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EU GeoCapacity

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Contents

Introduction	4
Project description	5
The GeoCapacity project consortium	6
Organisation.....	6
Work package structure	8
Work Package 1: Inventory of emissions and infrastructure, GIS	9
Work Package 2: Storage capacity	9
Work Package 3: Economic uses of CO ₂	10
Work Package 4: Standards and site selection criteria	10
Work Package 5: Economic evaluations	10
Work Package 6: International Cooperation.....	10
Work Package 7: Project Management and Reporting.....	10
WP 1 Inventories and GIS	11
WP 1.1 CO ₂ Emission Inventory	11
WP 1.2 Project GIS.....	11
WP 1.3 Maps of Emissions and Storage Sites	12
Deliverables	18
WP 2 Storage Capacity	19
Work package 2.1-2.4.....	19
Deliverables	20
WP 3 Economic Uses of CO₂	22
WP 3.1 Storage Capacity in Hydrocarbon Fields	22
WP 3.2 Storage Capacity in Coal Beds.....	23
Deliverables	24
WP 4 Standards and Site Selection Criteria	25
WP 4.1 Site Selection Criteria.....	25
WP 4.2 Storage Capacity Standards.....	25
Deliverables	26
WP 5 Economic Evaluations	27
WP 5.1 DSS Development.....	27
WP 5.2 Economic Evaluations	28
Deliverables	28
WP 6 International Co-operation	29
WP 6.1 Initiation of Technology Transfer in China	29
WP 6.2 Framework for International Co-operation	30
Deliverables	31

WP 7 Project Management and Reporting	32
WP 7.1 Overall Project Management	32
WP 7.2 Reporting	33
Reporting to the EU	33
Website	33
Reporting	33
WP1	34
WP2	34
WP3	34
WP4	34
WP5	35
WP6	35
WP7	35
Use and dissemination of knowledge	36
Conclusion	37

Introduction

EU GeoCapacity is an acronym for Assessing European Capacity for Geological Storage of Carbon Dioxide. The GeoCapacity project is a 3 year project and started on January 1st 2006 and ended on December 31st 2008.

This report is the Publishable Final Activity Report of the EU GeoCapacity project. The study has been carried out by 26 partners in 21 countries and a large number of individuals in the many involved organisations have contributed to the project. Furthermore a large number of institutions and organisations outside the project consortium have contributed with data to the project.

The project is co-funded by the EU within FP6 - the 6th Framework Programme of the European Community for Research, Technological Development and demonstration activities, contributing to the creation of the European Research Area and to innovation (2002 to 2006). The total budget is 3,5 million Euro and the contribution from the European Commission amounts to 1,9 million Euro.

A website has been established that contains available public information. The website address is www.geocapacity.eu and will be updated until the end of 2009 and accessible until the end of 2018.



Project description

The main objective of the project is to assess the European capacity for geological storage of CO₂. The project includes full assessment of a number of countries not covered before, and updates of previously covered territory, see Table 1 and Figure 1. Other priorities have been the further development of innovative methods for capacity assessment, economic modelling and site selection criteria. Finally, an important mission has been to initiate scientific collaboration with China and other CSLF members.

The GeoCapacity project comprises most European sedimentary basins suitable for geological storage of CO₂ and located within the EU member states. The detailed objectives of the project are:

- Full assessment of countries not previously covered
- Update of GESTCO and CASTOR countries
- Inventory of major CO₂ emission point sources and infrastructure
- Assessment of regional and local potential for geological storage of CO₂ in:
 - deep saline aquifers
 - hydrocarbon fields (incl. EOR/EGR)
 - coal fields (incl. ECBM)
- Technical site selection criteria and methodology for ranking
- Contribution to guidelines for assessment of geological storage capacity
- Analysis of source – transport – sink scenarios and economical evaluations
- Further development of mapping and analysis methodologies (GIS/DSS)
- Collaboration with China and other CSLF countries e.g. India and Russia

Table 1: Type of capacity assessment in the participating countries.

<i>Country</i>	Bulgaria Croatia Czech Republic Estonia Hungary Italy Latvia Lithuania Poland Romania Slovakia Slovenia Spain	Albania Macedonia (FYROM) Bosnia-Herzegovina Luxemburg	Germany Denmark United Kingdom France Greece The Netherlands	CSLF collaboration: • China • (later India) • (later Russia)
<i>Type of Capacity Assessment</i>				
Full Country Evaluation				
Neighbour Country Review				
Country Update				
International Cooperation				

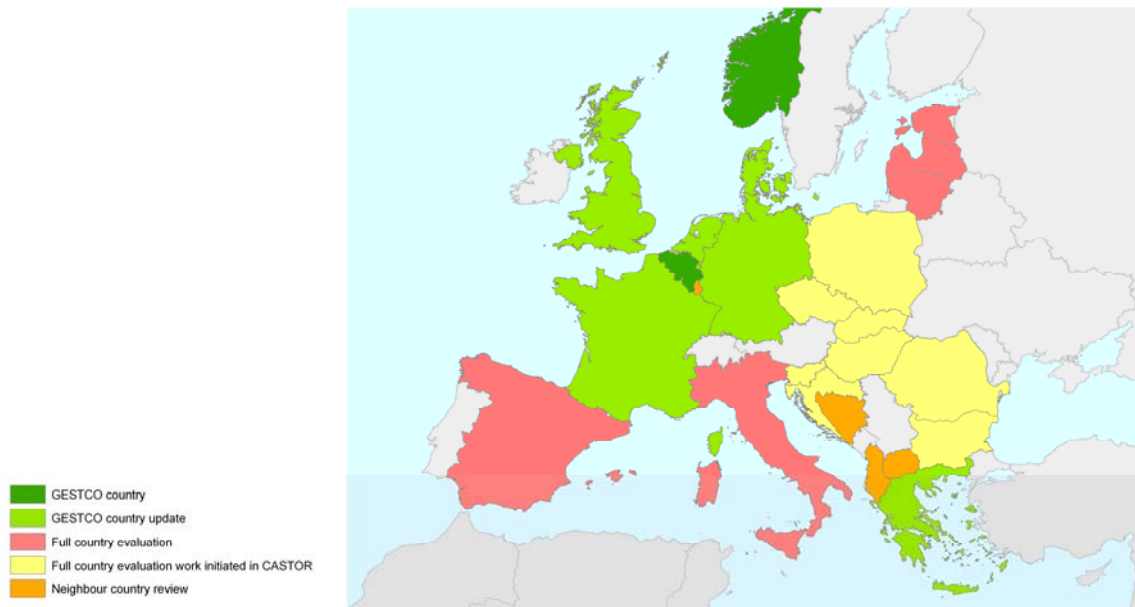


Figure 1: Overview of participating countries.

The GeoCapacity project consortium

The GeoCapacity project consortium includes 26 partners – geological surveys and a range of other research partners throughout Europe – and has been in a unique position to carry out this R&D study (see Table 2). The surveys and other state institutes have over decades, and in some instances for more than a century, studied and mapped the distribution and composition of hard rocks and sediments in the subsurface. The project partners thus have access to large amounts of accumulated knowledge of the subsurface geology of Europe obtained from work with mineral exploitation, geothermal studies, hydrocarbon activities such as seismic mapping and drilling for oil. The variety of maps, other data and previous work have made it possible for the project partners to produce reasonable evaluations of the CO₂ storage capacity of the selected representative study areas.

Organisation

The organisational structure of the project is depicted in the diagram in Figure 2. Steering committee meetings have been held twice per year together with general work meetings.

The Coordinator the Geological Survey of Denmark and Greenland, GEUS have overseen all activities and made working relationships and agreements with all of the other partners. GEUS have also led the work with assessment of geological storage capacity and the work on capacity standards and site selection criteria.

The British Geological Survey, BGS have led all work relating to GIS and Institute Francais du Petrole, IFP the work with evaluations of storage potential in hydrocarbon and coal fields. The Geological Survey of the Netherlands, TNO have led the development of DSS

and the economic work and Bureau de Recherche de Geologie et Miniere, BRGM the international cooperation.

An End-User Advisory Group - comprising potential end-users has followed the work and had access to work meetings and website.

Table 2: Partners in the GeoCapacity project consortium.

Partic. Role *	Partic. Number	Participant Name	Participant Short name	Country
CO	1	Geological Survey of Denmark and Greenland	GEUS	Denmark
CR	2	University of Sofia	US	Bulgaria
CR	3	University of Zagreb	RGN	Croatia
CR	4	Czech Geological Survey	CGS	Czech Republic
CR	5	Institute of Geology at Tallinn University of Technology	IGTUT	Estonia
CR	6	Bureau de Recherche de Geologie et Miniere	BRGM	France
CR	7	Institute Francaise du Petrole	IFP	France
CR	8	Bundesanstalt für Geologie und Rohstoffen	BGR	Germany
CR	9	Institute for Geology and Mining Engineering	IGME	Greece
CR	10	Eötvös Loránd Geophysical Institute of Hungary	ELGI	Hungary
CR	11	Istituto Nazionale Oceanografie e Geofisica Sperimentale	OGS	Italy
CR	12	Latvian Environment, Geology & Meteorology Agency	LEGMA	Latvia
CR	13	Institute of Geology and Geography	IGG	Lithuania
CR	14	Geological Survey of the Netherlands	TNO-NITG	Netherlands
CR	15	Ecofys	Ecofys	Netherlands
CR	16	Academy of Science (MEERI)	MEERI	Poland
CR	17	Geophysical Exploration Company	PBG	Poland
CR	18	GeoEcoMar	GeoEcoMar	Romania
CR	19	Dionyz Stur State Geological Institute	SGUDS	Slovakia
CR	20	GEOINZENIRING	GEO-INZ	Slovenia
CR	21	Instituto Geologico y Minero de Espana	IGME	Spain
CR	22	British Geological Survey	BGS	UK
CR	23	EniTecnologie (Industry Partner)	ENI	Italy
CR	24	ENDESA Generacion (Industry Partner)	Endesa	Spain
CR	25	Vattenfall Utveckling AB (Industry Partner)	VUAB	Sweden
CS	26	Tsinghau University	TU	P. R. CHINA

