EU GeoCapacity

Assessing European Capacity for Geological Storage of Carbon Dioxide

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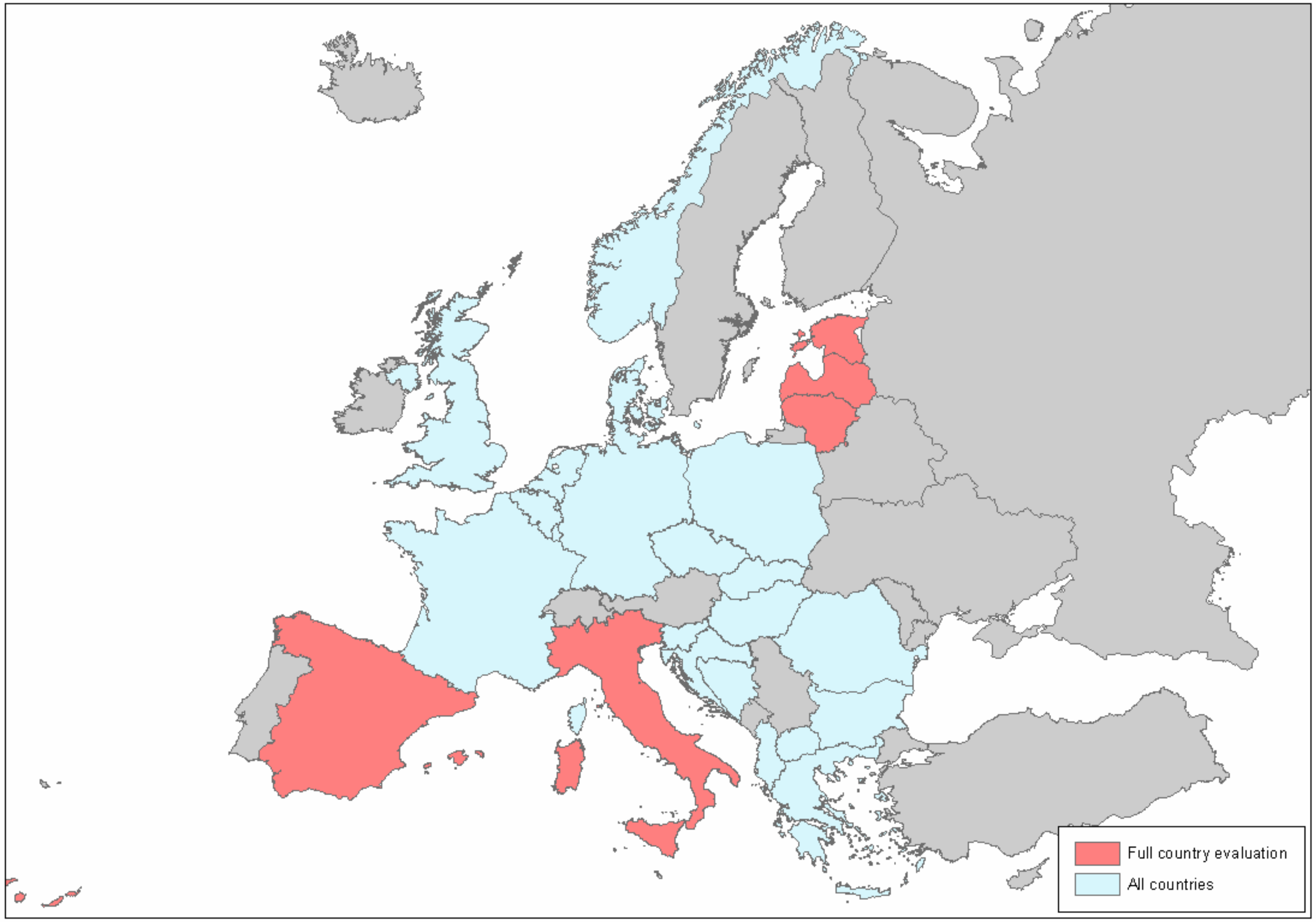
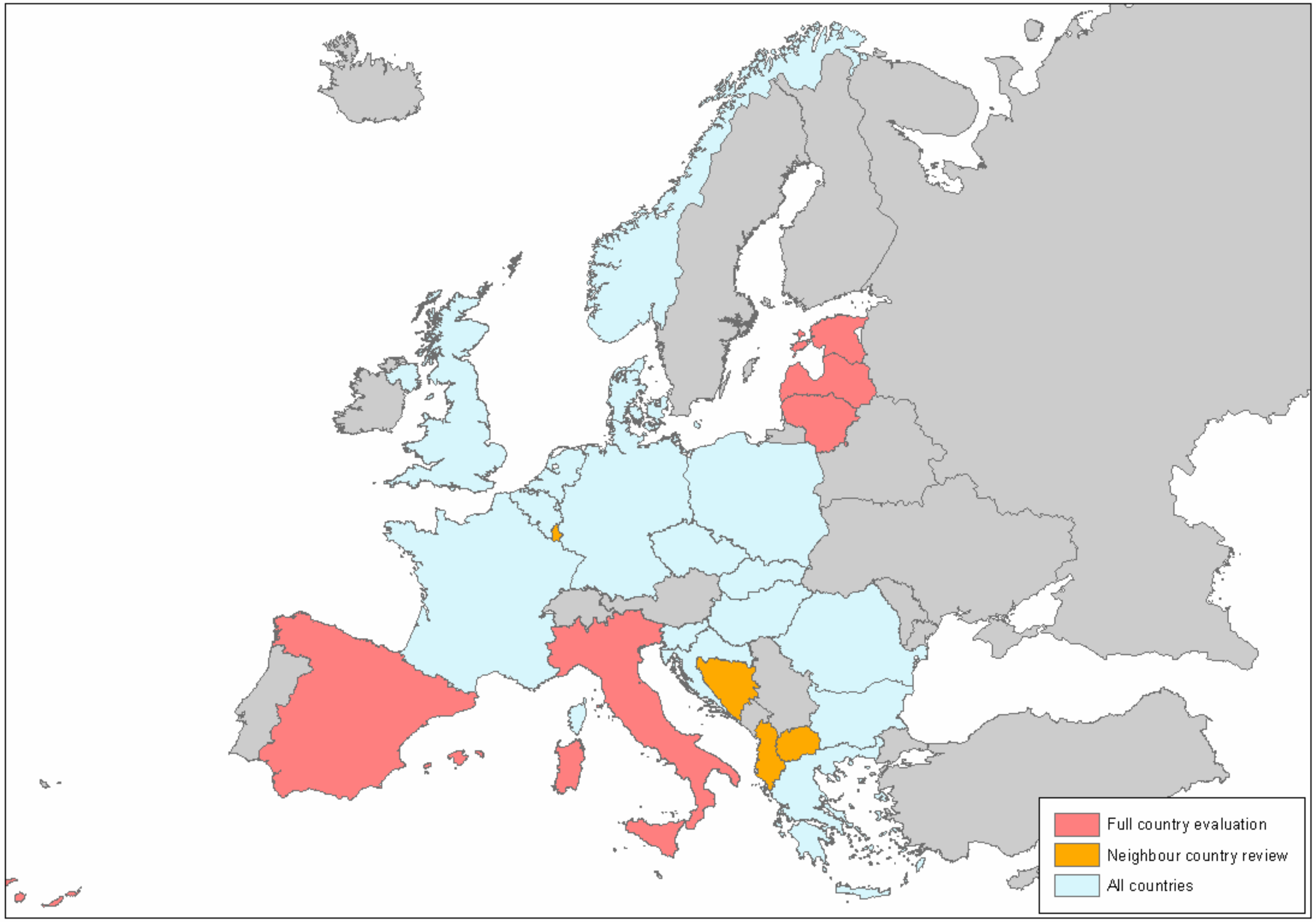
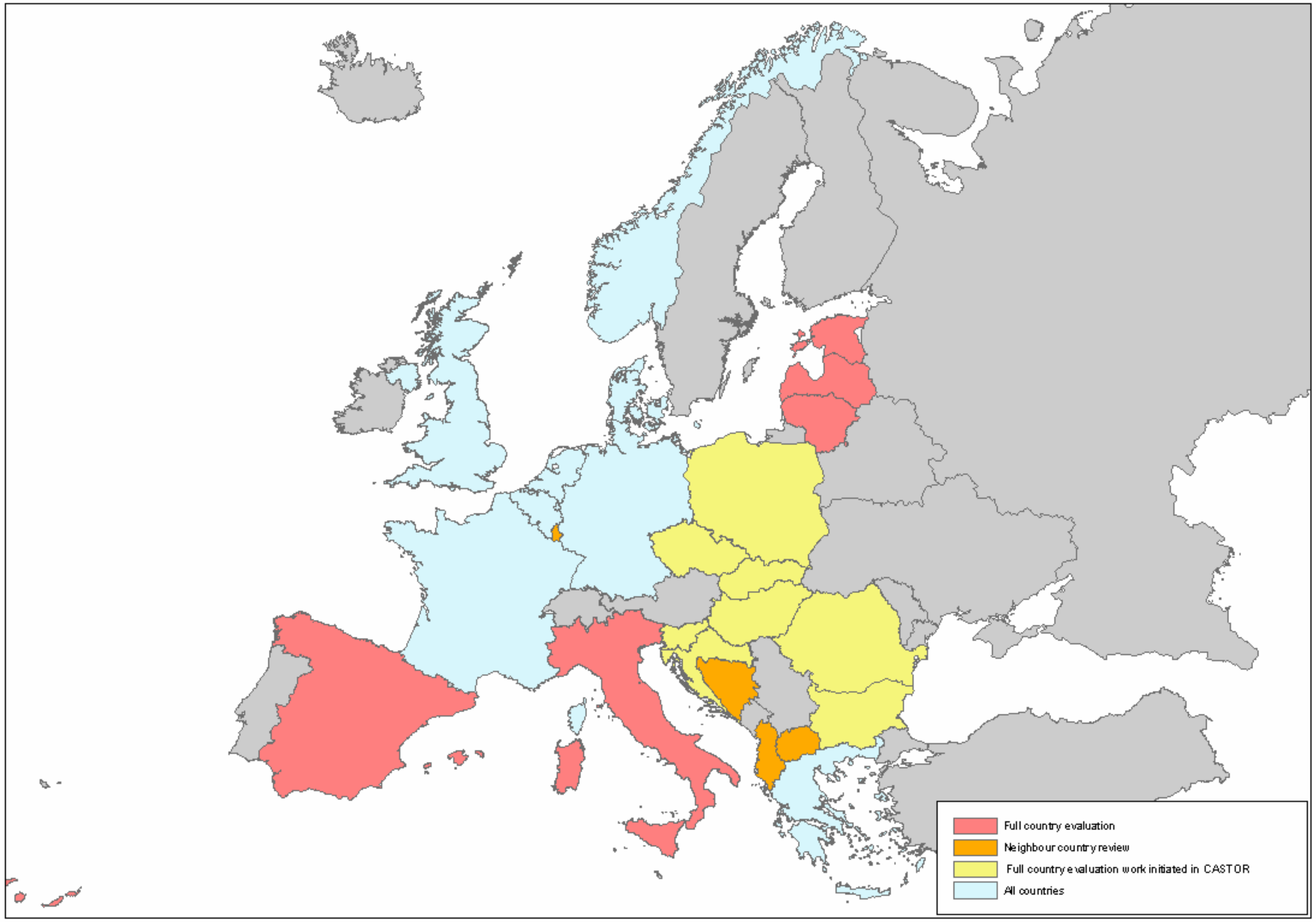
CO_2 Capture and Storage – Response to Climate Change
2nd CO_2net east Regional Workshop for CE and EE Countries
Bratislava, Slovakia, 3-4 March 2009

