Reserves and resources for CO_2 storage in Europe: the CO_2StoP project

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The challenge of climate change demands reduction in global CO_2 emissions. In order to fight global warming many countries are looking at technological solutions to keep the release of CO_2 into the atmosphere under control. One of the most promising techniques is carbon dioxide capture and storage (CCS), also known as CO_2 geological storage. CCS can reduce the world's total CO_2 release by about one quarter by 2050 (IEA 2008, 2013; Metz *et al.* 2005). CCS usually involves a series of steps: (1) separation of the CO_2 from the gases produced by large power plants or other point sources, (2) compression of the CO_2 into supercritical fluid, (3) transportation to a storage location and (4) injecting it into deep underground geological formations.

CO_2StoP is an acronym for the *CO_2 Storage Potential in Europe* project. The CO_2StoP project which started in January 2012 and ended in October 2014 included data from 27 countries (Fig. 1). The data necessary to assess potential locations of CO_2 storage resources are found in a database set up in the project.

A data analysis system was developed to analyse the complex data in the database, as well as a geographical information system (GIS) that can display the location of potential geological storage formations, individual units of assessment within the formations and any further subdivisions (daughter units, such as hydrocarbon reservoirs or potential structural traps in saline aquifers). Finally, formulae have been developed to calculate the storage resources. The database is housed at the Joint Research Centre, the European Commission in Petten, the Netherlands.

Background and methods

CO_2 storage resource assessment

A resource can be defined as anything potentially available and useful to man. The pore space in deeply buried reservoir rocks that can trap CO_2 is a resource that can be used for CO_2 storage. It is of utmost importance to be aware that the mere presence of a resource does not indicate that any part of it can be economically exploited, now or in the future.

A reserve can be defined as that part of a resource that is available to be economically exploited now using currently available technology. Thus, in order to move from a resource estimate to a reserve estimate, a whole series of technical, economic, legal and socio-economic criteria must be applied. These criteria will then identify the fraction of the resource that can actually be economically exploited in a particular jurisdiction area, using available technology.

Consequently, a very high level of technical assessment is required to demonstrate the existence of a CO_2 storage reserve, and in most cases these kinds of resources are only available within a demonstration or commercial storage project. For these reasons, it was impossible to define any CO_2 storage reserves in the present project.

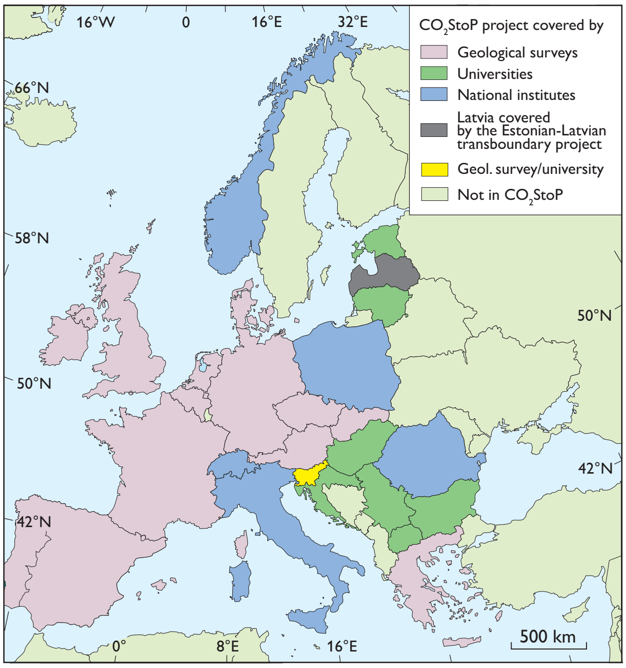

Fig. 1. Twenty-seven countries participated in the CO_2StoP project. Latvia was covered by the Estonian–Latvian border project. The following member states of the European Union participated: Austria, Belgium, Bulgaria, Croatia, Czech Republic, Denmark, Estonia, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, the Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain and UK and the following non-member states: Macedonia, Norway, Serbia and Switzerland.

Storage mechanisms

CO_2 can be retained in reservoir rocks by a number of mechanisms: (1) structural and stratigraphic trapping, in which CO_2 is retained by impermeable barriers, (2) residual trapping, in which free phase CO_2 is trapped by capillary forces in pore spaces, (3) dissolution of CO_2 into pore fluids, (4) precipitation of CO_2 into minerals and (5) adsorption onto shale or coal layers. Only the first two of these mechanisms are significant within a CO_2 storage project's time frame of 10 to 50 years; the other mechanisms take much longer (van der Meer & van Wees 2006).

Therefore, most previous studies of CO_2 storage resources (e.g. USGS Assessment; DOE Storage Atlases; Norwegian Assessment; IEA Best Practices document) focussed on determining the amount of CO_2 that can be retained in conventional reservoir rocks as a dense fluid in the fluid-filled pore spaces between the grains that make up the matrix of the rock and in fluid-filled fractures. Moreover, the vast majority of the CO_2 will be trapped either in structural and stratigraphic traps or by capillary forces as a residual saturation (Bachu *et al.* 2007).