* CO = Co-ordinator, CR = Contractor, CS = Contractor; partnership built through the CSLF

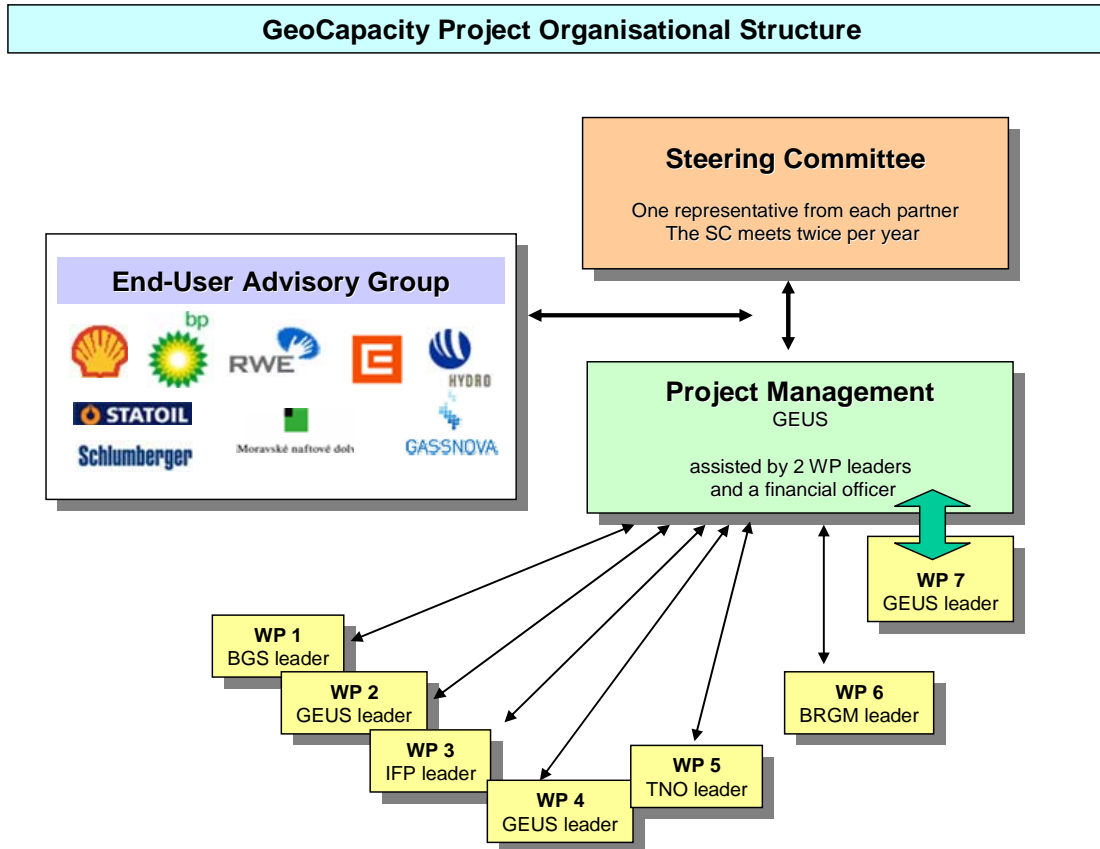


Figure 2: Organisational structure of the GeoCapacity project.

Work package structure

The focus of the GeoCapacity project is GIS mapping of CO₂ point sources, infrastructure and geological storage in Europe. The main objective is to assess the European capacity for geological storage of CO₂ 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 include 26 countries and comprise most European sedimentary basins suitable for geological storage of CO₂.

The Work in GeoCapacity has been structured in 7 work packages (see also Figure 3):

- WP1: Inventory of emissions and infrastructure, GIS
- WP2: Storage capacity
- WP3: Economic use of CO₂
- WP4: Standards and site selection criteria
- WP5: Economic evaluations
- WP6: International cooperation
- WP7: Project management and reporting

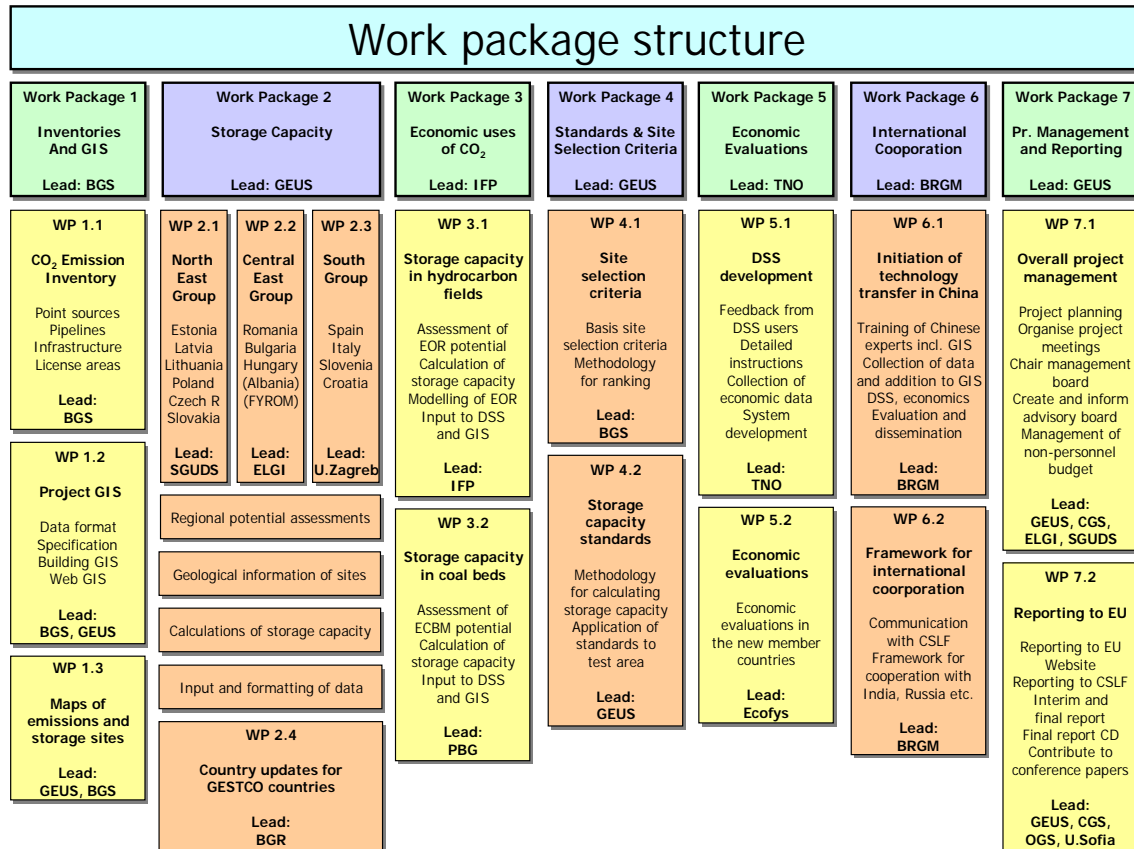


Figure 3: Work package structure of the GeoCapacity project.

Work Package 1: Inventory of emissions and infrastructure, GIS

The scope of WP1 is collation of point source CO₂ emissions greater than 100,000 tonnes per year in all of the territories involved in the project (limited to a test area in China). Emission data and information regarding plant characteristics, pipelines and other infrastructure are entered into a project dedicated Geographical Information System (GIS) and the construction of the GIS is also part of this WP. The use of data for China will be regulated by relevant Chinese procedures.

Work Package 2: Storage capacity

This is the main WP dealing with assessment of CO₂ storage potential, in all of the involved European countries, with a particular emphasis on the countries not previously covered. Emphasis is on aquifer capacity as hydrocarbon fields and coal beds are covered in WP3. Capacity estimates are made on a national/regional basis as well as on a more detailed level in two case studies for each country. The work is coordinated in three regional groups and a fourth group of updating countries previously part of the GESTCO project.

Work Package 3: Economic uses of CO₂

As a supplement to the aquifer capacity work of WP2, an assessment is made of the potential for use and storage of CO₂ in hydrocarbon structures combined with CO₂ EOR and in deep coal beds combined with ECBM. The main emphasis is on storage capacity, while simultaneously looking for early opportunities for CO₂ activities with better economies than basic storage.

Work Package 4: Standards and site selection criteria

This key activity comprises two important issues. One is defining the technical criteria for selection of suitable and safe sites for long term storage of CO₂ for a wide range of geological conditions. The other, also of wide reaching importance, is to improve methodologies for assessment of geological storage capacity, thus providing a set of standards for this and future projects. Part of the work is carried out in synergy with the CSLF Task Force for Review and Identification of Standards for CO₂ Storage Capacity Estimation.

Work Package 5: Economic evaluations

The main effort is on improving the Decision Support System software, making it capable of more complex assessments while also making it much more user-friendly. This economic evaluation tool – combined with the GIS – already constitutes the most advanced tool of its kind and is further improved in the project. Finally, it is used for economic evaluation of the many national source-transport-storage scenarios resulting from the case studies in WP2.

Work Package 6: International Cooperation

The work is defined specifically to strengthen collaboration between the EU and the CSLF. Activities focus on technology transfer to China and initiation of cooperation with India and Russia. A Chinese part of the GIS database is established.

Work Package 7: Project Management and Reporting

The scope is planning and execution of project activities and facilitation of partner collaboration. Effort is also dedicated to liaison with the project industry partners and the End-User Advisory Group. Reporting to the EU is co-ordinated from this WP, as well as early creation of a project website.