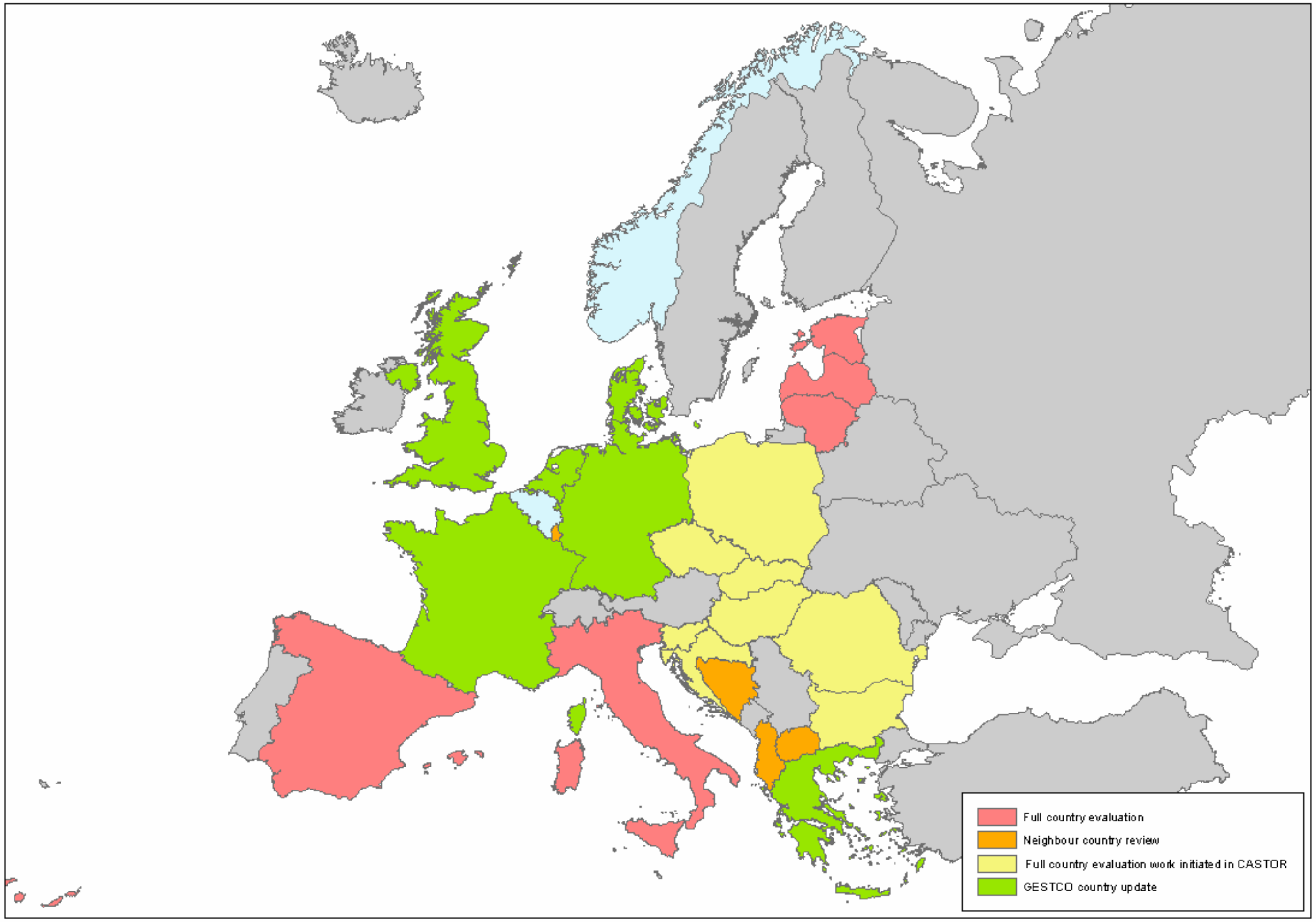
The work in GeoCapacity comprised:

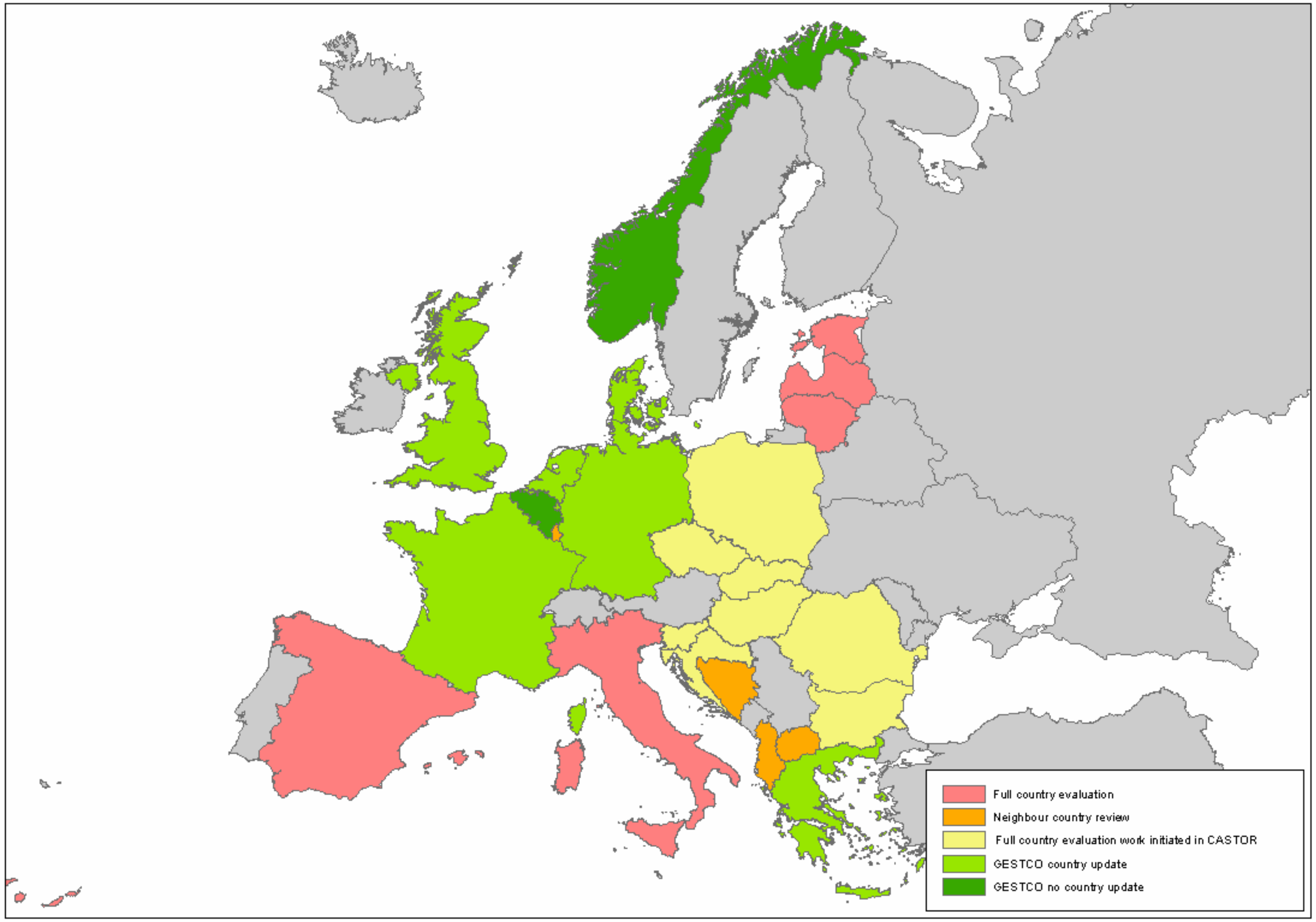
- Full assessment of countries not previously covered
- Update of GESTCO and CASTOR countries
- Inventory of major CO_2 emission point sources and infrastructure
- Assessment of regional and local potential for geological storage of CO_2 in:
    - deep saline aquifers
    - hydrocarbon fields (incl. 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


Full country evaluation
All countries


Full country evaluation
Neighbour country review
All countries


Full country evaluation
Neighbour country review
Full country evaluation work initiated in CASTOR
All countries

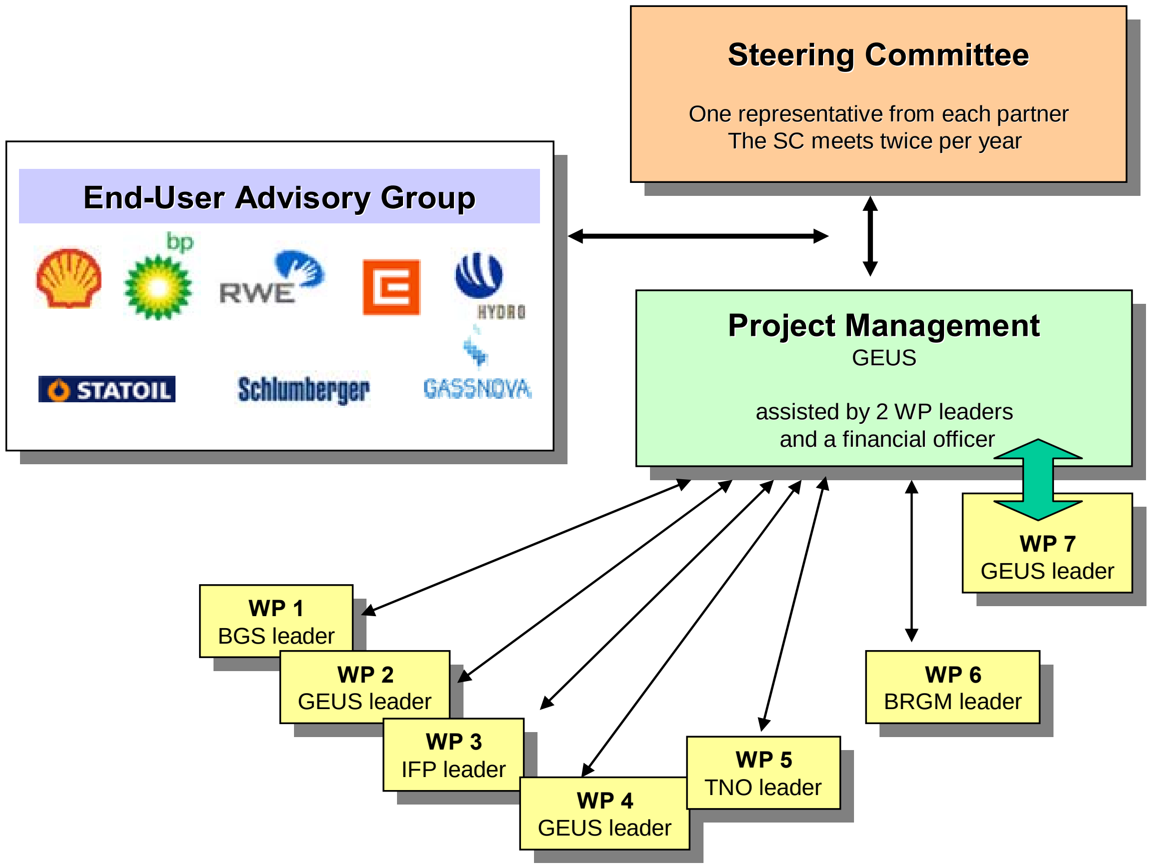

Full country evaluation
Neighbour country review
Full country evaluation work initiated in CASTOR
GESTCO country update