Constraints on CO_2 storage capacity

Each jurisdiction area contains a given amount of pore space within its subsurface. The total resource of pore space that is potentially available for CO_2 storage is that part which can be filled with, and will retain, injected CO_2. Geology and physics dictate that this will be far less than the available total pore space. These limitations mean that only a small fraction of the total resource of pore space can be filled with CO_2. It is possible to define a common method that can be used to estimate the fraction of the total pore space resource that can be used for storage (Brennan 2014). If appropriate CO_2 densities at reservoir conditions are applied to this volume, this allows estimation of the theoretical CO_2 storage resource.

In practice, only a fraction of the theoretical CO_2 storage resource in any given jurisdiction area can actually be utilised – for a variety of technical, economic, legal and social reasons. In the CO_2StoP project, the pore space in a jurisdiction area is subdivided into reservoir formations. These are mappable bodies of rock which display mainly sufficient porosity and permeability. Each reservoir formation contains one or more storage units. A storage unit is defined as a part of a reservoir formation that is found at depths greater than 800 m and which is covered by an effective cap rock. These units are potential CO_2 storage units and they form the basis for the CO_2 storage assessments made in the CO_2StoP project. Each storage unit may contain one or more daughter units. Daughter units are defined as structural or stratigraphic traps which have the potential to immobilise CO_2 within them, e.g. structural domes or proven oil and gas fields. The storage potential of daughter units can be estimated separately in CO_2StoP.

The CO_2StoP method

The CO_2StoP project has established a database, a geographical information system (GIS; ESRI's ArcGIS 10) and a calculation engine that can provide probabilistic estimates of CO_2 storage capacities. The Data Analysis & Interrogation Tool is a combination of Microsoft Access (Data Interrogation tool), and Excel (StoreFit tool) with external code (linked to Excel) to perform injection rate calculations. Calculations carried out with the Database Analysis & Interrogation Tool include: storage capacity, injection rates and stochastic analyses of the storage capacity and injection rates (Fig. 2).

The work to establish internationally recognised standards for capacity assessments was initiated by the Carbon Sequestration Leadership Forum (CSLF) about a year before the start of the European Union GeoCapacity project, and a CSLF Task Force has been active since. The paper 'Estimation of CO_2 storage capacity in geological media – phase 2' by Bachu *et al.* (2007) published by the CSLF presents comprehensive definitions, concepts and methods to be used in estimating CO_2 storage capacity.

As in the EU GeoCapacity, the CO_2StoP method complies with the CSLF recommendations. The methods and calculations for determining the fractions of the resource, used in the CO_2StoP project, also align with the recent International Energy Agency proposals for harmonising CO_2 storage capacity estimation methods (Heidug 2013). The CO_2StoP method estimates the TASR (see below) and the storage resource in structural and stratigraphic traps, which have later been divided into two subsets: hydrocarbon fields and aquifer daughter units.

The technically accessible CO_2 storage resource (TASR)

The CO_2StoP calculation engine can produce a resource estimate that is similar to the technically accessible CO_2 storage resource (TASR) estimated by the US Geological Survey (Brennan *et al.* 2010; Blondes *et al.* 2013; U.S. Geological Survey Geologic Carbon Dioxide Storage Resources Assessment Team 2013). This is the fraction of the theoretical storage resource that can be accessed using all currently available technologies regardless of cost. The International Energy Agency recommended that the first step in all CO_2 storage resource estimates should be to assess the TASR (Heidug 2013).

