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Assessing European capacity for geological storage of carbon dioxide – the EU GeoCapacity project

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Abstract

The focus of the GeoCapacity project is GIS mapping of CO_2 point sources, infrastructure and geological storage in Europe. The main objective is to assess the European capacity for geological storage of CO_2 in deep saline aquifers, oil and gas structures and coal beds. Other priorities are further development of methods for capacity assessment, economic modelling and site selection as well as international cooperation, especially with China. The results of GeoCapacity will include 25 countries and comprises most European sedimentary basins suitable for geological storage of CO_2.

CCS; Europe; GIS; CO_2 point sources; storage potential; capacity estimation; site selection; economic tool; China; COACH, UK-NZEC

1. Introduction

Assessment of storage potential is an essential prerequisite for Carbon Capture and Storage (CCS) to be adopted on a large-scale in Europe. The three-year EU-based GeoCapacity project was launched in January 2006 and is focussing on mapping large CO_2 point sources, infrastructure and potential for geological storage in most European countries. A key element of the project is also constructing a comprehensive GIS database of the results and GeoCapacity continues the basic work and results generated by the GESTCO and CASTOR EU research projects

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which pioneered the development of CO_2 emission and geological storage GIS mapping in Europe and have served as international examples. GeoCapacity is carried out by 25 European partners and 1 Chinese partner, all in a unique position for this study and many being geological surveys or institutes or other state institutions.

The main objective of the project is to assess the European capacity for geological storage of CO_2 in deep saline aquifers, oil and gas structures and coal beds and includes full assessment and GIS mapping of countries which have not already been covered, and updates of previously covered territory. Full assessment is carried out in 13 European countries (Bulgaria, Croatia, Czech Republic, Estonia, Hungary, Italy, Latvia, Lithuania, Poland, Romania, Slovakia, Slovenia, Spain). 4 countries are reviewed by neighbouring states (Albania, FYROM, Bosnia-Herzegovina, Luxemburg) and 6 countries are updated (Germany, Netherlands, Denmark, UK, France, Greece).

Other priorities is further development of innovative and standardized methods for capacity assessment, economic modelling and site selection criteria and building towards a framework for international cooperation especially with other CSLF countries beginning with China and later India and Russia. The work includes:

- Mapping of major CO_2 emission point sources and infrastructure
- Assessment and mapping of regional and local potential for geological storage of CO_2
- Guidelines for assessment of geological storage capacity
- Technical storage site selection criteria and ranking methodology
- Development of mapping and analysis methodologies (GIS and Decision Support System, DSS)
- Analysis of source-transport-sink scenarios and economical evaluations using the DSS
- International collaborative activities with China and other CSLF countries

In the following the stepwise process of identifying storage potential and assessing storage capacity will be described together with the construction of the European GIS mapping system and the DSS tool for economic evaluations, the site selection and ranking criteria and methodology, the efforts for standardizing storage capacity estimates and the international cooperation.

2. Identification of storage potential

Storage capacity assessment begins with identifying sedimentary basins. The GeoCapacity project comprises most of the sedimentary basins suitable for geological storage of CO_2 located within the EU and the Central and Eastern European new member states and candidate countries. Figure 1 shows European CO_2 storage prospectivity with major CO_2 emission point sources. This is not a map of actual storage capacity, but a map of where to look for storage capacity.

Once the suitable sedimentary basins in a region or country have been outlined the next step is to identify potential reservoir and sealing units for CO_2 storage and characterization of their geological and physical properties. At this point regional CO_2 storage estimates based on the bulk volume of aquifers can be calculated. More precise estimates can be provided if stratigraphic or structural traps with suitable reservoir and sealing properties are identified within the aquifers and the storage potential of the individual trap is calculated. Regional estimates can now be calculated as the sum of storage potential of all the traps identified.

3. GIS-based inventorying & mapping

The GeoCapacity GIS database provides updated CO_2 emission data, infrastructure such as pipelines, roads and urban areas and locations of potential geological storage capacity in deep saline formations, hydrocarbon and coal fields. The emission data include technical information on the type of industry (power, cement, iron and steel, paper), fuel, technology, capacity etc. and the pipeline data properties such as diameter and length. The storage data include geological and physical properties of the reservoir and sealing formations as well as estimates of the storage capacity of each of the identified potential storage possibilities, Smith et al. [1].