WP 1 Inventories and GIS

Work package 1 includes the following sub work packages:

- WP 1.1 with the purpose of establishing an inventory of CO₂ point sources with emissions above 0.1 Mt/year as well as infrastructure such as pipelines and urban centres.
- WP 1.2 with the purpose of building a GIS system including guidelines and specification of format for data input from partners.
- WP 1.3 with the purpose of producing regional maps of emissions and storage sites to help enable the process of source and sink matching.

The results of WP 1 are described in detail in technical reports and in the public report D8 WP 1 Report, Inventories and GIS.

WP 1.1 CO₂ Emission Inventory

Data specification and database templates were sent out to all partners for population. All CO₂ source data was collated by each partner country and entered into the database templates.

The base map data within the project includes country boundaries, major urban areas, lakes, rivers, roads and railways. For China province boundaries are also included.

The CO₂ emission source database includes data from sources with emissions of 0.1 Mt of CO₂ per year and above and contains information on the location as well as emissions and technical details such as full load hours, capacity, emission factor, technology and fuel type etc. In Table 3 in the chapter on WP2 is given the CO₂ emissions in the database by country.

The location of existing pipelines and pipeline terminals which could represent potential routes for new pipelines and easy access on and offshore for those pipelines is also included in the GIS.

WP 1.2 Project GIS

The Geocapacities GIS has been developed using ESRI's ArcGIS 9.2 software and all available project data is accessible via the GIS either as viewable data or through links from the GIS to external files. The data specification and format was developed and produced by BGS based on lessons learned from the GESTCO project. The database templates were developed in Microsoft Access 2003 and included forms designed to guide the user through the data input procedure.

New databases were designed for use for the DSS which are to be supplied to TNO who are developing the module. These new databases include additional data that is required for calculations within the DSS, for example, standard deviation values in addition to the original average values that have been supplied. The original data provided by partners was uploaded to these new databases and the databases were returned to partners with a request for any additional data that they could enter into the new attribute fields within the databases.

Line and polygon datasets were also collected and compiled into merged datasets to cover the project area. These included polygons indicating the extent of the sinks and a pipeline dataset.

The GIS allows users to simultaneously view one or more layers of data including the location of the CO₂ sources and potential CO₂ sinks. These individual layers can be turned on and off and zoomed in or out to depending on what the user specifically wants to show or view. It also enables the user to perform extensive onscreen analysis on all the available data. Geoscience datasets included in the GIS comprise:

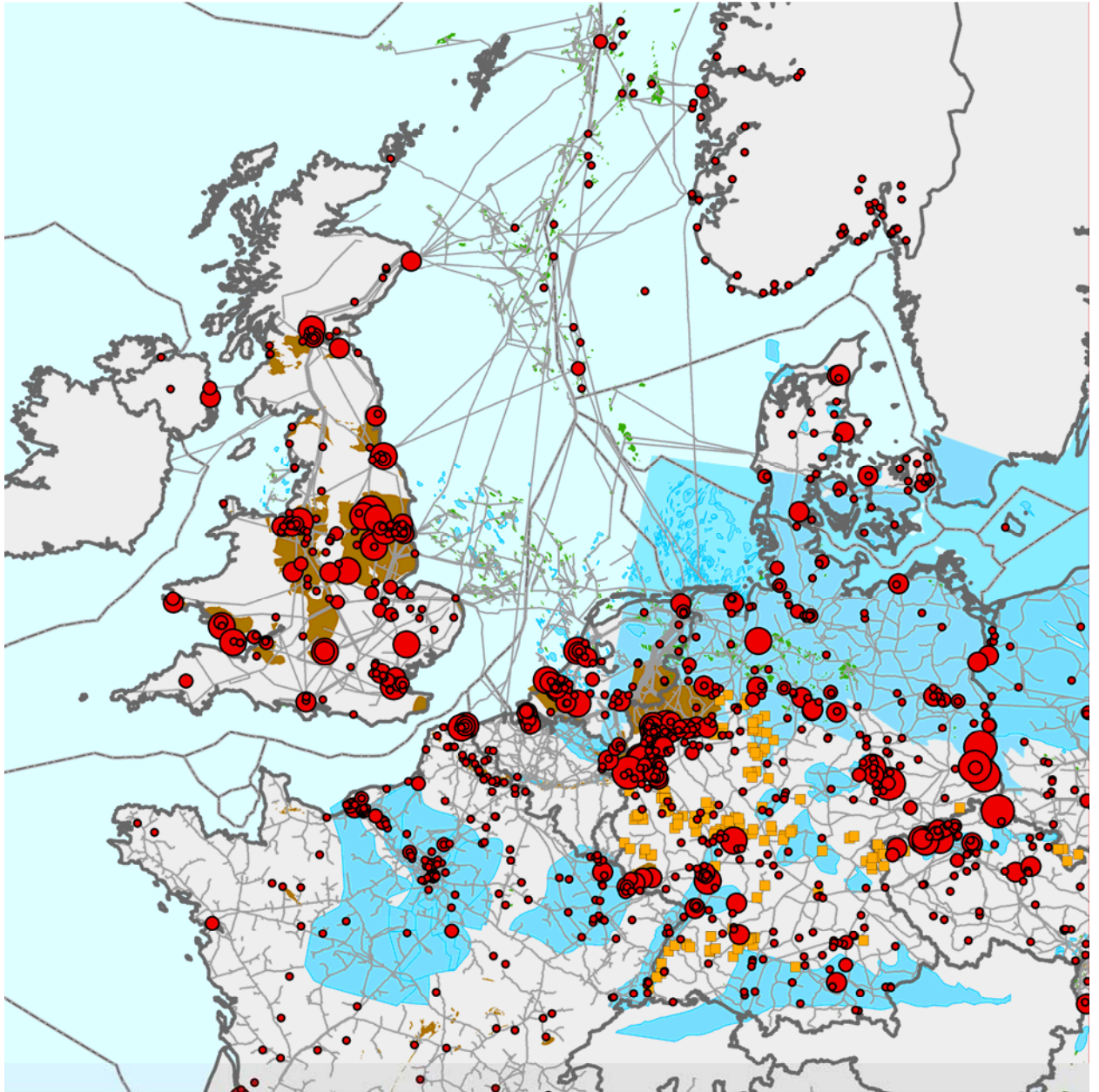
- CO₂ sources locations
- potential aquifer storage sites
- potential aquifer injection points
- hydrocarbon field locations
- hydrocarbon field injection points
- coal fields
- potential coal field injection points
- existing pipelines and pipeline terminals
- natural sources of CO₂

WP 1.3 Maps of Emissions and Storage Sites

Maps of emissions and storage sites to help source-sink matching have been developed and produced by GEUS based on the final GIS database provided by BGS. Detailed maps for each country have been produced as well as five regional maps:

- Northwest Europe
- Northeast Europe
- Central East Europe
- Southwest Europe
- Southeast Europe

The regional maps are shown in Figure 4 to Figure 8 below.



GeoCapacity maps of Sources & Sinks

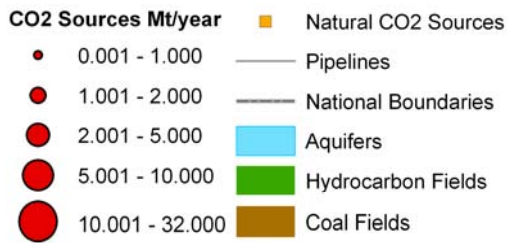
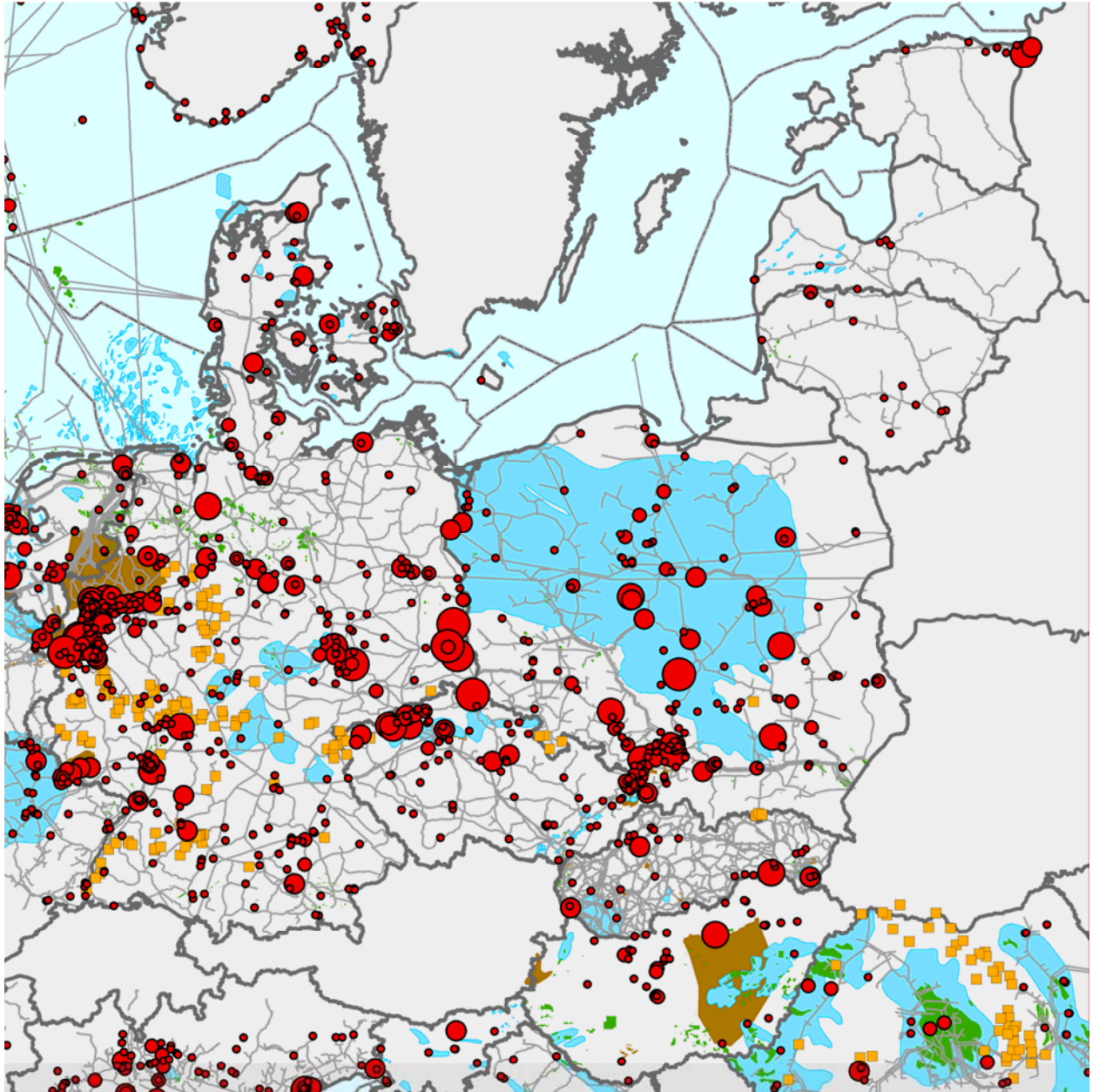


Figure 4: Map of CO₂ emissions, infrastructure and storage capacity in Northwest Europe.