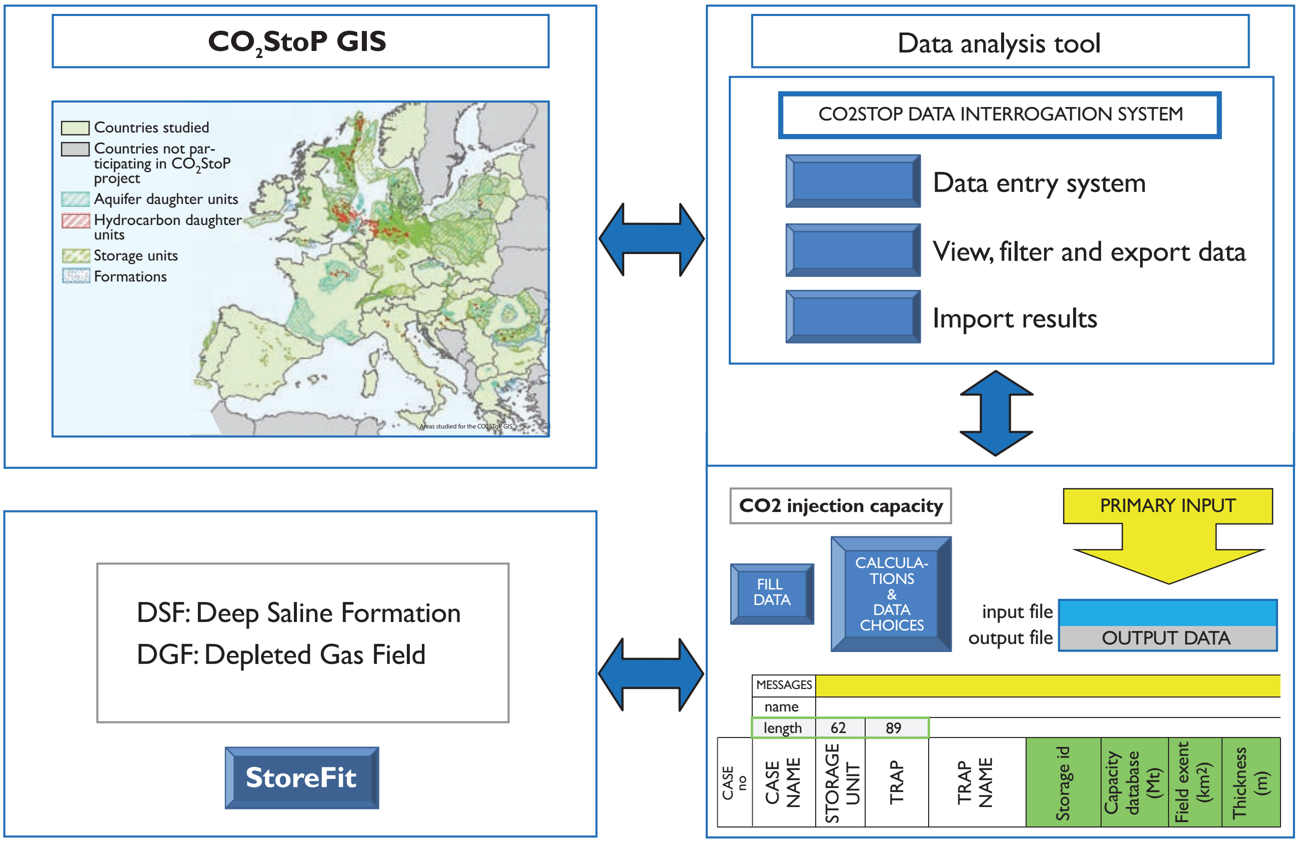

Fig. 2. Schematic representation of the Database Analysis & Interrogation Tool, showing the GIS and the StoreFit Monte Carlo analysis tool. Arrows indicate data exchange between the separate elements of the tool. The map shows the reported resources in the CO_2StoP project.

The CO_2StoP estimate differs in one main respect from the TASR estimated by the U.S. Geological Survey method, namely that CO_2StoP adds the storage capacity of hydrocarbon fields to that of the saline aquifers. This has to be done because the pore volume of the hydrocarbon fields is not provided in the project's database, so it cannot be subtracted from the pore volume of the storage units before their storage capacity is estimated. There are other minor differences in the constraints and assumptions; nevertheless, the two methods produce results that are sufficiently similar to allow them to be compared.

Results

The assessment of the various fractions of the CO_2 geological storage resource performed in the CO_2StoP project is currently only at a provisional level. Unfortunately, large differences exist between the types and quality of data available for each country, and the extent to which the data can be made public also varies widely. Some countries only have data available from traps for buoyant fluids, where the TASR will be low not taking into account any potential for storage outside such traps by residual saturation. Some countries have included aquifer formation data; here the TASR calculation will be more meaningful. In the great majority of countries, uncertainties related to lack of reservoir parameter data also remain. The acquisition of such data will potentially require a sustained campaign of geological mapping and characterisation of storage capacity, or at least significantly more time and financial resources to assemble and enter all available data. These factors limit the results obtained from the CO_2StoP project and it is recommended that further resources are made available for improving the results.

In a European context, the technically accessible CO_2 storage resource (TASR) or theoretical storage resource should only be used for extra-European international resource comparisons because it is clear that the TASR is several times greater than the practical CO_2 storage capacity. Consequently quoting the TASR can be misleading, giving false impressions of capacity if a critical distinction between resource and reserve estimates is not made.

Conclusions

The calculations of CO_2 storage locations throughout Europe made by the CO_2StoP project database paint a broad picture, but also identify the gaps in our knowledge. These gaps must be filled with further data entry and, potentially, new geological studies, seismic surveys and drilling must be undertaken to make more precise data available. A common European legislation allowing equal access to proprietary subsurface information would be beneficial for this purpose.

It is critically important to understand the assumptions that lie behind the storage capacity estimates. These are especially relevant for saline formations, the capacities of which were derived without taking regulatory or economic limitations into account.

The CO_2StoP method has made significant progress towards establishing probabilistic estimates of the CO_2 storage resource in Europe in a way that will allow comparisons with other regions of the world, and which will also be useful to policy makers. However, the partial data entry into the project database means that the current project only marks the beginning of the process of resource estimation and certainly not the end.

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Legal notice

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