Full country evaluation
Neighbour country review
Full country evaluation work initiated in CASTOR
GESTCO country update
GESTCO no country update

26 Project partners from 20 countries

- Geological Survey of Denmark and Greenland
- University of Sofia
- University of Zagreb
- Czech Geological Survey
- Institute of Geology at Tallinn University of Technology
- Bureau de Recherce de Geologie et Miniere
- Institute Francais du Petrole
- Bundesanstalt für Geologie und Rohstoffen
- Institute for Geology and Mining Engineering
- Eötvös Loránd Geophysical Institute of Hungary
- Isituto Nazionale Oceanografie e Geofisica Sperimentale
- Latvian Environment, Geology & Meteorology Agency
- Institute of Geology and Geography
- Geological Survey of the Netherlands
- Ecofys
- Academy of Science (MEERI)
- Geophysical Exploration Company
- GeoEcoMar
- Dionyz Stur State Geological Institute
- GEOINZENIRING
- Instituto Geologico y Minero de Espana
- British Geological Survey
- EniTecnologie (Industry Partner)
- ENDESA Generacion (Industry Partner)
- Vattenfall Utveckling AB (Industry Partner)
- Tsinghua University

GeoCapacity Project Organisational Structure



Work package structure

Work Package 1
Inventories And GIS
Lead: BGS

WP 1.1
CO_2 Emission Inventory
Point sources
Pipelines
Infrastructure
License areas
Lead: BGS

WP 1.2
Project GIS
Data format
Specification
Building GIS
Web GIS
Lead: BGS, GEUS

WP 1.3
Maps of emissions and storage sites
Lead: GEUS, BGS

Work Package 2
Storage Capacity
Lead: GEUS

WP 2.1
North East Group
Estonia
Latvia
Lithuania
Poland
Czech R
Slovakia
Lead: SGUDS

WP 2.2
Central East Group
Romania
Bulgaria
Hungary
(Albania)
(FYROM)
Lead: ELGI

WP 2.3
South Group
Spain
Italy
Slovenia
Croatia
Lead: U.Zagreb

Regional potential assessments

Geological information of sites

Calculations of storage capacity

Input and formatting of data

WP 2.4
Country updates for GESTCO countries
Lead: BGR

Work Package 3
Economic uses of CO_2
Lead: IFP

WP 3.1
Storage capacity in hydrocarbon fields
Assessment of EOR potential
Calculation of storage capacity
Modelling of EOR
Input to DSS and GIS
Lead: IFP

WP 3.2
Storage capacity in coal beds
Assessment of ECBM potential
Calculation of storage capacity
Input to DSS and GIS
Lead: PBG

Work Package 4
Standards & Site Selection Criteria
Lead: GEUS

WP 4.1
Site selection criteria
Basis site selection criteria
Methodology for ranking
Lead: BGS

WP 4.2
Storage capacity standards
Methodology for calculating storage capacity
Application of standards to test area
Lead: GEUS

Work Package 5
Economic Evaluations
Lead: TNO

WP 5.1
DSS development
Feedback from DSS users
Detailed instructions
Collection of economic data
System development
Lead: TNO

WP 5.2
Economic evaluations
Economic evaluations in the new member countries
Lead: Ecofys

Work Package 6
International Cooperation
Lead: BRGM

WP 6.1
Initiation of technology transfer in China
Training of Chinese experts incl. GIS
Collection of data and addition to GIS
DSS, economics
Evaluation and dissemination
Lead: BRGM

WP 6.2
Framework for international coorporation
Communication with CSLF
Framework for cooperation with India, Russia etc.
Lead: BRGM

Work Package 7
Pr. Management and Reporting
Lead: GEUS

WP 7.1
Overall project management
Project planning
Organise project meetings
Chair management board
Create and inform advisory board
Management of non-personnel budget
Lead: GEUS, CGS, ELGI, SGUDS

WP 7.2
Reporting to EU
Reporting to EU
Website
Reporting to CSLF
Interim and final report
Final report CD
Contribute to conference papers
Lead: GEUS, CGS, OGS, U.Sofia

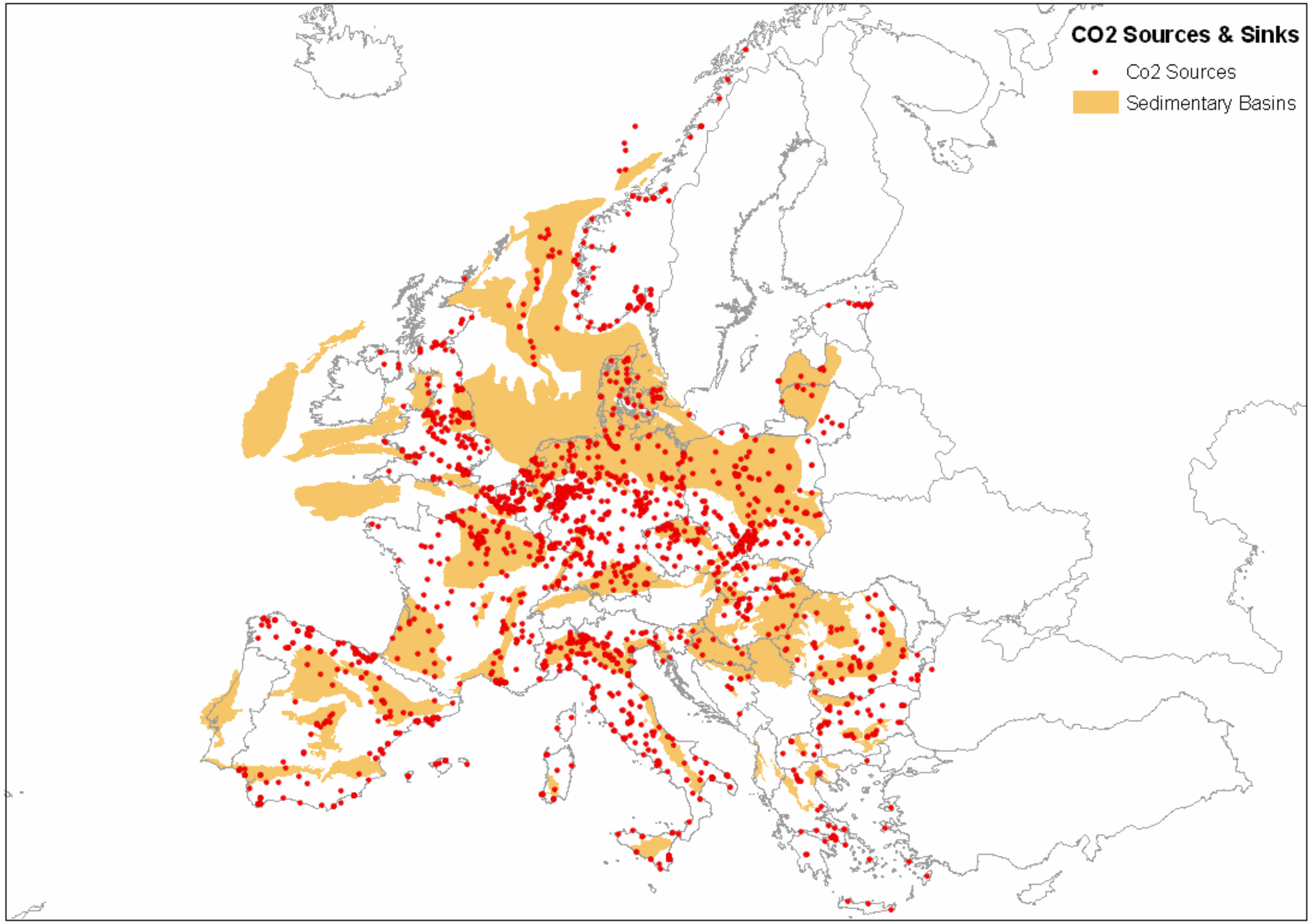
Mapping of emission sources and infrastructure

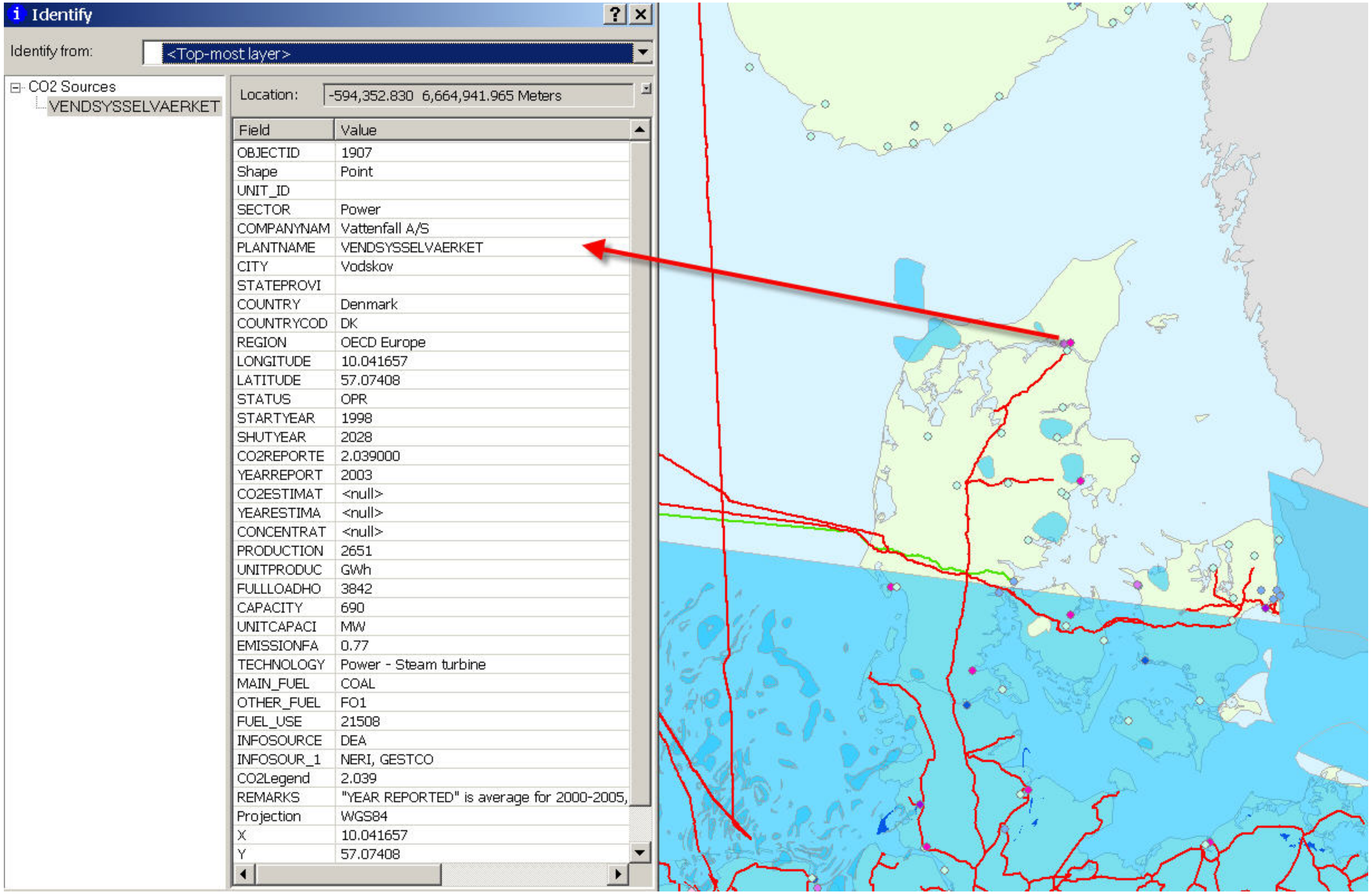
Stationary sources exceeding 100 kt CO_2 / year