GeoCapacity maps of Sources & Sinks

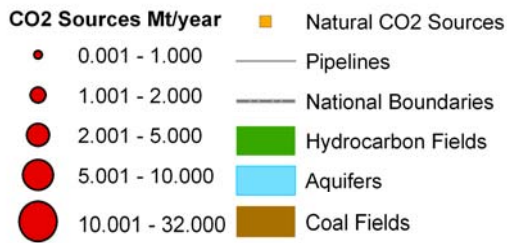
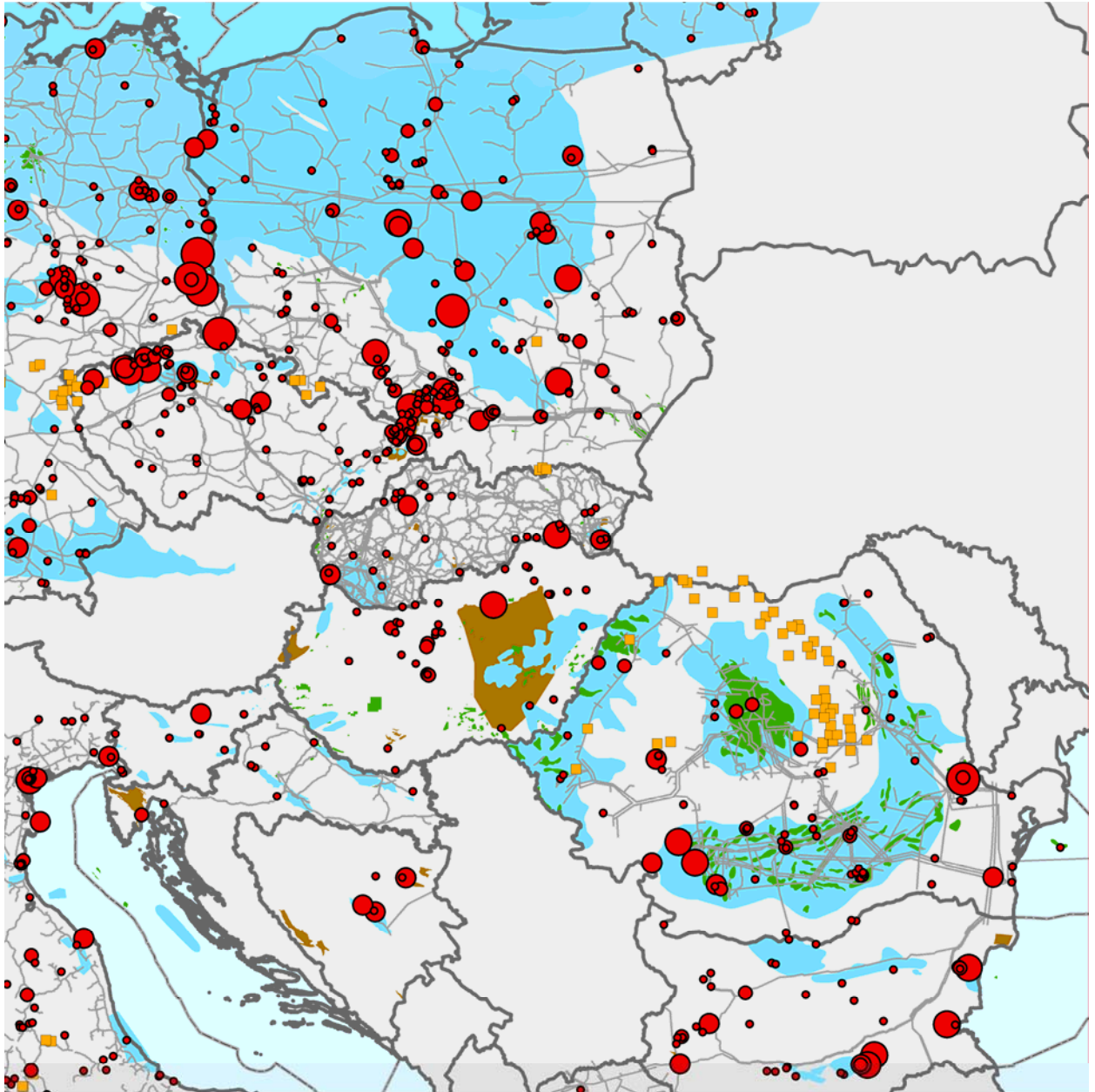


Figure 5: Map of CO₂ emissions, infrastructure and storage capacity in Northeast Europe.



GeoCapacity maps of Sources & Sinks

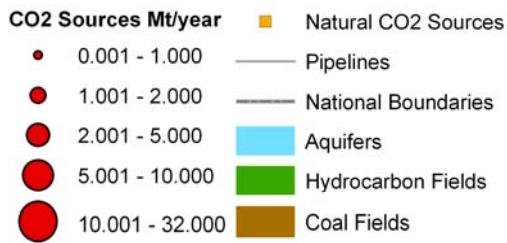
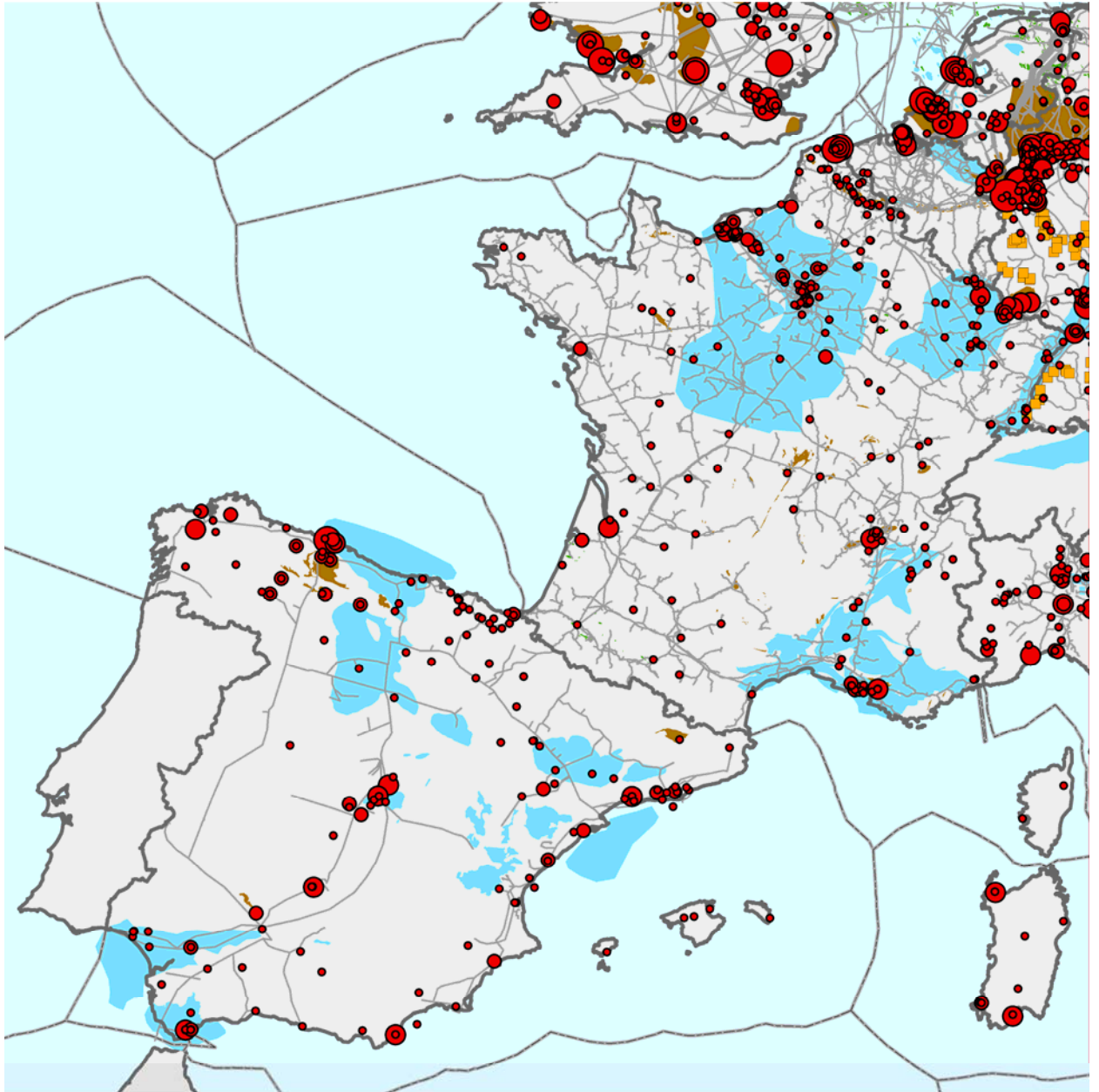


Figure 6: Map of CO₂ emissions, infrastructure and storage capacity in Central-East Europe.