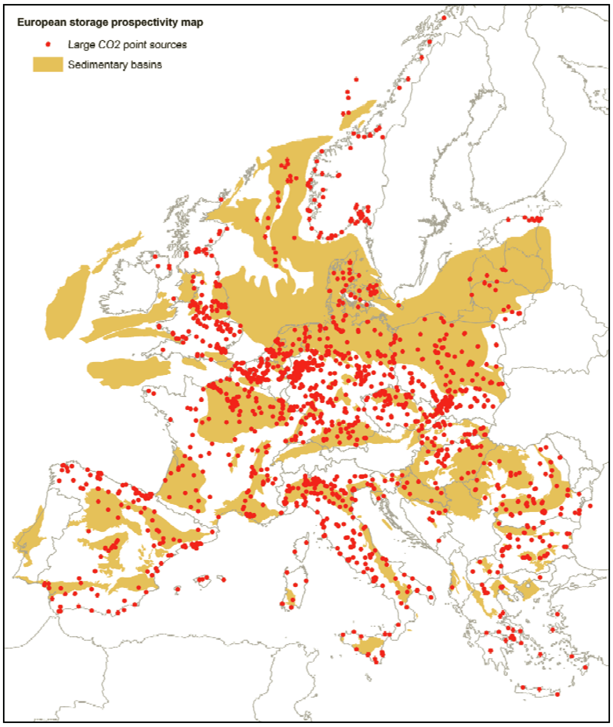

Figure 1: European CO_2 storage prospectivity map with major CO_2 emission point sources.

The basic methodology for GIS-based inventorying and mapping of CO_2 emissions and geological storage capacity was developed in the GESTCO project. In GeoCapacity the GIS has been further developed, improving the functionality and making the system more user-friendly. The GIS allows the user to view several layers of data simultaneously i.e. CO_2 sources and potential CO_2 sinks and also allows extensive on-screen analysis of all the available data. The GIS can also provide visual representation of the data both on-screen and through the production of large and small scale images and printed maps. The database now covers 25 countries in Europe (including two countries covered in GESTCO but not updated in GeoCapacity), and a web-based GIS is available to the project partners. The GIS database also provides input for the DSS economic evaluations and overall, it has been the aim to produce work of such quality and detail that it sets the standard for building this type of GIS system.

4. The DSS economic evaluation method

The Decision Support System (DSS) software tool for economic evaluation of 'source–transport–storage' scenarios was also initially developed in the GESTCO project, and it has already set the standards for evaluation of source-sink scenario economics. New facilities developed in GeoCapacity include multi-source and multi-sink evaluations, a stochastic approach in calculations and web application of the tool.

5. Site selection criteria, screening and ranking of sites

The understanding of the basic geological/technical site selection criteria is important. A set of criteria for the selection of proper storage sites have been produced and they have been described together with their related geological/physical parameters in a dedicated report, Vosgerau et al. [2]. The basic site selection criteria used in GeoCapacity are:

- **Sufficient depth of reservoir** to ensure that CO_2 reach its supercritical dense phase but not so deep that permeability and porosity is too low.
- **Integrity of seal** to prevent CO_2 migrating out of the storage site.
- **Sufficient CO_2 storage capacity** to hold the required volumes of CO_2 from the source(s) e.g. lifetime emissions of a power plant.
- Effective **petrophysic reservoir properties (porosity and permeability)** to ensure CO_2 injectivity to be economically viable and that sufficient CO_2 can be retained.

Furthermore the process of screening for potential storage sites have been described as have examples of ranking identified sites.

6. Storage capacity estimation standards

Previous assessments of geological storage capacity of different countries, areas and regions have shown that the detail and quality of work is varied. In GeoCapacity we have been aiming at adapting and defining common standards in order to produce uniform assessments of geological storage capacity, Vangkilde-Pedersen et al. [3]. The work with establishing internationally recognised standards for capacity assessments was initiated by the Carbon Sequestration Leadership Forum (CSLF) about a year before the start of the GeoCapacity project and a CSLF Task Force has been active since. GeoCapacity has contributed to the work of the Task Force and has continued the progress on this issue in Europe. The applications of methodologies described by the CSLF, Bachu et al. [4], have already led to initiation of further work on defining the storage efficiency factor by the Task Force, proving the synergic effects between projects.

