening purposes. As a Geophysicist, this may be one way to propel mankind's effort towards net zero by 2050 as emphasized by IPCC ^[12].

Methodology

With the rapid advancements in cutting-edge technologies, it is of utmost importance today to integrate them with the efforts of mitigating climate change. CCUS (Carbon Capture, Utilization, and Storage) holds the potential to bring down global CO₂

levels but a steady development of CCUS technology is needed ^[16]. The crux of the CCS scenario lies in locating geological formations to become potential CO₂ storage sites. Doing this assessment manually is time-consuming and less efficient as it involves handling numerous data files of various types. To overcome these difficulties, a user interface (UI) based application is proposed using PyQt^[5] library of Python. Among many other frameworks available, PyQt is chosen because of its unique and versatile attributes. It provides readily available resources with regular updates which makes it easy to work with. With a range of features, functionalities, and in-built widgets, PyQt also integrates well with other Python libraries.

On the main window of the application, checkboxes indicating different file extensions namely, .las, .txt, .csv, .sgy, .xlsx, and .pdf are displayed (using QtCheckbox from QtWidgets). It allows the selection of multiple extensions at a time. On checking the boxes corresponding to the extensions of the data files to be uploaded, a 'Select Files' widget is shown, by ticking the necessary files that can be uploaded. On uploading multiple files of different extensions, the code runs through the files of each extension. For a .las file, the application first reads the contents of the file and then saves the header portion to a variable named 'content'. It then searches for those logs in the 'content' which are necessary to analyze the carbon storage capacity of the site. These include gamma ray (GR/CGR), sonic (compressional - DT, shear - DTS), caliper data (for identifying bad hole conditions), resistivity (shallow, medium, and deep), porosity (neutron porosity - NPPI), and bulk density logs (Figure 1). On an output screen, available logs are shown. This is done by defining a check keyword function. Next, the application also extracts and shows top depth and base depth values from the file. Further, it strips and displays those lines from .las files that contain temperature and salinity data. Similarly, from .csv or .xlsx files information on geological formations is extracted. The .pdf and .txt files are checked for data related to laboratory rock deformation tests, ultrasonics, internal friction angle, well-completion report, and others. The application also reads the header of the .sgy file and outlines stored data types, i.e., seismic stack, velocity, reservoir characterization products (acoustic

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impedances, Vp/Vs ratio, lithofacies, etc.), and others.

In the next phase, the application uses previously listed data files to tick mark (Figure 2) those of the following listed properties, for which analysis and computation can be performed: dynamic elastic properties, static elastic properties, volume of shale, pore pressure, fracture pressure, permeability, rock strength, in-situ stress, geomechanical model, reservoir thickness, seal quality assessment, and others.

In the final stage, a detailed report on the given geological formation is generated after combining all databases and their input properties to indicate its potential for the screening phase as a future CO₂ storage site.

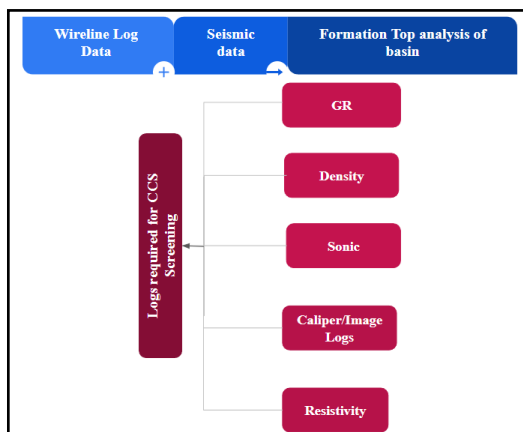


Figure 1: Primary data required for CCS screening

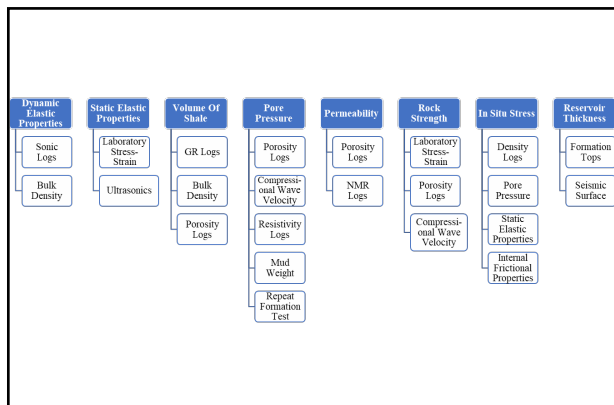


Figure 2: Subsurface data required for potential CCS screening phase in depleted oil/gas reservoirs and saline aquifers.

Data and Demonstration

The data used for the demonstration of CCS screening analysis in this study is from the Ichthys gas field in the Browse basin, Western Australia. The Ichthys gas field has undergone considerable studies over the last decades to identify and isolate gas-bearing zones. The field is projected to produce about 9 million tons of liquid natural gas per annum, as per production data from INPEX, the contractor in charge of the Ichthys field [13]. There have been multiple studies on the monitoring of the Ichthys using field data to examine the changes in geology over time as more and more hydrocarbons are extracted from it [14][15].

On the contrary, there have been little to no studies on the feasibility of Ichthys field for carbon storage purposes. Therefore, we have an attempt to analyze that in this field by investigating the data availability of the open-access well database [17].