GeoCapacity maps of Sources & Sinks

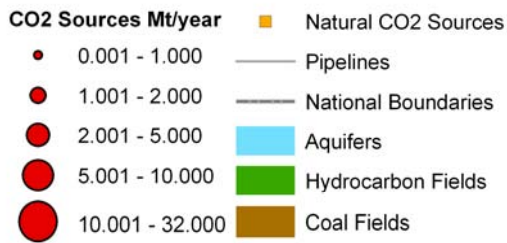
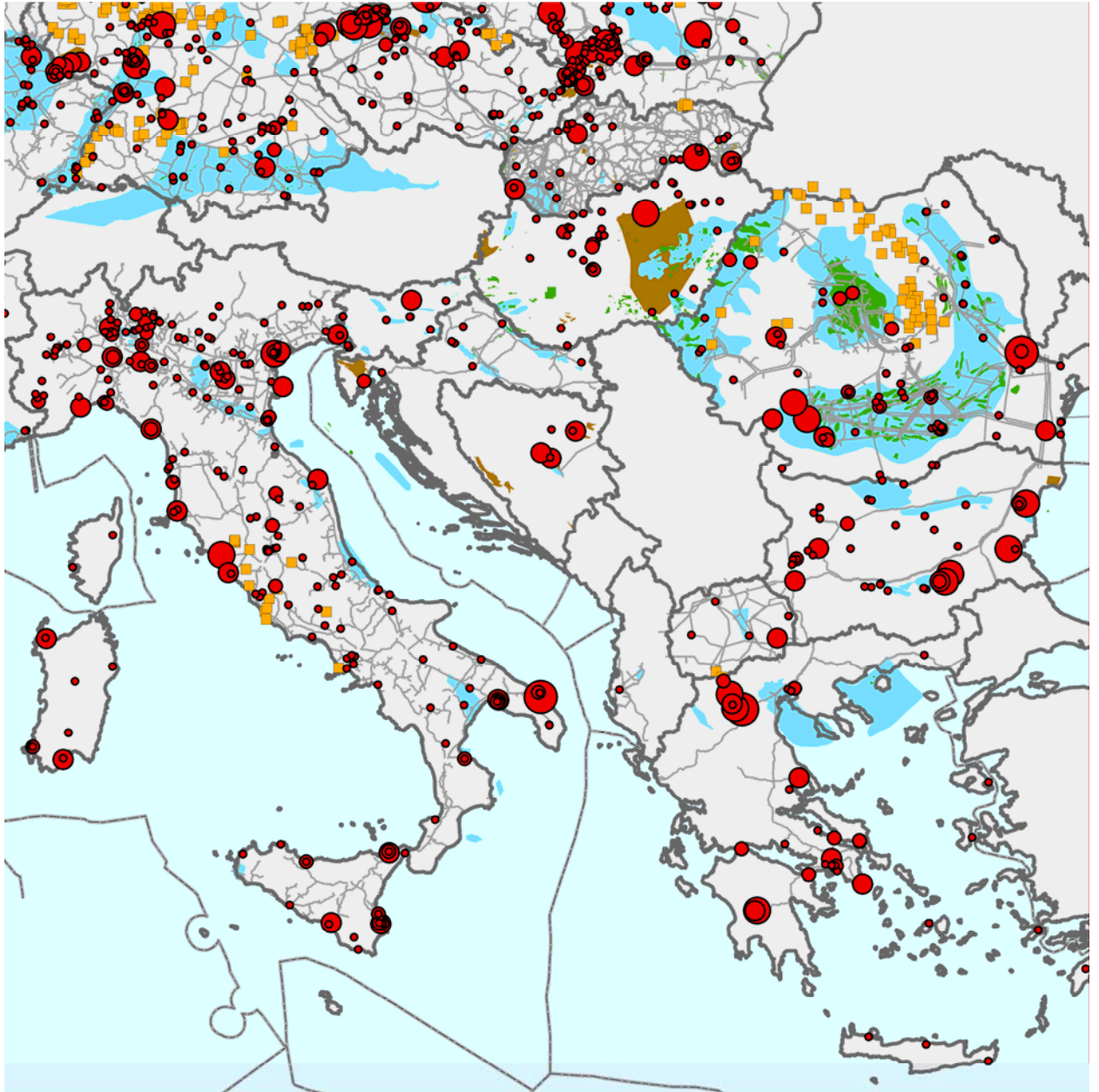


Figure 7: Map of CO₂ emissions, infrastructure and storage capacity in Southwest Europe.



GeoCapacity maps of Sources & Sinks

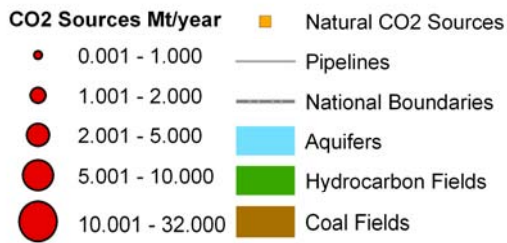


Figure 8: Map of CO₂ emissions, infrastructure and storage capacity in Southeast Europe.

Deliverables

A total of nine deliverables were included in WP 1:

- D1 Data Specification
- D2 Questionnaire
- D3 Inventory of point sources
- D4 Infrastructure data
- D5 Project GIS
- D6 Web enabled GIS
- D7 Sink source maps
- D8 WP 1 Report
- D9 GIS user manual

The deliverables D1, D2, and D9 are technical reports only available for the partners of the project consortium. D2 is described in the D1 report. The deliverables D3, D4 are data input to the GIS and D5 and D6 is the project GIS itself and a web enabled GIS and also only available to the consortium. Deliverables D7 and D8 are a collection of maps and a summary report of the work carried out in the work package, respectively and publicly available from the project website: www.geocapacity.eu.

WP 2 Storage Capacity

In work package 2 the participating countries have been divided into three geographical groups facilitating regional cooperation. The groups comprise new countries and countries previously participating in the CASTOR project and work initiated in CASTOR has been continued and further detailed in GeoCapacity. A fourth group consists of countries previously part of the GESTCO project and they have been updating, supplementing and detailing their country profiles in the GeoCapacity project. Thus work package 2 includes the following sub work packages:

- WP 2.1 covering Slovakia, Estonia, Latvia, Lithuania, Poland and Czech Republic.
- WP 2.2 covering Hungary, Romania, Bulgaria and Albania and FYROM (both covered by Greece).
- WP 2.3 covering Croatia, Spain, Italy, Slovenia and Bosnia-Herzegovina (covered by Croatia).
- WP 2.4 covering Germany (also including Luxemburg), The Netherlands, France, Greece, United Kingdom and Denmark.

The results of WP 2 are described in detail in technical reports and in the public report D16 WP 2 Report, Storage Capacity.

Work package 2.1-2.4

Work package 2.1-2.4 all include regional assessment and calculation of potential CO₂ storage in saline aquifers, hydrocarbon fields and coal beds as well as input of geological information to the GIS database. All new and previous CASTOR countries in the first three geographical groups have carried out the following tasks in WP2:

- Performed a regional screening for potential CO₂ storage sites/storage possibilities in saline aquifers, hydrocarbon fields and coal beds etc.
- Provided geological information from the potential storage sites.
- Calculated the regional storage capacity for each country using the methodology agreed in WP4.
- Provided the data requested in WP1 for the GIS database in the specified project format.
- Described two case studies in terms of more detailed information of the storage sites and the capture - storage scenarios for economic modelling in WP5.

The fourth group of previous GESTCO partners have updated their country profiles and provided updated and new capacity estimates and data for the GIS.

The resulting GeoCapacity GIS database include a total storage capacity of 360 Gt with 326 Gt in deep saline aquifers, 32 Gt in depleted hydrocarbon fields and 2 Gt in unmineable coal beds. 116 Gt is onshore storage capacity and 244 Gt is offshore storage capacity. Some of the estimated storage capacity is associated with geological trap structures, but a

large part is in regional deep saline aquifers without identification of specific trap structures. Almost 200 Gt of the total storage capacity in the database is located offshore Norway and these estimates are dating back to the GESTCO project in 2003 and have not been updated in the GeoCapacity project.

The GeoCapacity GIS is a comprehensive database of European storage capacity, but it does not necessarily represent all available storage capacity in each country. It rather represents the extent of work and level of detail which has been possible within the available economic frame of the project. On the other hand, not all storage capacity in the database may necessarily be equally exploitable. As a supplement to the capacity estimates in the database more cautious and conservative estimates for each country have therefore been provided. Thus, in the summary of European storage capacity given in Table 3 below are used only the conservative estimates as they probably give the most realistic picture of storage capacity that can be realized in Europe. For Norway and Belgium which were not updated as part of the GeoCapacity project the conservative estimates has been estimated from the GESTCO values included in the database using the same ratio between database and conservative estimates as for Denmark.

The sum of the conservative storage capacity estimates in Table 3 is 96 Gt CO₂ in deep saline aquifers, 20 Gt in depleted hydrocarbon fields and 1 Gt in unmineable coal beds. This totals 117 Gt CO₂ of conservative European storage capacity of which approx. 25 % is offshore Norway in mainly deep saline aquifers. These figures must be compared to a total of 1,9 Gt of CO₂ emissions from large point sources emitting more than 0.1 Mt/year. Thus the conservative storage capacity estimate of 117 Gt CO₂ corresponds to 62 years of storage of the 1,9 Mt yearly emissions of CO₂ from large point sources emitting more than 0.1 Mt/year.

Deliverables

A total of seven deliverables were included in WP 2:

- D10 Maps of regional storage potential
- D11 Geological information of storage sites
- D12 Storage capacities
- D13 Data for project GIS
- D14 Case Study Scenarios
- D15 Country Updates
- D16 WP 2 Report

Deliverable D10 is a collection of maps of very preliminary regional storage capacity and deliverable D11, D12, D13 and D15 are data input to the GIS. D11 and D12 have furthermore been produced as a combined technical report on saline aquifers as well as D14 is produced as a technical report on the case studies. All deliverables are only available to the consortium except deliverable D16 which is the summary report of the work carried out in the work package and which is publicly available from the project website: www.geocapacity.eu.