GeoCapacity has adopted a simplified version of the storage potential pyramid suggested by the CSLF with distinction between theoretical, effective and practical capacity estimates, see Figure 2. We have decided not to consider theoretical storage capacities (at least for saline aquifers) as these include large unrealistic and uneconomic volumes. The estimates in the GIS database will thus be effective storage capacity. For case studies performed and reported by individual countries the estimates will be effective or practical storage capacity.

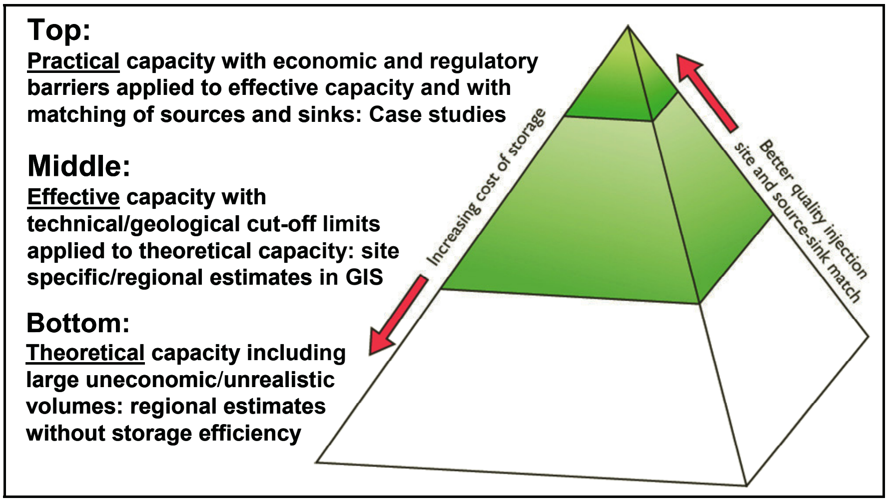

Figure 2: Simplified version of the storage potential pyramid suggested by CSLF.

Also for storage capacity calculations we have adopted the methodologies described by the CSLF or modifications hereof. The storage capacity methodologies used in GeoCapacity for deep saline aquifers, hydrocarbon fields and coal fields, respectively, are briefly described below:

Deep saline aquifers

The basic formula used for capacity estimation in deep saline aquifers is given in (1):

$$M_{CO2} = A \times h \times NG \times \phi \times \rho_{CO2r} \times S_{eff} \quad (1)$$

where:

M_{CO2}:	regional or trap aquifer storage capacity
A:	area of regional or trap aquifer
h:	average thickness of regional or trap aquifer
NG:	average net to gross ratio of regional or trap aquifer (best estimate)
ϕ:	average reservoir porosity of regional or trap aquifer (best estimate)
ρ_{CO2r}:	CO_2 density at reservoir conditions (best estimate)
S_{eff} :	storage efficiency factor (for regional or trap aquifer)

No advice is given by the CSLF on values of the storage efficiency factor which will be site-specific. In GeoCapacity we have chosen to distinguish between storage capacity estimates for regional aquifers and estimates for individual structural or stratigraphic traps.

For regional aquifers we suggest in GeoCapacity to use a storage efficiency factor of 2 % based on work by the US DOE. In Frailey [5], Monte Carlo simulations result in a P_{50} between 1,8 and 2,2 % for the storage efficiency factor of the bulk volume of a regional aquifer (with low and high values of 1 % and 4 %, respectively).

For individual structural or stratigraphic traps we have in GeoCapacity suggested different approaches. The most simple is a rule-of-thumb approach, assuming that the surrounding aquifer is an open or semi-closed system and suggesting storage efficiency values in the range between 3 % and 40 % for semi-closed low quality and open high quality reservoirs, respectively. Another approach is assuming closed aquifer systems and is based on trap to aquifer volume ratio, rock and water compressibility and allowable average pressure increase. This approach suggests a range of storage efficiency factors depending on depth (i.e. in fact pressure) and trap to aquifer volume ratio. For a reservoir at 2000 m depth, the respective storage efficiency factor for trap to aquifer volume ratios of 5, 10, 50 and 100 is 1 %, 2 %, 10 % and 20 % assuming a maximum allowable average pressure increase of 10 % of the hydrostatic pressure and a total compressibility (rock comp. + fluid comp.) of 10^{-4} bar^{-1}.