For demonstration, on the main window of the application (Figure 3(a)), the four extensions, .las, .xlsx, .csv, and .pdf are selected (Figure 3(b)). Through the 'Select Files' widget, four files - 2 .las files, 1 .xlsx file, and 1 pdf file are uploaded. The .las files are of Dinichthys-1 well which contains well log data [18]. The Excel (.xlsx) file contains information about the geological formations and the .pdf file contains information about the laboratory stress-strain tests and frictional angle. On the output screen, the logs from the .las files which are necessary for analysis are mentioned. It also displays important information from each of the selected files - top depth, base depth, and temperature data from the .las files, no. of formations from the .xlsx file, and others (Figure 3(c)).

From the available information of the selected files, the application also shows which other necessary parameters for CCS screening can be estimated. In this case, only volume of shale and pore pressure can be estimated which is shown by a tick mark.



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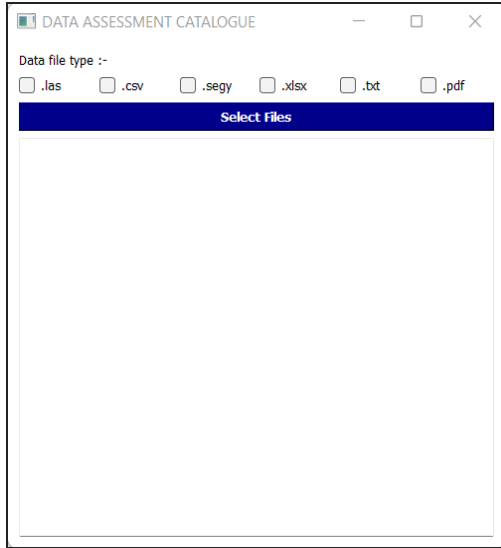


Figure 3(a)

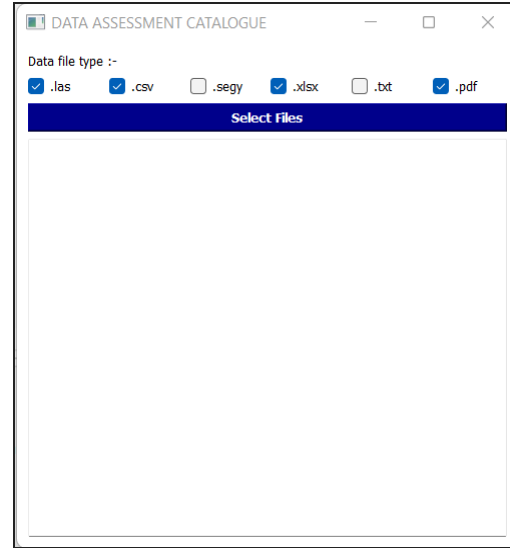


Figure 3(b)

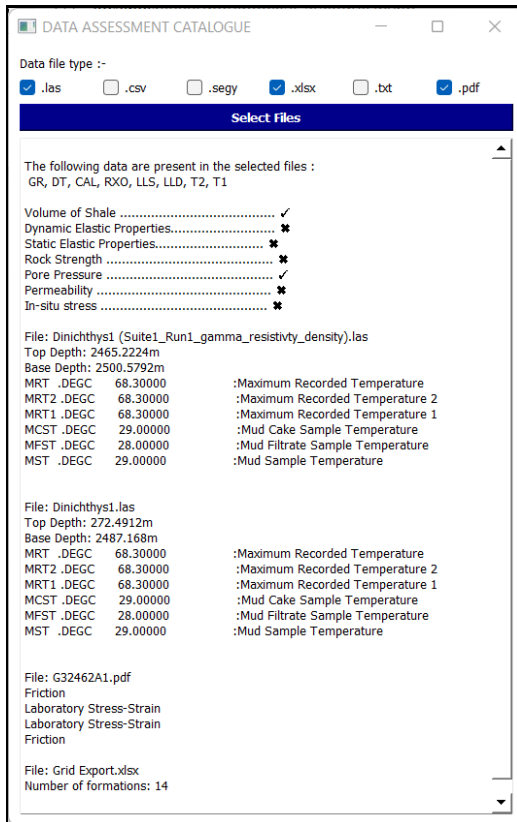


Figure 3(c)

Figure 3: (a) Main Window of Data Assessment Catalogue Application showing checkboxes corresponding to various extensions of which data files it can access and read. (b) Selection of checkboxes for testing. (c) For testing purposes, 4 files - 2 .las, 1 .pdf and 1 .xlsx from the Ichthys database were uploaded. Data was analyzed and a report was generated.

Conclusions

Climate change is the greatest threat to mankind, and it seeks urgent, sincere, and cooperative global efforts now more than ever. It is a cross-sectoral concern and geophysics has a major scope in mitigating it and reaching net zero emissions. CCUS has the potential to play a significant role in reducing global CO₂ levels in the upcoming years, but it requires rapid advancement in CCUS technology to meet the global climate goals. With this motive, an attempt has been made to successfully interlink geophysics with technology to reduce atmospheric CO₂. The Python script-based database management system devised will largely reduce the time and effort required to analyze each geological site to estimate its potential capacity and feasibility. Analyzing numerous data files for a particular site is a tedious and time-consuming task. The application built has a user-friendly interface and can be used by a layman with basic knowledge. It takes multiple varied file inputs and searches them for the necessary data to plan screening of CO₂ storage potential of subsurface



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geological formations (depleted oil and gas reservoirs and/or saline aquifers). It further generates a detailed report of the geological site. The application is tested on limited data and therefore has room for further analytical developments in the years to come.

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