Table 3: European summary of CO₂ emissions and storage capacity estimates.

Country	Annual total emissions of CO ₂ (Mt)	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)
Slovakia	46	23	1716	-	-
Estonia	21	12	-	-	-
Latvia	4	2	404	-	-
Lithuania	18	6	30	7	-
Poland	325	188	1761	764	415
Czech Republic	128	78	766	33	54
Hungary	79	23	140	389	87
Romania	74	67	7500	1500	-
Bulgaria	52	42	2100	3	17
Albania	0	0	20	111	-
FYROM	6	4	390	-	-
Croatia	23	5	2710	189	-
Spain	423	158	14000	34	145
Italy	212	140	4669	1810	71
Slovenia	20	7	92	2	-
Bosnia-Herzegovina	-	9	197	-	-
Germany	864	465	14900	2180	-
Luxemburg	-	-	-	-	-
The Netherlands	180	92	340	1700	300
France	-	131	7922	770	-
Greece	110	69	184	70	-
United Kingdom	555	258	7100	7300	-
Denmark	52	28	2553	203	-
Norway	-	28	26031	3157	-
Belgium	-	58	199	-	-
Total	-	1893	95724	20222	1089

WP 3 Economic Uses of CO₂

Work package 3 includes the following sub work packages:

- WP 3.1 with the purpose of assessing the CO₂ storage capacity in hydrocarbon fields and the potential for enhanced oil and gas recovery (EOR/EGR) as well as modelling of EOR in few chosen fields.
- WP 3.2 with the purpose of assessing the CO₂ storage capacity in unmineable coal beds and the potential for enhanced coal bed methane production (ECBM).

The results of WP 3 are described in detail in technical reports and in the public report D22 WP 3 Report, Economic uses of CO₂.

WP 3.1 Storage Capacity in Hydrocarbon Fields

The work in WP3.1 have included geological descriptions of the hydrocarbon fields in each country and assessment of their possible use and capacity for CO₂ storage as well as collation and input of data on hydrocarbon field storage to the GIS database.

The CO₂ storage capacity in hydrocarbon fields in the GeoCapacity database are calculated using either the methodology described by the Capacity estimation task force of the CSLF or the simplified formula from the GESTCO project. Both are described in more detail in technical reports of WP3 and WP4 and in the public reports D22 WP3 Report, Economic uses of CO₂ and D26 WP4 Report, Capacity standards and site selection criteria.

The methodology used for hydrocarbon fields yield theoretical storage capacity according to the methodology described by the 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.

The storage capacity of hydrocarbon fields is given in Table 3 in the WP 2 chapter.

Also in WP3.1 IFP has developed a model for estimation of CO₂ storage capacity in oil reservoirs incorporating the production of oil associated with enhanced oil recovery (EOR). The model assumes miscible CO₂ flood (secondary or tertiary) prior to CO₂ 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 CO₂ storage
- At the end of the CO₂ storage: this pressure is usually the initial reservoir pressure at discovery

2) Oil recovery and CO₂ storage calculation under miscible conditions

This step calculates oil recovery and CO₂ storage in two stages:

- Until the breakthrough of the CO₂
- After the breakthrough of the CO₂, assuming that CO₂ is recycled

3) CO₂ storage without oil production

This step accounts for the amount of CO₂ 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 CO₂ storage and EOR and as such should be considered as an intermediate model between a single formula and complex modelling such as a numerical model. Single formula expressions either set a given storage factor (e.g. 6% for aquifers) or in oil fields considers the replacement of oil produced by the injected CO₂ without any consideration for the additional oil which could be produced by EOR. Such formulas may oversimplify the CO₂ problem, but on the other hand, numerical modelling requires a rich database, making the study too long for quick estimations. This model is a rapid estimator of the oil recovery and the CO₂ storage capacity and can lead to quick parametric studies.

Using data provided by Polish, Czech and Danish partners of the project, the model was applied to estimate the CO₂ storage capacity. Data were also received from Croatia, but for the Croatian fields, the miscibility pressure being higher than the initial reservoir pressure, the model could not apply.

WP 3.2 Storage Capacity in Coal Beds

The work in WP3.2 have included geological descriptions of the coal fields in each country and assessment of their possible use and capacity for CO₂ storage as well as collation and input of data on coal field storage to the GIS database.

In order to assess the CO₂-ECBMR potential (Enhanced Coal-Bed Methane Recovery with the use of CO₂ storage) of un-mined coal fields, the approach and methodology already applied in the GESTCO project were employed. The methodology are described in more detail in technical reports of WP3 and WP4 and in the public reports D22 WP3 Report, Economic uses of CO₂ and D26 WP4 Report, Capacity standards and site selection criteria.

Prospects for CO₂ usage in coal fields exist in Czech Republic, Hungary, Poland and Spain and the capacity has been assessed based on either large individual fields or smaller coal basins. Some potential might exist in one area in Romania, but the geological conditions

are rather unsuitable. Croatia and Slovakia have shallow and small coal fields, beyond the range of the economic use for CO₂-ECBMR. Estonia, Lithuania and Latvia have no coal resources (neither hard coal, nor brown coal nor lignite). For Bulgaria, Slovenia and Italy the assessments were made during the second part of the work package.

In the second part of the work package more detailed calculation of the amounts of CO₂ that could be stored in coal beds during possible future CO₂-ECBMR operations was performed. Storage capacity was recalculated for smaller areas of coal fields and basins, more likely suitable for ECBM. For two countries, Bulgaria and Italy, studies on storage capacity for coal fields were included as data became available.

Simultaneously, analyses using the CoalSeq ECBM screening simulator by ARI were carried out. This tool makes it possible to present general CO₂-ECBMR production scenarios, particularly assessing the amount of methane production after injecting a certain amount of carbon dioxide. Information on coal permeabilities, coal rank, depth of coal beds in question, estimations of injection rate and spacing between injection and production wells were collected for a number of scenarios, relevant to particular coal fields in WP3.2 countries.

After analyzing CoalSeq options it followed that the highest methane 'production' occurs when the project area (spacing) is the smallest, i.e. when respective injection and production wells spacing are not greater than 40 m. The 'production' means a difference between a base case (no injection) and a continuous injection timing for a period of 15 years (production due to ECBMR application only, within a given period).

It also seems from CoalSeq simulations that medium to low volatile coals might be more interesting from an economic point of view of CO₂-ECBMR than others, provided they have sufficient reservoir properties, i.e. not a very low permeability. The simulations also suggest rather more conservative recovery ratios for CO₂-ECBMR (up to 0.4 in case of medium to low volatile coals) than previously assumed.

Deliverables

A total of six deliverables were included in WP 3:

- D17 Potential for CO₂ use in hydrocarbon fields
- D18 Potential for CO₂ use in coal beds
- D19 GeoCapacity economic use of CO₂ in hydrocarbon fields
- D20 GeoCapacity economic use of CO₂ in coal beds
- D21 Data inputted into GIS and DSS
- D22 WP 3 Report

The deliverables D17, D18, D19 and D20 are technical reports only available for the partners of the project consortium. Deliverable D21 are data input to the GIS and also only available to the consortium. Deliverable D22 is a summary report of the work carried out in the work package and publicly available from the project website: www.geocapacity.eu.

WP 4 Standards and Site Selection Criteria

Work package 4 includes the following sub work packages:

- WP 4.1 with the purpose of producing a set of basic geological criteria required when considering sites for geological storage and developing a methodology for ranking of sites.
- WP 4.2 with the purpose of developing methodology for calculating storage capacity in different geological settings (aquifers, hydrocarbon fields and coal fields) and application of the standards to a test area.

The results of WP 4 are described in detail in technical reports and in the public report D26 WP 4 Report, Capacity standards and site selection criteria.

WP 4.1 Site Selection Criteria

The objective of WP4.1 was to produce a set of site selection criteria required when considering sites for geological storage and to develop a site ranking methodology based on geological suitability for CO₂ storage and on data availability and confidence. After discussion in project meetings and smaller workshops, a set of basic geological criteria were agreed:

1. Sufficient **depth of reservoir** to ensure that CO₂ reach its supercritical dense phase but not so deep that permeability and porosity is too low.
2. **Integrity of seal** to prevent CO₂ migrating out of the storage site.
3. Sufficient CO₂ **storage capacity** to hold the required volumes of CO₂ from the source e.g. lifetime emissions of a power plant.
4. Effective **petrophysic reservoir properties** to ensure CO₂ injectivity is economically viable and that sufficient CO₂ can be obtained.

These criteria were expanded on and described together with the associated geological parameters in a technical report and in the public D26 WP4 Report, Capacity standards and site selection criteria.

The site selection criteria have been applied to a test case study by BGR looking at an area near the Polish-German border with an attempt to rank the sites.

WP 4.2 Storage Capacity Standards

The objective of WP4.2 has been development of methodologies for calculating storage capacity in different geological settings using GESTCO experience and referring to other international projects (US and Australian) as well as application of the standards to a test area. The work in WP4.2 took basis in the standards suggested and published by the CSLF Task Force on Storage Capacity Estimation. During P1 and P2 GeoCapacity partners has participated in developing the CSLF standards and contributed to the CSLF publications on

this subject and GEUS has represented the EU as a member of the CSLF Task Force. Simultaneously the partners involved in WP4.2 have worked with the GeoCapacity application of the CSLF standards and further developments of methodology. The methodologies applied and developed in GeoCapacity for CO₂ storage capacity estimations in deep saline aquifers, hydrocarbon fields and coal beds, respectively, are described in detail together with a discussion of the background for our choices and suggestions in a technical report and in the public report D26 WP4 Report, Capacity standards and site selection criteria. The standards have been applied by GeoCapacity partners when estimating storage capacity ensuring quality, consistency and comparability and can be applied to other projects and future work as well.