Data sources:

- –annual reports for the EU ETS
- –national allocation plans
- –qualified estimations where data not available

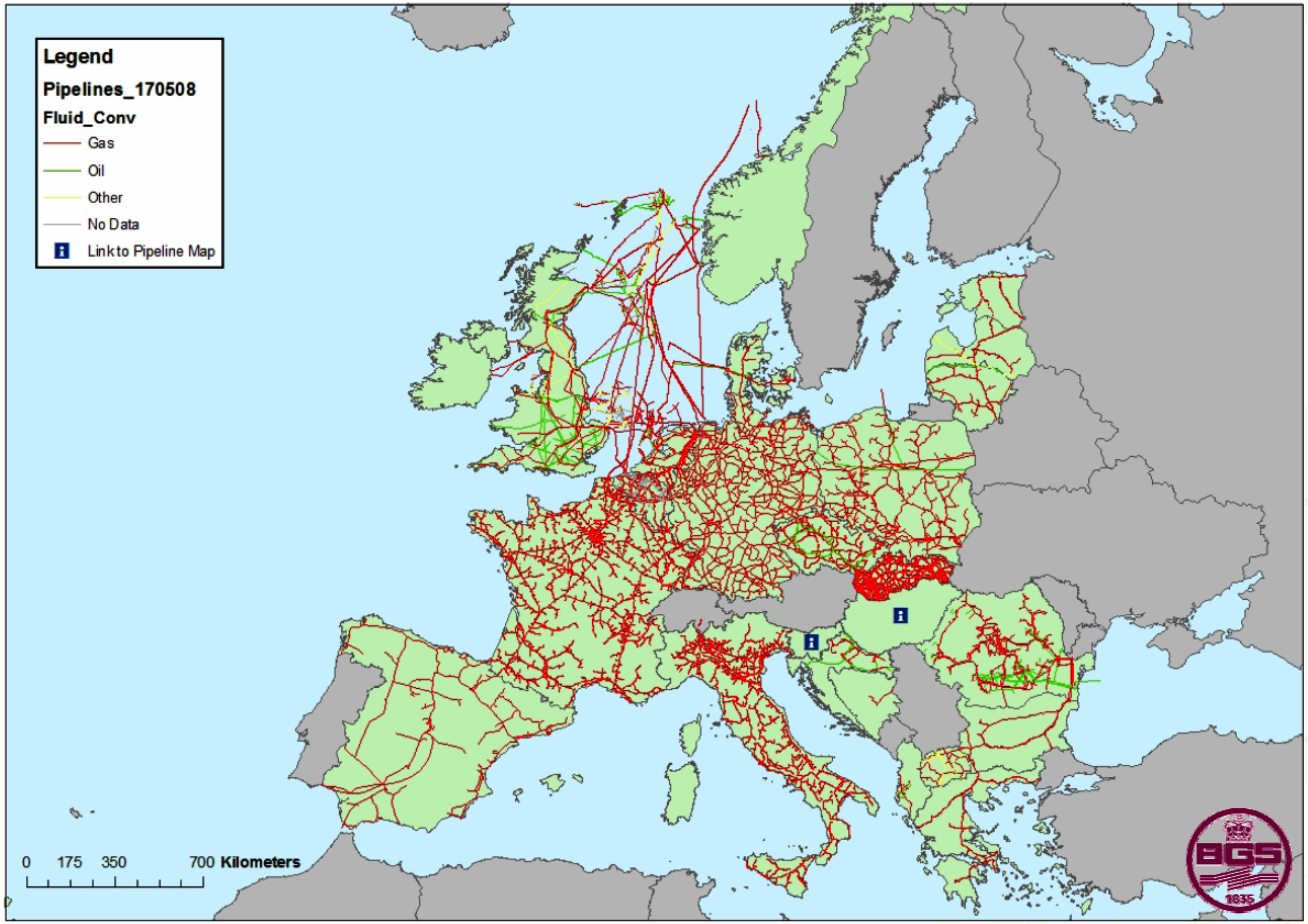
Existing pipelines


CO2 Sources & Sinks
Co2 Sources
Sedimentary Basins



Field	Value
OBJECTID	1907
Shape	Point
UNIT_ID	
SECTOR	Power
COMPANYNAM	Vattenfall A/S
PLANTNAME	VENDSYSSELVAERKET
CITY	Vodskov
STATEPROVI	
COUNTRY	Denmark
COUNTRYCOD	DK
REGION	OECD Europe
LONGITUDE	10.041657
LATITUDE	57.07408
STATUS	OPR
STARTYEAR	1998
SHUTYEAR	2028
CO2REPORTE	2.039000
YEARREPORT	2003
CO2ESTIMAT	<null>
YEARESTIMA	<null>
CONCENTRAT	<null>
PRODUCTION	2651
UNITPRODUC	GWh
FULLLOADHO	3842
CAPACITY	690
UNITCAPACI	MW
EMISSIONFA	0.77
TECHNOLOGY	Power - Steam turbine
MAIN_FUEL	COAL
OTHER_FUEL	FO1
FUEL_USE	21508
INFOSOURCE	DEA
INFOSOUR_1	NERI, GESTCO
CO2Legend	2.039
REMARKS	"YEAR REPORTED" is average for 2000-2005,
Projection	WGS84
X	10.041657
Y	57.07408

Pipelines


Legend
Pipelines_170508
Fluid_Conv
Gas
Oil
Other
No Data
Link to Pipeline Map
0 175 350 700 Kilometers

Mapping of storage sites

Initial screening for sedimentary formations

3 main types of storage considered

- aquifers
- hydrocarbon fields
- unmineable coal seams

Application of site selection criteria

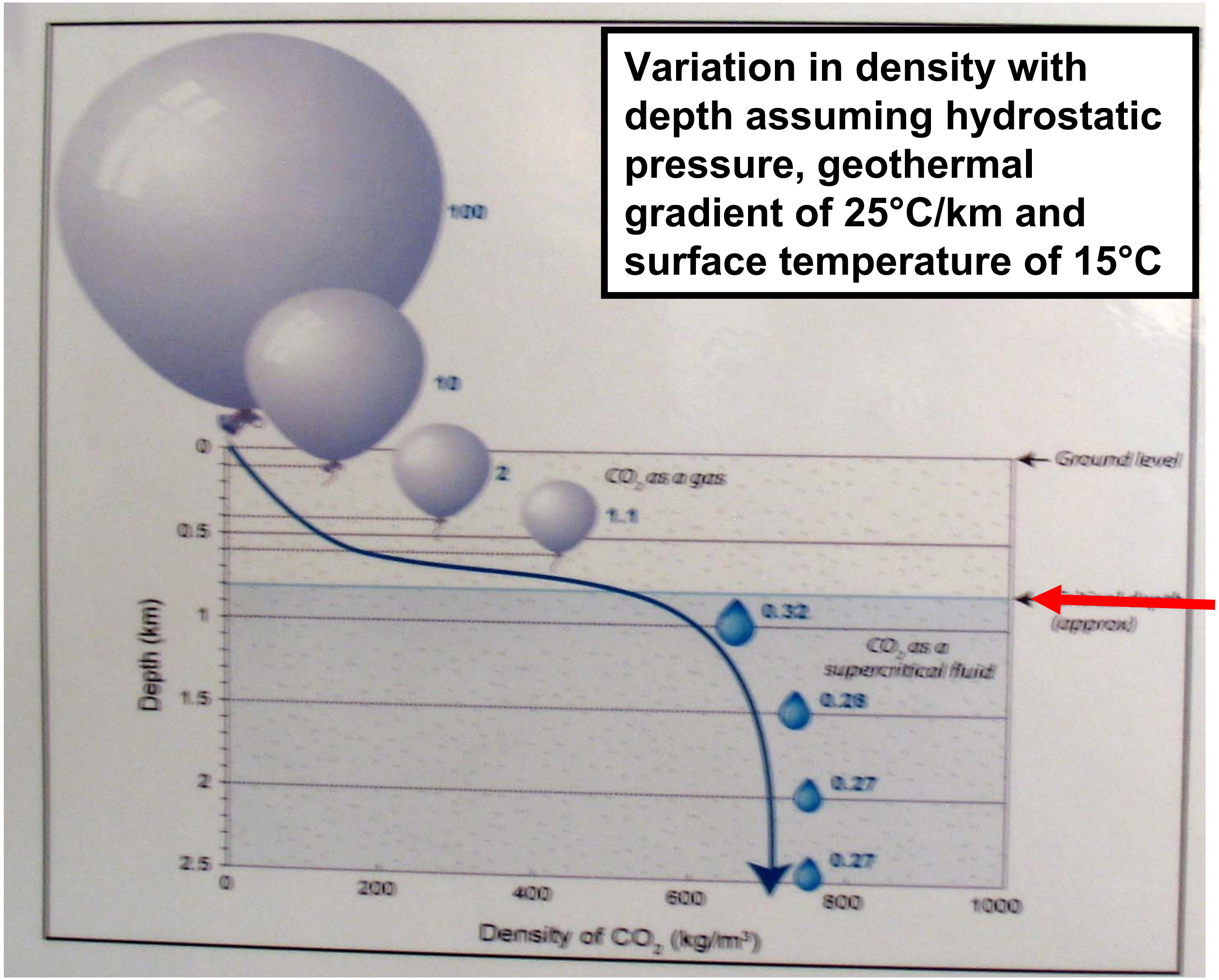
Storage capacity estimations

Collection of data for GIS and project DSS

Basic site selection criteria

- Sufficient depth and storage capacity
  - supercritical CO_2 below 700-800 m (rule of thumb)