In summary the following guidelines are recommended for capacity estimation in deep saline aquifers:

- It is necessary to distinguish between estimates for regional aquifers and estimates for individual structural or stratigraphic traps
- The choice of storage efficiency factor for traps is partly dependent on whether the aquifer system is open, semi-closed or closed
- The choice of storage efficiency factor for traps can be based on either a rule-of-thumb approach for open and semi-closed aquifer systems or trap to aquifer volume ratios and allowable pressure increases for closed aquifer systems
- Storage capacity estimates should always be accompanied with information on assumptions and the approach taken

Hydrocarbon fields

The basic formulas used for capacity estimation in hydrocarbon fields are given in (2) for gas fields and (3) for oil fields:

$$M_{CO2} = \rho_{CO2r} \times R_f \times (1\text{-}F_{ig}) \times OGIP \times B_g \quad (2)$$

$$M_{CO2} = \rho_{CO2r} \times (R_f \times OOIP \times B_o - V_{iw} + V_{pw}) \quad (3)$$

where:

M_{CO2}:	hydrocarbon field storage capacity
ρ_{CO2r}:	CO_2 density at reservoir conditions (best estimate)

R_f : recovery factor
F_{ig}: fraction of injected gas
OGIP: original gas in place (at surface conditions)
B_g: gas formation volume factor << 1
OOIP: original oil in place (at surface conditions)
B_o: oil formation volume factor > 1
V_{iw}: volume of injected water
V_{pw}: volume of produced water

For a number of countries a simplified formula (4) from the GESTCO project has been used, Schuppers et al. [6]:

$$M_{CO2} = \rho_{CO2r} \times UR_p \times B \qquad (4)$$

where:

M_{CO2}: hydrocarbon field storage capacity
ρ_{CO2r}: CO_2 density at reservoir conditions (best estimate)
UR_p: proven ultimate recoverable oil or gas
B: oil or gas formation volume factor

In (4) UR_p in fact represents $R_f \times$ OGIP from (2) and $R_f \times$ OOIP from (3), respectively, but the formula does not take F_{ig}, V_{iw} and V_{pw} into account. UR_p is the sum of the cumulative production and the proven reserves and typically the methodology for calculating/estimating the proven reserves may vary a little from country to country.

The methodology used for hydrocarbon fields yield theoretical storage capacity according to the methodology described by CSLF. To reach effective storage capacity CSLF introduce a number of capacity coefficients representing mobility, buoyancy, heterogeneity, water saturation and aquifer strength, respectively and all reducing the storage capacity. However, there are very few studies and methodologies for estimating the values of these capacity coefficients and hence we have chosen in GeoCapacity not to distinguish between theoretical and effective storage capacity for hydrocarbon fields.

Within work package 3 of the GeoCapacity project a model for estimation of CO_2 storage capacities of oil reservoirs incorporating the production of additional oil associated to the CO_2 storage process, Bossie-Codreanu [7], has been developed. The model assumes miscible CO_2 flood (secondary or tertiary) prior to CO_2 storage without oil production. The model is based on the following steps:

1. Miscibility Test
   The model determines whether miscibility develops:
   - At the beginning of the CO_2 storage
   - At the end of the CO_2 storage: this pressure is usually the initial reservoir pressure at discovery
2. Oil recovery and CO_2 storage calculation under miscible conditions
   This step calculates oil recovery and CO_2 storage in two stages:
   - Until the breakthrough of the CO_2
   - After the breakthrough of the CO_2, assuming that CO_2 is recycled.
3. CO_2 storage without oil production
   This step accounts for the amount of CO_2 to be stored under a given pressure difference between the initial injection pressure and the final pressure, often chosen as the initial reservoir pressure at discovery.