The issue of storage capacity calculation and especially the storage efficiency factor for aquifers has been discussed intensively at all project meetings during the lifetime of the project and this discussion will, and should, probably go on in the future between CCS geo-experts. Nevertheless the GeoCapacity project has done a great effort for producing uniform and comparable capacity estimates. Two different approaches are suggested for open and semi-closed and closed aquifers by GEUS and TNO, respectively and also suggestions for capacity estimation of bulk volumes of regional aquifers are included supplementary to the capacity standards suggested by the CSLF.

For capacity estimation of hydrocarbon fields an alternative model has been developed in WP3.1 supplementary to the methodology described by the CSLF and the method applied previously in the GESTCO project.

The capacity estimation standards have been applied to a Danish test area by GEUS and the technical report comprises a sensitivity analysis of change in storage capacity based on different methodology for storage capacity estimation in aquifers, hydrocarbon and coal fields.

Deliverables

A total of four deliverables were included in WP 4:

- D23 Site selection criteria
- D24 Storage capacity standards
- D25 Application of standards
- D26 WP 4 Report

The deliverables D23, D24 and D25 are technical reports only available for the partners of the project consortium. Deliverable D26 is a summary report of the work carried out in the work package and publicly available from the project website: www.geocapacity.eu.

WP 5 Economic Evaluations

Work package 5 includes the following sub work packages:

- WP 5.1 with the purpose of improving a tool for the analysis of economic feasibility of CCS projects.
- WP 5.2 with the purpose of applying the tool to hypothetical, yet realistic, CCS projects in a number of countries.

The results of WP 5 are described in detail in technical reports and in the public report D30 WP 5 Report, DSS Report.

WP 5.1 DSS Development

The aim of this work package was to develop an economic decision support system (DSS); a tool to support the decision making for the development of CCS projects. The economic tool developed in the EU GESTCO project was the starting point. The GESTCO tool offered the capability of analyzing one source of captured CO₂ and one storage location. The tool used a database of emission points and storage locations, developed in the GESTCO project, and a GIS interface to allow users to select a source and a sinks from a map. The tool produced cost estimates of elements of the CCS project, such as capture, transport and storage, as well as of the CCS project as a whole. The cost of each element in the CCS chain was computed by a dedicated algorithm.

The GESTCO tool, although its results were useful, was considered too restricted in its functionality. An improved tool was required to analyse more complex CCS projects, representing the uncertainty inherent to this kind of analysis. The economic tool developed in WP5.1 has the following properties:

- Multi-source, multi-sink capability. This is considered essential for an up-to-date tool, as future large-scale CCS will involve multiple sources connected through a transport network to several sinks.
- Stochastic analysis of costs. Estimating the costs of a CCS project involves dealing with uncertainties. These can arise from e.g. uncertainties in development of prices. The Geocapacity economic tool uses a Monte Carlo approach. It handles uncertainties in any of the (many) input values and propagates these into the results, which all are represented as a probability distribution. This explicitly shows the user the uncertainty in the economic assessment of his future CCS project, as a result of the uncertainty in the data he presently has available.
- Level of detail in the analysis. The storage part of the CCS chain is often characterized by both large uncertainties and lack of data. This is especially true for aquifer storage, where initially often relatively little data is available. The tool contains a number of algorithms that represent the storage part of the CCS chain, that require different amounts of data. This allows the user to obtain results, even when little data are available, and to improve the result as more data are obtained.

The tool is implemented in Java and separated into a web-based part and an application that runs on a local computer. The web-based application shows the Geocapacity emission and storage database on a Google Maps web page. The user can construct a CCS project, selecting sources and sinks and constructing the connecting network of pipelines. The data are then transferred to the local application, which performs the Monte Carlo analysis of capture, compression, transport and storage. Results, such as NPV, capex, opex and unit cost are computed and presented in the form of a probability distribution function.

WP 5.2 Economic Evaluations

In this work package, the DSS web-based tool is applied for CCS test cases in various countries, i.e. the new countries compared to the GESTCO project. A CCS test case comprises one or more actual sources of carbon dioxide and one or more geological storage reservoirs. The geological description of the geological reservoirs has been made by each partner in WP2 of the project. In order to run the DSS program and to do the economical analysis, this information has been expanded with more in-depth geological and economical data for the storage reservoirs and technical and economical data for the selected sources of CO₂ and the applied capture, compression and transport system.

To run the DSS properly and with the most added value, it is necessary to collect as much statistical data on as many parameters as possible, to better estimate the uncertainty in the economic feasibility of the test case. Statistical data (e.g., standard deviations) can be included for almost all parameters for emission points, capture installations and storage sites. The Geocapacity sink database is designed to contain some of this information, but some site specific information had to be collected additionally for the test cases.

The economic tool was used to estimate the economic feasibility of capturing, transporting and storing CO₂ in the CCS systems modelled. The results of these analyses should be regarded as first, rough estimates of CCS feasibility. As such it can not yet be seen as fully optimised CCS scenarios. The description and evaluation of the test cases were completed with some non-technical evaluations and identifying gaps in knowledge.

Deliverables

A total of four deliverables were included in WP 5:

- D27 DSS
- D28 Economic evaluation
- D29 DSS user manual
- D30 WP 5 Report

Deliverable D27 is the DSS tool itself and deliverables D28 and D29 are technical reports only available for the partners of the project consortium. Deliverable D30 is a summary report of the work carried out in the work package and publicly available from the project website: www.geocapacity.eu.

WP 6 International Co-operation

Work package 6 includes the following sub work packages:

- WP 6.1 with the purpose of initiating technology transfer in China by training of Chinese experts in storage methodology and building a Chinese part of the GIS database.
- WP 6.2 with the purpose of promoting and developing CO₂ Capture and Storage in countries of the Carbon Sequestration Leadership Forum – CSLF, e.g. Russia and India.

The results of WP 6 are described in detail in a technical report and in the public report D35 WP 6 Report, International cooperation.

WP 6.1 Initiation of Technology Transfer in China

Similarly to the programme carried out in parallel by the European GeoCapacity partners, the objective of this WP was to make an inventory of CO₂ emissions sources in one province, assess the storage capacity in one test area (e.g. petroleum province or aquifer system) and, using the available data at this scale, propose scenarios of sources-sink matching.

The study was applied to the Hebei province, which is located in the Bohai Basin, NE China and the following data were inputted to the GIS:

- CO₂ emission sources in the Hebei province (points)
- Oil and gas pipelines in the Jizhong depression (polylines)
- Hydrocarbon fields in the Jizhong depression (polygons)
- Injection points in 25 hydrocarbon fields in the Jizhong depression
- Extent of the Tertiary Guantao aquifer at depths >850m (three tectonic sags) (polygon) with one injection point for each sag (points)
- Thickness of the Guantao aquifer in the Jizhong depression
- Structural base map (raster)

Training of Chinese experts took place through cooperation, meetings and presentations. Short courses were held during the three years in connection with other projects: formal official meetings (NSEC), joint general assembly meetings (COACH), specific meetings (GeoCapacity), and thematic meetings (NSEC/COACH/GeoCapacity Basin Workshop). Except one COACH meeting in Rueil-Malmaison (France) and the basin workshop in Dongying (China), all the meetings were held in Beijing.

Two formal training sessions for beginners on GIS were given by BGS in Beijing (the first assisted by GEUS), and informal follow up for advanced users of ArcGIS was provided by BRGM all along the project.

The case studies described in WP2 for Europe are complemented by the case study of the Jizhong depression. Due to the specific Chinese context, a dedicated type of DSS, based on GIS grids and least cost calculation was initiated thanks to a separate cooperation work on own expenses by 3E/INET (Tsinghua University) and BRGM. This specific tool built on respective experiences of both partners and is designed to be applied to the other ongoing EU/UK CCS projects in China, namely the Jilin province after the Hebei province.

Clustering with other European projects in China has developed a synergy between them. Thus the GeoCapacity experience is currently useful for the other EU (COACH) and UK (NZEK) projects which cover other provinces of the same basin and other basins in other provinces.

The results of GeoCapacity WP6.1 were brought to the International Community through a GHGT9 paper and oral communication. Bridges also exist with regulation and economic aspects in the EU STRACO2 project through BRGM.

The China-EU cooperation through the GeoCapacity project was:

Useful for China: Thanks to the effort of all the partners, the GeoCapacity experience in China was successful and has initiated the impulse for other complementary projects of the same type, applied to other provinces. The work performed together during the work sessions in China aided the Chinese team to be more accurate in CCS research.

Useful for other European projects in China: Due to a constant and tight clustering and synergy with the current European projects in China: COACH, NZEK, STRACO2, the work carried out in EU GeoCapacity was shared and can be applied to other provinces of the same basin and other basins in other provinces.

Useful for China-EU cooperation: Missions to China and to Europe, as well as imbedded internships have brought to each other cultural and technical satisfactions. In fine, the results of this study were brought to the International Community through a GHGT9 publication.

WP 6.2 Framework for International Co-operation

The objective of this WP was to establish links of cooperation with major CO₂ emitters of the Carbon Sequestration Leadership Forum, namely the emerging economies China, Russia, and India. This was done by identifying partnerships and projects in these countries, and by initiating sustainable contacts and exchanges with stakeholders and institutions in order to promote CCS knowledge, use and implementation.

Technology transfer in China was developed mainly by the cooperation of BRGM, BGS and GEUS, communication links in India, through BGS and BRGM and in Russia through BRGM, IBES (International Bureau for Environmental Studies, Brussels) and University La Sapienza Roma (CO₂GeoNet).