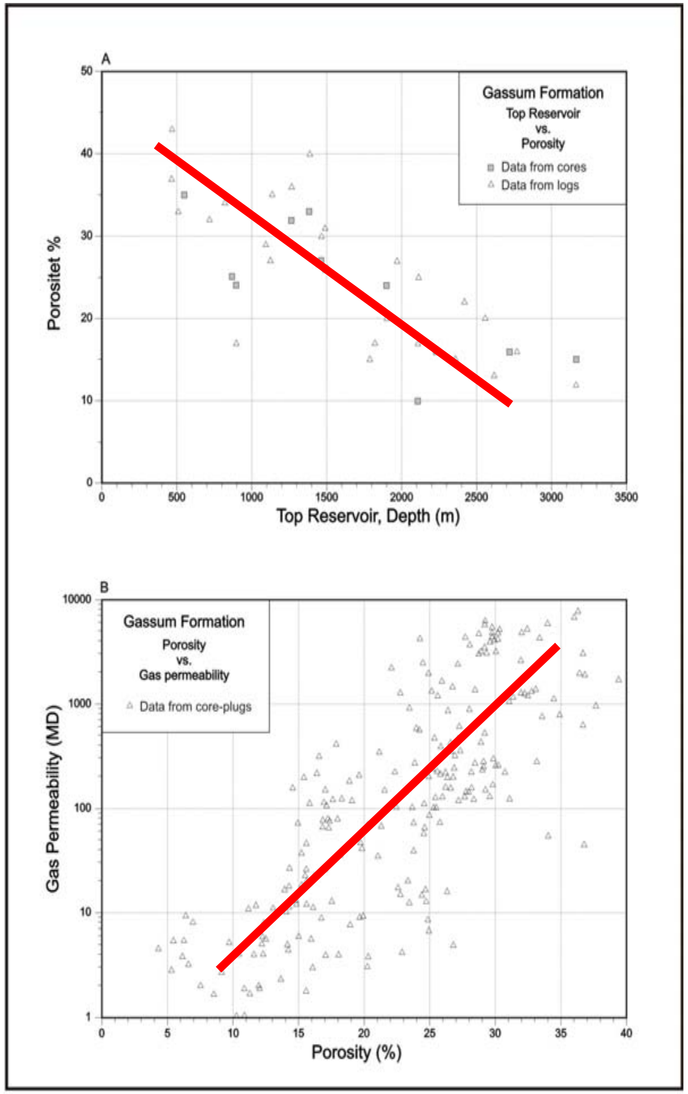
Variation in density with depth assuming hydrostatic pressure, geothermal gradient of 25°C/km and surface temperature of 15°C



Great change in density / volume at ~ 800 m

Basic site selection criteria

- Sufficient depth and storage capacity
  - supercritical CO_2 below 700-800 m (rule of thumb)
  - porosity may deteriorate below 2500-3000 m



One of the regional Danish reservoir sandstones

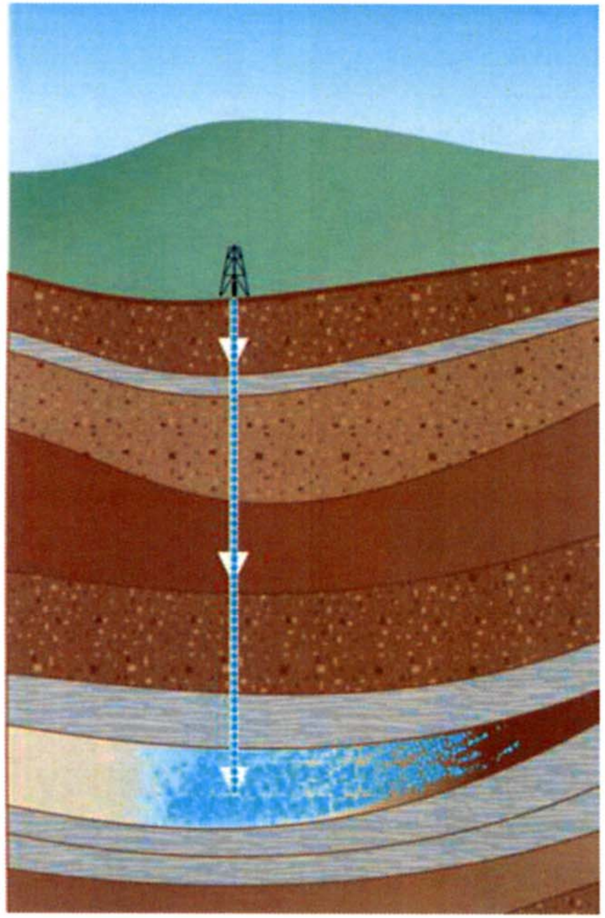
Decreasing porosity with depth

Decreasing permeability with decreasing porosity

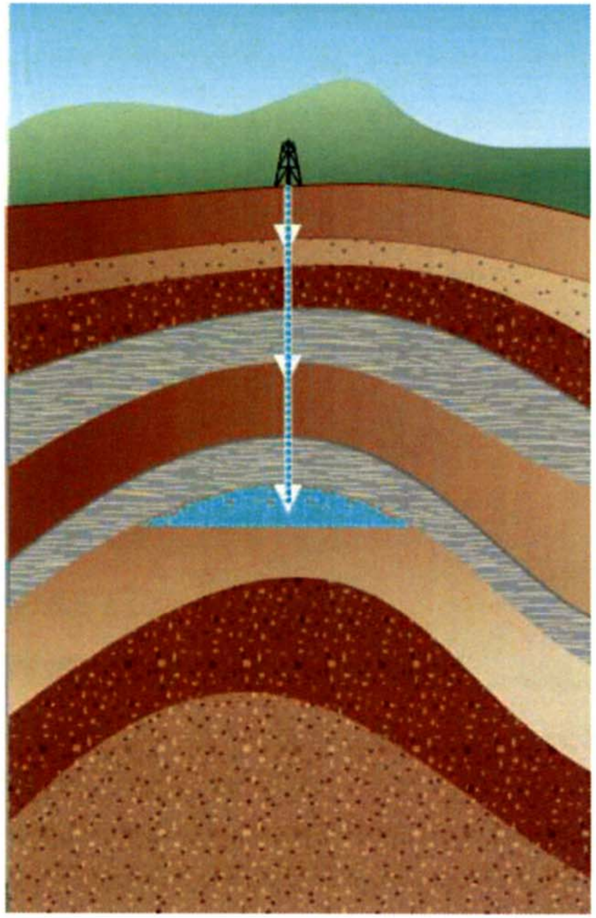
In practise this means a depth window of 800-2500 m

Basic site selection criteria

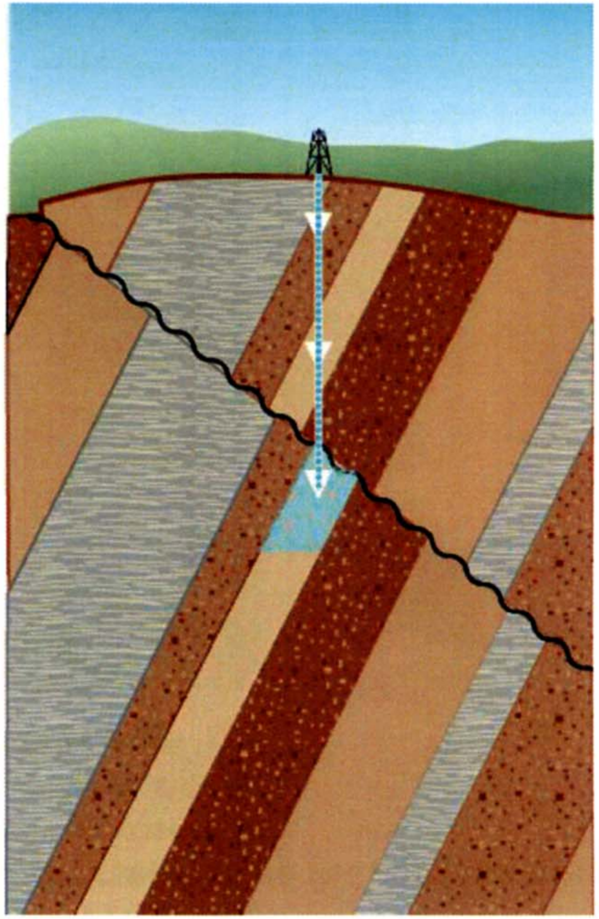
- Sufficient depth and storage capacity
  - supercritical CO_2 below 700-800 m (rule of thumb)
  - porosity may deteriorate below 2500-3000 m
  - trap type / areal extent / thickness



Stratigraphical trapping; porous layer bounded by tight seal



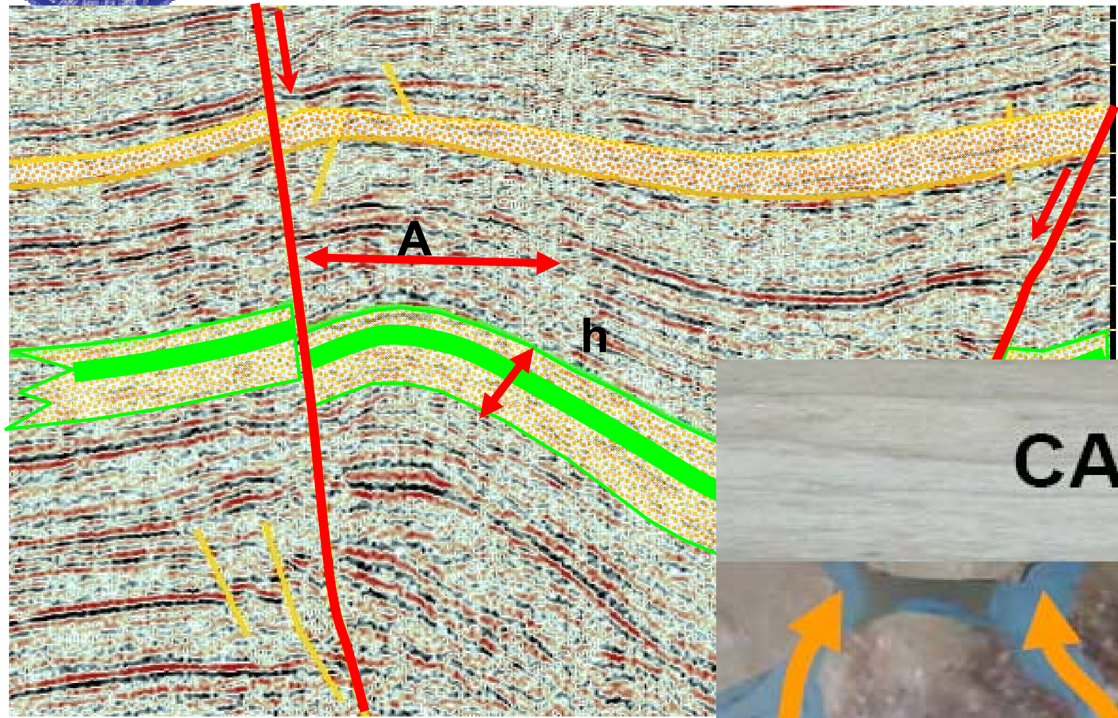
Structural trapping; porous layer topped by tight seal



Structural trapping; porous layer in fault contact with seal

Basic site selection criteria

- Sufficient depth and storage capacity
    - supercritical CO_2 below 700-800 m (rule of thumb)
    - porosity may deteriorate below 2500-3000 m
    - trap type / areal extent / thickness
    - storage capacity