This overall approach should be considered as an effort to estimate the co-optimization of CO_2 storage and as such should be considered as an intermediate model between a single formula and a complex modelling such as a numerical model. Thus the model is a rapid estimator of the oil recovery and the CO_2 storage capacity and can lead itself to quick parametric studies.

Coal fields

The basic formula used for capacity estimation in coal fields is given in (5):

$$M_{CO2} = PGIP \times \rho_{CO2r} \times ER \qquad (5)$$

where:

M_{CO2}: storage capacity
PGIP: producible gas in place
ρ_{CO2r} : CO_2 density
ER: CO_2 to CH_4 exchange ratio

and:

$$PGIP = (pure^*)\ coal\ volume \times coal\ density \times CH_4\ content \times completion\ factor \times recovery\ factor \qquad (6)$$

*(*excluding ash and moisture, if CH_4 content refers to pure coal samples)*

In (6) the completion factor represents an estimate of that part of the net cumulative coal thickness that will contribute to gas production or storage and recovery factor represents the fraction of gas that can be produced from the coal seams.

7. International cooperation

In addition, GeoCapacity have been aiming to work towards a structure for international cooperation especially with China, but also including countries like India and Russia. Focusing on technology transfer may help these countries to undertake similar studies, as they perhaps face an even greater challenge to reduce CO_2 emissions due to their rapidly growing energy demands. Thus, GeoCapacity has pioneered storage capacity estimation and GIS mapping in China through a comprehensive study of the Hebei Province located close to Beijing and partly in the Bohai Bay sedimentary basin. A GIS database has been build for the Hebei Province in parallel with the GIS work in Europe and will be covering further provinces around Beijing as other projects such as the EU funded COACH project and the UK-NZEC project evolves.

8. Conclusions

The combined efforts of the many partners in GeoCapacity will provide a detailed and comprehensive GIS database with emission, infrastructure and storage data for Europe. A preliminary summary of results is shown in Table 1 and in Figure 3 is an illustration of the content of the GeoCapacity database. The preliminary summary in Table 1 comprises all potential CO_2 storage capacity currently included in the database and hence should be regarded an optimistic estimate of European storage capacity. The final results of the study will be summarized at the completion of the project in public work package reports. Based on individual assessments the public reports will include conservative storage estimates country by country and hence also a more conservative European summary of storage capacity.

It is our hope and intention that the technical and geological results of GeoCapacity will provide a solid foundation on which the application of the CCS concept in Europe can be judged, and – hopefully – found sufficiently sound to warrant wider application.

Table 1: Preliminary summary of GeoCapacity results.

Annual CO_2 emissions from large point sources, (Mt)	**CO_2 storage capacity in deep saline aquifers, (Mt)**	**CO_2 storage capacity in hydrocarbon fields, (Mt)**	**CO_2 storage capacity in coal fields, (Mt)**
2,000	**325,000**	**30,000**	**1,500**

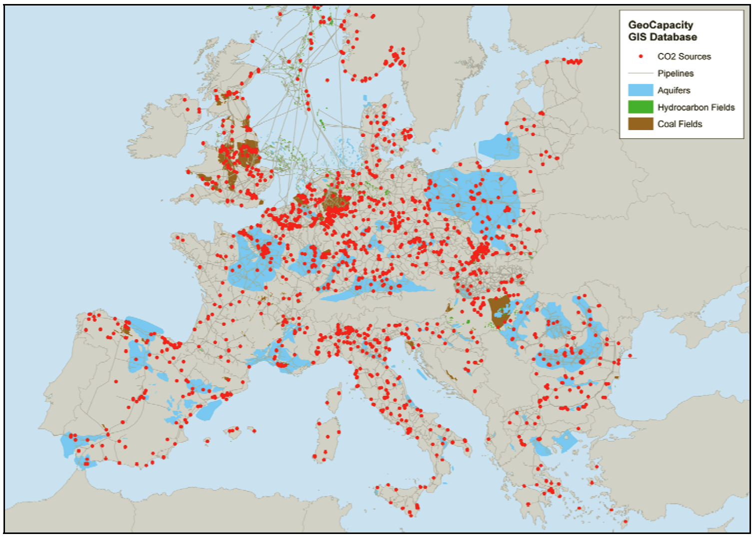

Figure 3: Illustration of the content of the GeoCapacity database.

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