In Russia, the current project INTAS 06-100025-9220, 'Assessment of the Feasibility of CO₂ Storage in the Russian Permafrost', according to its objectives, *'uses synergies with other European projects, especially EU-GeoCapacity'*. In India, the IEAGHG R&D Programme project: 'CO₂ Storage Potential in the Indian Subcontinent', was recently completed and carried out partly by BGS, Maulana Azad National Institute of Technology, Indian Institute of Management (Ahmedabad) and an India-based geological consultancy. Taking into account the present Indian context, and based on the BRGM/BGS background in India, a new enlarged Indo-EU partnership was created in 2008 at the initiative of BRGM, BGS and Energy Research Centre of the Netherlands (ECN) to promote further CCS projects in India.

Deliverables

A total of five deliverables were included in WP 6:

- D31 Chinese demonstration report
- D32 Demonstration GIS China
- D33 Chinese demonstration DSS
- D34 Stakeholder meeting, China
- D35 WP 6 Report

Deliverable D31 is a technical report and only available for the partners of the project consortium. Deliverable D33 is included in D31. Deliverable D32 is the Chinese part of the GIS database and also only available to the consortium. Deliverable D34 was a stakeholder meeting held in China in 2006 and Deliverable D35 is a summary report of the work carried out in the work package and publicly available from the project website: www.geocapacity.eu.

WP 7 Project Management and Reporting

Work package 7 includes the following sub work packages:

- WP 7.1 with the purpose of overall project management including project planning, organisation of meetings and management of budget.
- WP 7.2 with the purpose of reporting including final report, reporting to the EU and maintaining a project website.

The results of WP 7 are described in detail in reports to the commission and in this public report D42 WP 7 Report, GeoCapacity Final Report.

WP 7.1 Overall Project Management

The project management carried out by GEUS (assisted by the country group leaders) comprised:

- Overall project planning and planning of work
- Arrangement of project meetings
- Arrangement of workgroup meetings
- Budget management
- Reporting to the commission

The GeoCapacity project was managed through combined work and steering committee meetings for the entire consortium twice every year:

Three meetings were held in Period 1:

- Kick-off Meeting - Copenhagen, February 2006
- 1st Project Meeting - Toledo, May - June 2006
- Storage capacity workshop – Spoleto – October 2006

Two meetings were held in Period 2:

- 2nd Project Meeting - Athens, March 2007
- 3rd Project Meeting - Tallinn, September 2007

Two meetings were held in Period 3:

- 4th Project Meeting - Dubrovnik, April 2008
- Final Project Meeting - Heviz, October 2008

Agenda, all presentations and minutes from the project meetings can be found on the GeoCapacity website www.geocapacity.eu.

WP 7.2 Reporting

Reporting to the EU

Reporting to the EU was carried out after each of the three periods P1, P2 and P3 and comprised financial statements and Period Activity and Management Reports according to the contract. The financial statements included audit certificates after P1 and P3 (covering P2 and P3). The financial statements were provided by each partner, assisted by GEUS where necessary and were compiled and submitted by GEUS. Contributions to the Periodic Activity Reports were provided by WP Leaders and leaders of sub-work packages and the reports were compiled and submitted by GEUS. Contributions to the Periodic Management Reports were provided by each partner and the reports were compiled and submitted by GEUS.

Website

CGS has been responsible for and carried out the construction, maintenance and updating of the GeoCapacity project website. The Project website was launched in January 2006. It is hosted by the Internet server of Czech Geological Survey. The website address is www.geocapacity.eu. The website comprises both a public part with sections Home / News / Project / Participants / Events / Publications / Links and a Working area accessible only to project partners. The website has been maintained and regularly updated during the project and it is planned that updating will continue until 31/12/2009 while the website itself will be running until 31/12/2018.

New parts and functionalities were added both to the open and to the members-only parts of the website during the project duration, like the End-User Group and Deliverables pages or the visitor's analytics. The website has also been used for information dissemination and exchange among the partners and End-User Group members. Until 31/12/2008, the website has registered 12,164 visits from 7,397 visitors coming from 117 countries.

Reporting

An overview of the deliverables in the GeoCapacity project and their availability is given below:

WP1

No.	Title	Type	Status
1	Data Specification	Report	Available on final report CD
2	Questionnaire	Report	Available on final report CD
3	Inventory of point sources	Other	Part of project GIS
4	Infrastructure data	Other	Part of project GIS
5	Project GIS	Demo	Available on DVD for consortium
6	Web enabled GIS	Proto	Access via website for consortium
7	Sink source maps	Other	Available on final report CD
8	WP 1 Report	Report	Available on project CD/website
9	GIS user manual	Report	Available on final report CD

WP2

No.	Title	Type	Status
10	Maps of regional storage potential	Other	Available on final report CD
11	Geological information of storage sites	Other	Available on final report CD/part of project GIS
12	Storage capacities	Other	Available on final report CD/part of project GIS
13	Data for project GIS	Other	Part of project GIS
14	Case Study Scenarios	O / R	Available on final report CD
15	Country Updates	Other	Part of project GIS
16	WP 2 Report	Report	Available on project CD/website

WP3

No.	Title	Type	Status
17	Potential for CO ₂ use in hydrocarbon fields	Report	Available on final report CD
18	Potential for CO ₂ use in coal beds	Report	Available on final report CD
19	GeoCapcatiy economic use of CO ₂ in hydrocarbon fields	R / O	Available on final report CD
20	GeoCapcatiy economic use of CO ₂ in coal beds	R / O	Available on final report CD
21	Data inputted into GIS and DSS	Other	Part of project GIS
22	WP 3 Report	Report	Available on project CD/website

WP4

No.	Title	Type	Status
23	Site selection criteria	Report	Available on final report CD
24	Storage capacity standards	Report	Available on final report CD
25	Application of standards	Other	Available on final report CD
26	WP 4 Report	Report	Available on project CD/website

WP5

No.	Title	Type	Status
27	DSS	Demo	Available on CD/website for consortium
28	Economic evaluation	Report	Available on final report CD
29	DSS user manual	Report	Available on final report CD
30	WP 5 Report	Report	Available on project CD/website

WP6

No.	Title	Type	Status
31	Chinese demonstration report	Report	Available on final report CD
32	Demonstration GIS China	Demo	Part of project GIS
33	Chinese demonstration DSS	Demo	Available on final report CD
34	Stakeholder meeting, China	Other	China, July 2006
35	WP 6 Report	Report	Available on project CD/website

WP7

No.	Title	Type	Status
36	Project planning	Other	Ad hoc
37	Project meetings	Other	Two in each year of the project
38	Workgroup meetings	Other	Ad hoc and with project meetings
39	Budget Management	Other	As specified in contract
40	Reporting to the commission	Report	As specified in contract
41	Interim Reports	Report	As specified in contract
42	Final Report	Report	Available on project CD/website
43	Final Report CD	Report	Available for the consortium
44	Conference papers	Other	See website and public Periodic Activity Report P1-P3
45	Website	Other	www.geocapacity.eu

Use and dissemination of knowledge

The dissemination of knowledge generated by and within GeoCapacity has been directed towards different target groups and stakeholders, at various classification levels. Knowledge aggregated in deliverables are protected or open for distribution in accordance with the classification codes given in Description of Work, Annex 1 to the contract between Coordinator and the Commission.

The following publishable results have been made available during the project:

- D8 WP1 Report, Inventories and GIS
- D16 WP2 Report, Storage capacity
- D22 WP 3 Report, Economic uses of CO₂
- D26 WP 4 Report, Capacity standards and site selection criteria
- D30 WP5 Report, DSS and economic evaluations
- D35 WP6 Report, International cooperation
- D42 GeoCapacity Final Report
- D44 Conference papers
- D45 Website

Deliverable D45 Website has been described above and contains available public information. The website address is www.geocapacity.eu.

As part of deliverable D44 GeoCapacity has been represented and/or presented at more than 25 international meetings and conferences since the start of the project. The GHGT-9 in Washington in November 2008 included 9 GeoCapacity contributions and the project has been covered by two editorials in the eStrategies Projects magazine and an advertisement in the Parliament Magazine.

The list of papers, extended abstracts and presentations based on project work counts more than 50 entries. Furthermore, four groups have been formed for looking into possibilities of dissemination of GeoCapacity results:

- Group 1: Investigation of publication possibilities in high ranking journals
- Group 2: Promotion of project results and reports on website, conferences etc.
- Group 3: Investigation of possibilities of dissemination through Parliament Magazine, GHG Journal and Newsletter etc.
- Group 4: Production of a professional brochure presenting GeoCapacity results

Finally, a GeoCapacity Result Seminar is planned in Copenhagen in 2009 (autumn) for project partners, end-users and other interested parties.

A detailed list of events, publications and presentations appears from the project website www.geocapacity.eu and the Periodic Activity Report covering the entire project period.

Conclusion

The GeoCapacity project does not comprise the development of a marketable product as such, but was designed to provide the rationale for and scientific documentation of a concept for CO₂ subsurface storage. This has been needed in order to show sufficient storage capacity for the concept to be viable for wide-scale application and to show that storage can be done cost efficiently. The results of the GeoCapacity study are thus aimed at the following three user groups:

- Policy makers (UN, EU, national level) for setting emission prices and accepting the concept as greenhouse gas sink
- Power companies facing emission level regulations
- Potential storage operators and providers of goods and services, looking for new markets for advanced products

The results of the GeoCapacity study are the first detailed pan-European assessment of CO₂ storage capacity and some of the main achievements in the project have been:

- Establishing a CCS inventory of Europe based on a GIS platform
- Developing an advanced Decision Support System (DSS)
- Paving the ground for a CO₂ storage atlas of Europe
- Contribution to standards and guidelines for assessment of geological storage capacity, site selection criteria and methodology for ranking
- Pioneering CCS work in many European countries and China

Results of the study are provided in public Work Package Reports and in the Final Report of the project. These reports are written for non-technicians and the technical and geological results are intended to provide a solid foundation upon which the concept of CCS can be judged and, hopefully, be declared sufficiently sound to warrant widespread application in Europe. Public/political acceptance is considered to be a prerequisite for further development of CCS into a marketable commodity.