Areal distribution and thickness of reservoir

Pore space in the reservoir

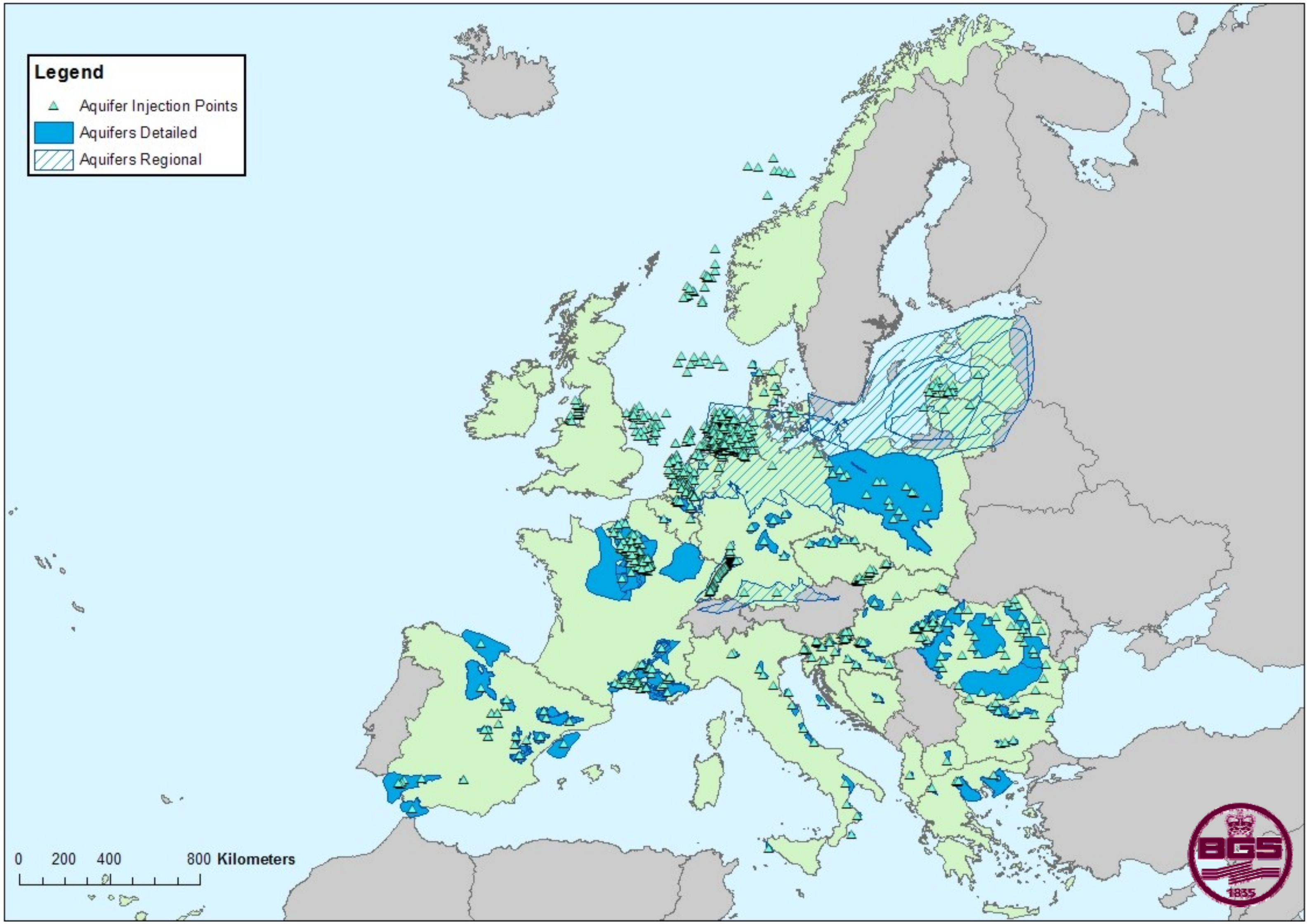
Basic site selection criteria

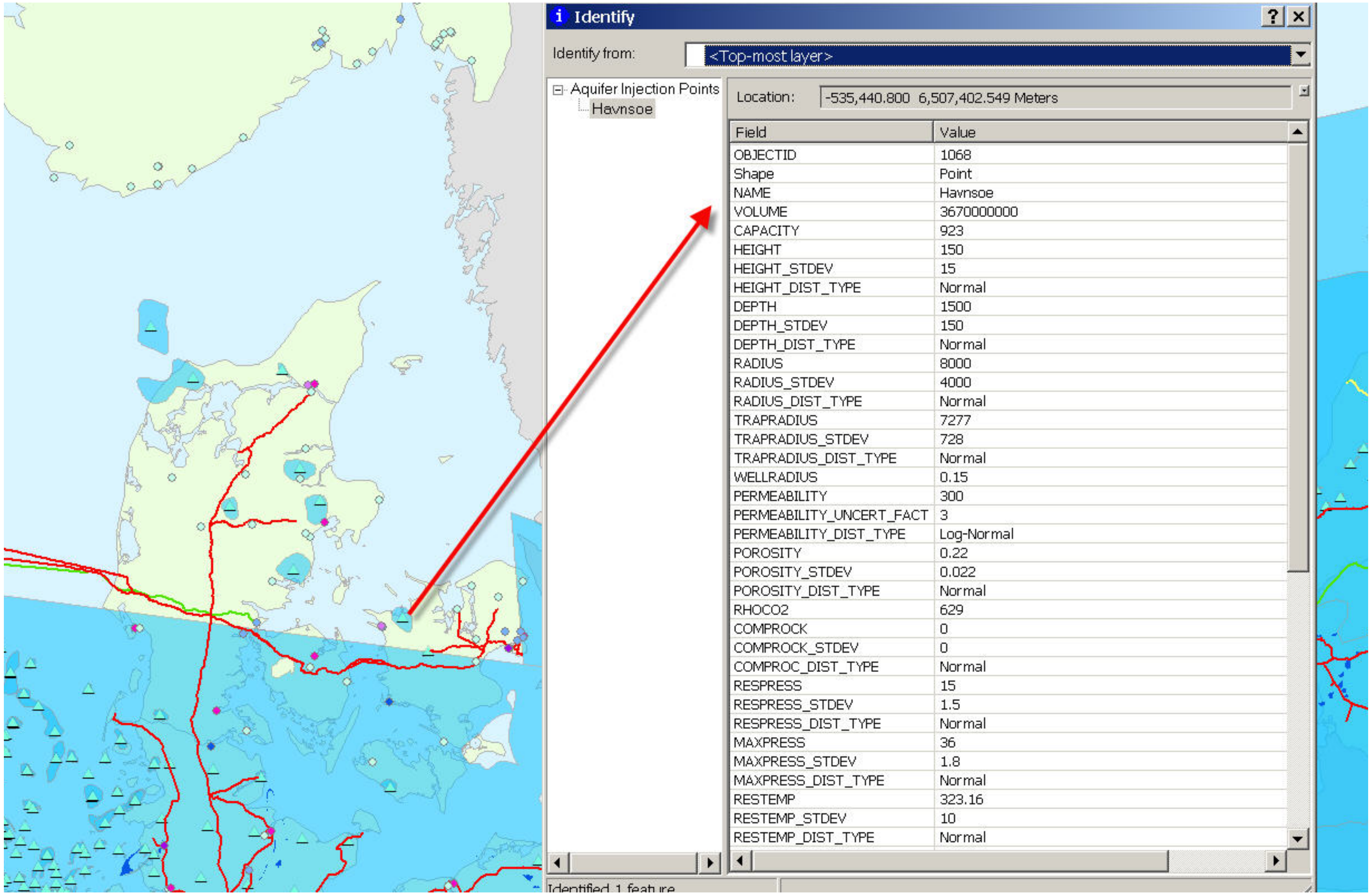
- Sufficient depth and storage capacity
  - supercritical CO_2 below 700-800 m (rule of thumb)
  - porosity may deteriorate below 2500-3000 m
  - trap type / areal extent / thickness
  - storage capacity

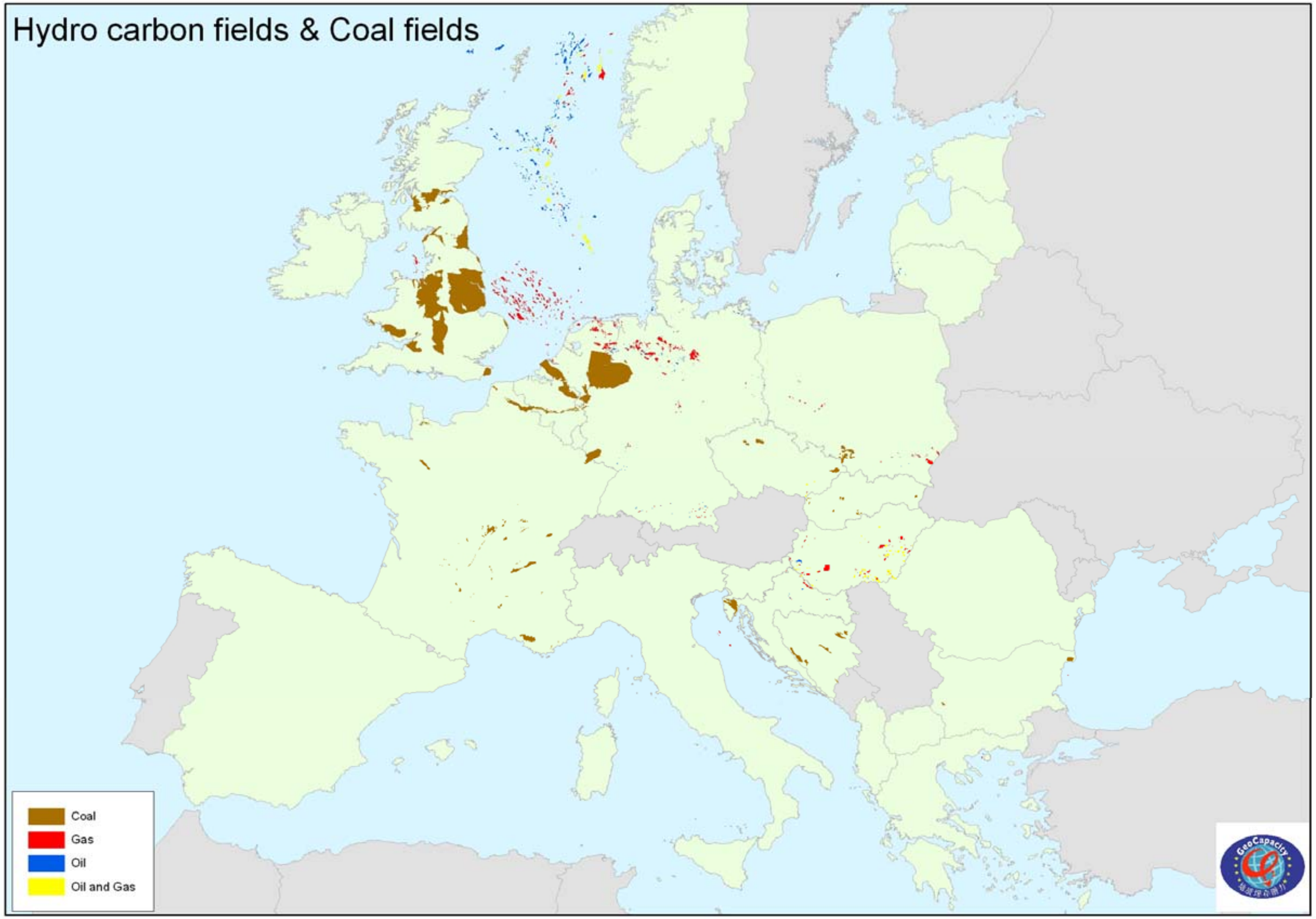
- Sufficient injectivity to be economically viable
  - permeability (as a rule of thumb > 200 mD)
  - reservoir lithology
  - heterogeneity of reservoir

- Integrity of seal
  - seal lithology and permeability
  - seal capillary pressure and pore entry pressure
  - faulting / tectonic activity / fracture pressure

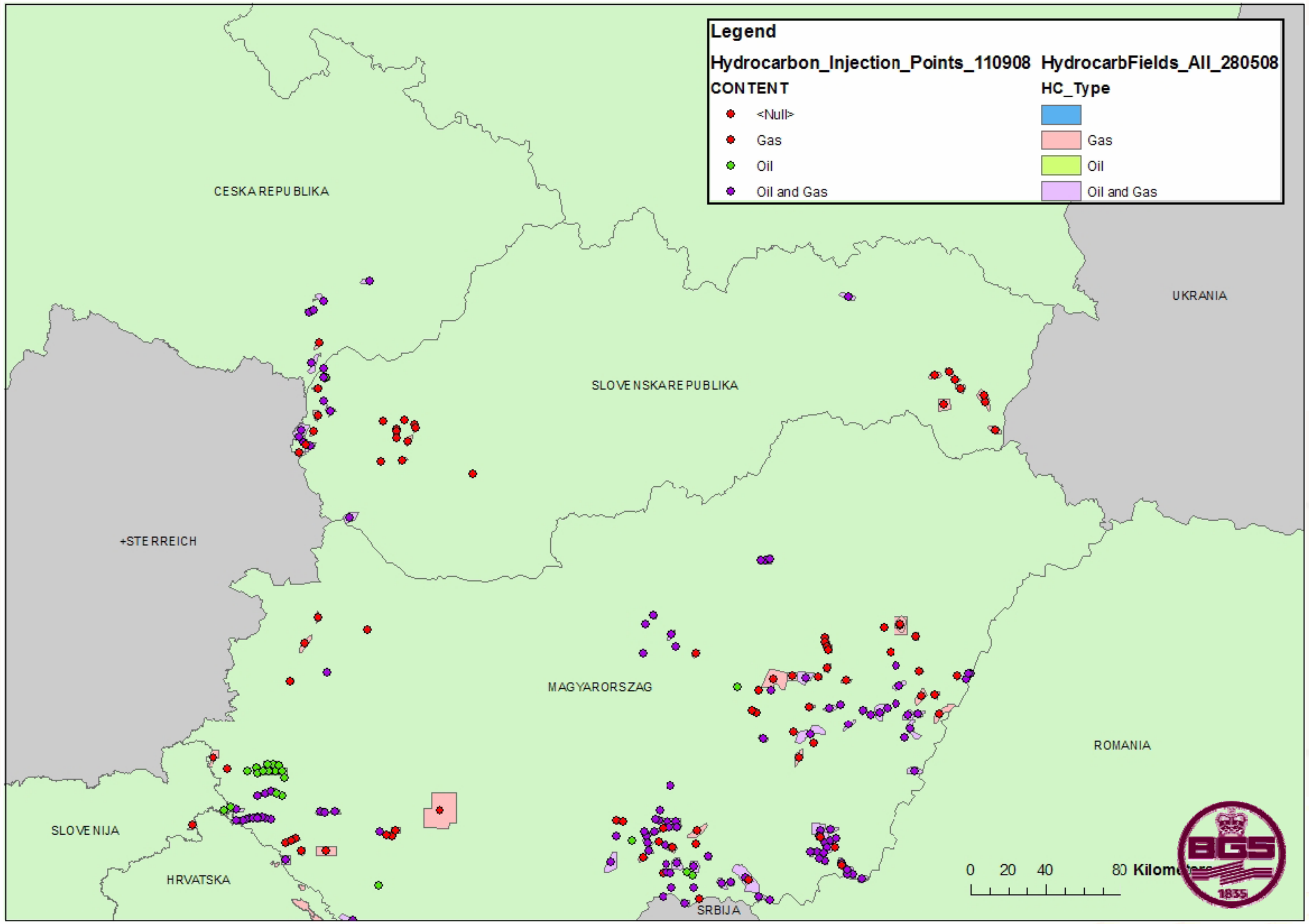
Aquifers


Legend
Aquifer Injection Points
Aquifers Detailed
Aquifers Regional
0 200 400 800 Kilometers

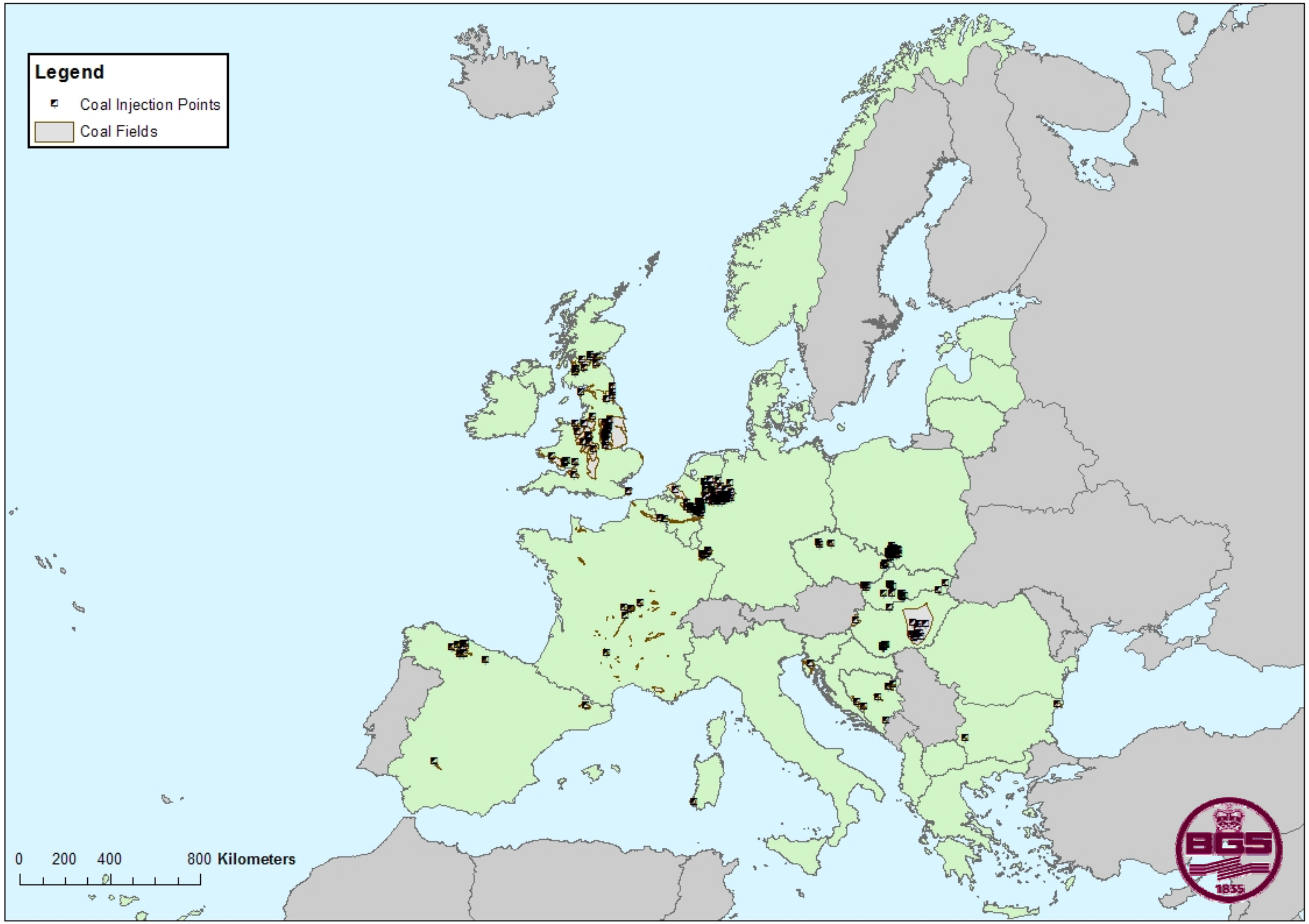

Identify
Identify from:
<Top-most layer>
Aquifer Injection Points
Havnsoe
Location:
-535,440.800 6,507,402.549 Meters
Field Value
OBJECTID 1068
Shape Point
NAME Havnsoe
VOLUME 3670000000
CAPACITY 923
HEIGHT 150
HEIGHT_STDEV 15
HEIGHT_DIST_TYPE Normal
DEPTH 1500
DEPTH_STDEV 150
DEPTH_DIST_TYPE Normal
RADIUS 8000
RADIUS_STDEV 4000
RADIUS_DIST_TYPE Normal
TRAPRADIUS 7277
TRAPRADIUS_STDEV 728
TRAPRADIUS_DIST_TYPE Normal
WELLRADIUS 0.15
PERMEABILITY 300
PERMEABILITY_UNCERT_FACT 3
PERMEABILITY_DIST_TYPE Log-Normal
POROSITY 0.22
POROSITY_STDEV 0.022
POROSITY_DIST_TYPE Normal
RHOCO2 629
COMPROCK 0
COMPROCK_STDEV 0
COMPROC_DIST_TYPE Normal
RESPRESS 15
RESPRESS_STDEV 1.5
RESPRESS_DIST_TYPE Normal
MAXPRESS 36
MAXPRESS_STDEV 1.8
MAXPRESS_DIST_TYPE Normal
RESTEMP 323.16
RESTEMP_STDEV 10
RESTEMP_DIST_TYPE Normal
Identified 1 feature


Hydro carbon fields & Coal fields
Coal
Gas
Oil
Oil and Gas

Hydrocarbon fields



Coal measures



Capacity calculations

Methodological resources:

- **CSLF Task Force on CO_2 Storage Capacity Estimation**
- **Modeling work by TNO**
- **US DOE methodology by the Geologic Working Group of the US Regional Carbon Sequestration Partnership Program**

Uncertainties for aquifers !

General considerations for saline aquifers

- Distinguish between estimates for bulk volume of regional aquifers and estimates for individual structural or stratigraphic traps
- For estimates based on the bulk volume of regional aquifers we suggest a storage efficiency factor of 2 % based on work by US DOE
- For trap estimates the choice of storage efficiency factor depends on whether the aquifer system is open, semi-closed or closed
- For traps in open or semi-closed aquifer systems we suggest a rule-of-thumb approach with values for the storage efficiency factor in the range between 3 % and 40 % for semi-closed low quality and open high quality reservoirs, respectively
- For traps in closed aquifer systems we suggest an approach based on trap to aquifer volume ratio, pore and water compressibility and allowable average pressure increase with typical values for the storage efficiency factor in the range between 1 % and 20 %
- Storage capacity estimates should always be accompanied with information on assumptions and approach for storage efficiency factor

US DOE estimation of storage efficiency factor

Terms included in the CO_2 storage efficiency factor are:

Term	Symbol (range)	Description
Terms used to Define the Entire Basin/Region Pore Volume		
Net to total area	A_n/A_t (0.2–0.8)	Fraction of total basin/region area that has a suitable formation present.
Net to gross thickness	h_n/h_g (0.25–0.75)	Fraction of total geologic unit that meets minimum porosity and permeability requirements for injection.
Effective to total porosity ratio	ϕ_e/ϕ_{tot} (0.6–0.95)	Fraction of total porosity that is effective, i.e. interconnected
Terms used to Define the Pore Volume Immediately Surrounding a Single Well CO_2 Injector		
Areal displacement efficiency	E_A (0.5–0.8)	Fraction of immediate area surrounding an injection well that can be contacted by CO_2; most likely influenced by areal geologic heterogeneity such as faults or permeability anisotropy.
Vertical displacement efficiency	E_I (0.6–0.9)	Fraction of vertical cross section (thickness), with the volume defined by the area (A) that can be contacted by the CO_2 plume from a single well; most likely influenced by variations in porosity and permeability between sublayers in the same geologic unit. If one zone has higher permeability compared with others, the CO_2 will fill this one quickly and leave the other zones with less CO_2 or no CO_2 in them.
Gravity	E_g (0.2–0.6)	Fraction of net thickness that is contacted by CO_2 as a consequence of the density difference between CO_2 and in situ water. In other words, 1-Eg is that portion of the net thickness **not** contacted by CO_2 because the CO_2 rises within the geologic unit.
Microscopic displacement efficiency	E_d (0.5–0.8)	Portion of the CO_2-contacted, water-filled pore volume that can be replaced by CO_2. Ed is directly related to irreducible water saturation in the presence of CO_2.

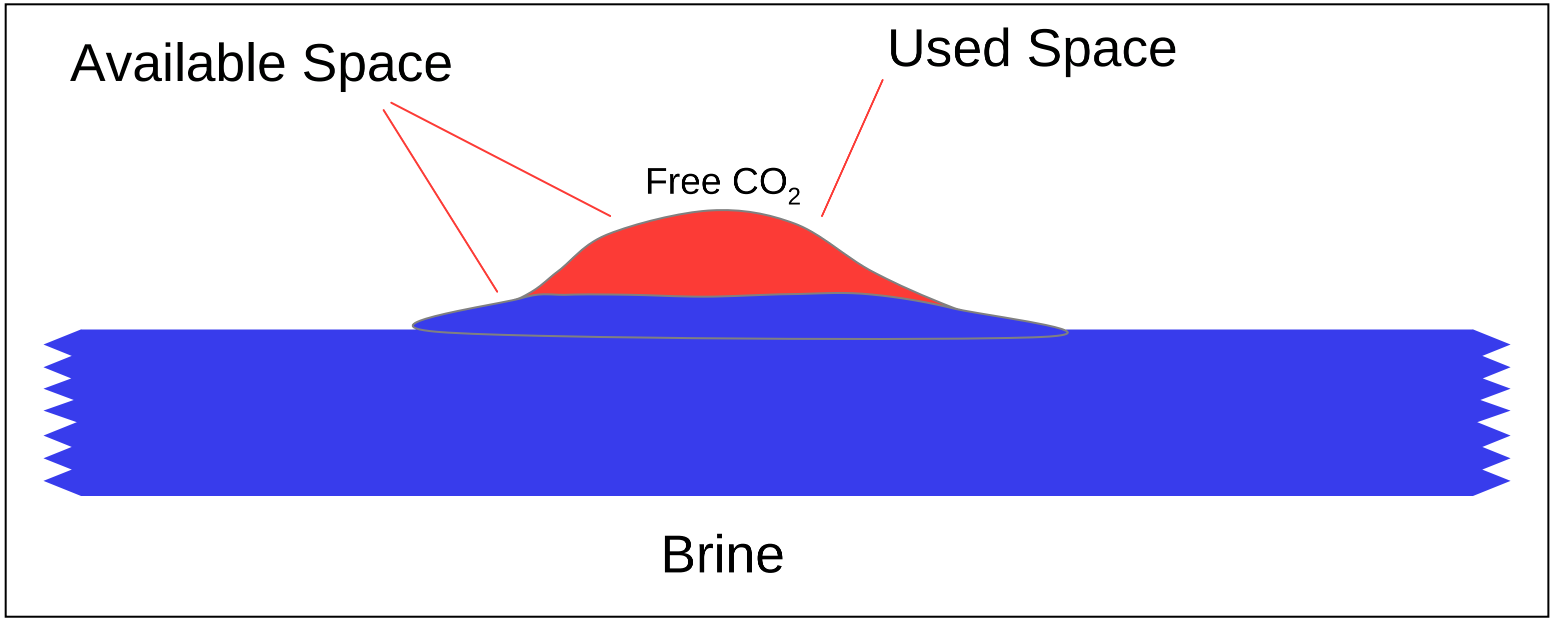
The range of values for each parameter is an approximation to reflect various lithologies and geologic depositional systems that occur throughout the Nation. The maximum and minimum are meant to be reasonable high and low values for each parameter.

$P_{15} : S_{eff.} = 1\ \%$

$P_{50} : S_{eff.} = 2\ \%$

$P_{85} : S_{eff.} = 4\ \%$

Conceptual model for open aquifers

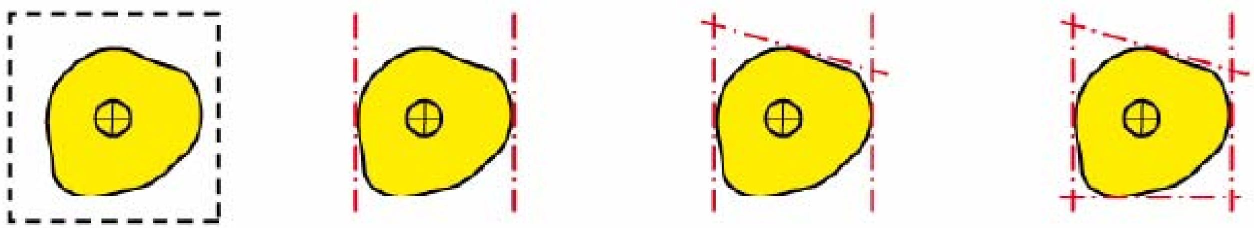


- Storage space is generated by displacing existing fluids and distributing pressure increase in surrounding aquifer system
- Storage volume = A · height · N/G · ϕ · S_{eff}
- S_{eff} depends on connectivity to surrounding aquifer
- S_{eff} = Used space/Available space

• **From Filip Neele, TNO**

Storage efficiency factor for open and semi-closed aquifers

Storage coefficient (by the rule-of-thumb) S_{cff}

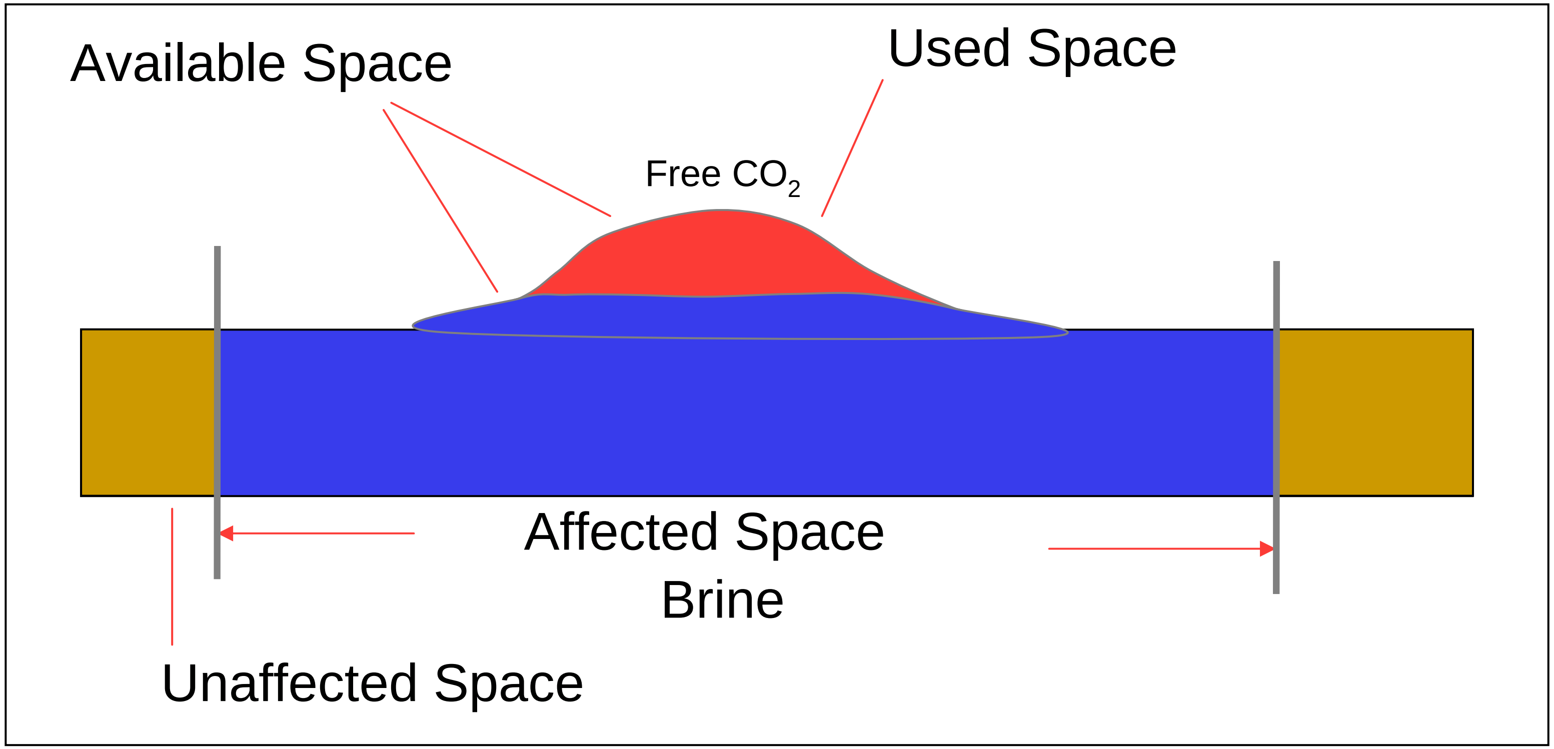


	1*	2	3	4
High quality reservoir	40 %	20 %	10 %	3–5 %
Low quality reservoir	20 %	10 %	5 %	<3 %

*Volume of bulk reservoir shall be 5-10 times the volume of the reservoir

–·–·– Fault

Conceptual model for open aquifers



- Affected space is full! (rock and water for aquifers)
- More space only via **pressure increase** and **compressibility**
- Storage volume = A · height · N/G · ϕ · $(C_w + C_p)$ · Δp_{avg}
- Δp_{avg} = allowed average pressure increase in affected area

• **From Filip Neele, TNO**

Storage efficiency factor for closed aquifers

$S_{eff} = V_{CO2} / (\varphi \cdot V_{trap})$

$V_{CO2} = c \cdot \Delta p \cdot \varphi \cdot V_{aquifer}$

$\Rightarrow$ $Seff = (c \cdot \Delta p \cdot \varphi \cdot V_{aquifer}) / (\varphi \cdot V_{trap}) = c \cdot \Delta p \, (V_{aquifer} / V_{trap})$

- Storage efficiency
  - -As function of $V_{aquifer} / V_{trap}$ (between 1 and 100)
  - -As function of depth
  - -In table: percentage of trap pore space filled with CO_2

- Pressure increase 10% ← Key parameter, site specific
- Compressibility
  - -Pore: typical value $6 \cdot 10^{-5}$ bar^{-1}
  - -Water: $4 \cdot 10^{-5}$ bar^{-1}
  - -Total: pore + water = $10 \cdot 10^{-5}$ bar^{-1}

$V_{aquifer} / V_{trap}$ →

Depth (m)	1	5	10	50	100
1000	0.10	0.5	1.0	5	10
1500	0.15	0.8	1.5	8	15
2000	0.20	1.0	2.0	10	20
2500	0.25	1.3	2.5	13	25
3000	0.30	1.5	3.0	15	30
3500	0.36	1.8	3.6	18	36

Small capacity of enclosed traps!

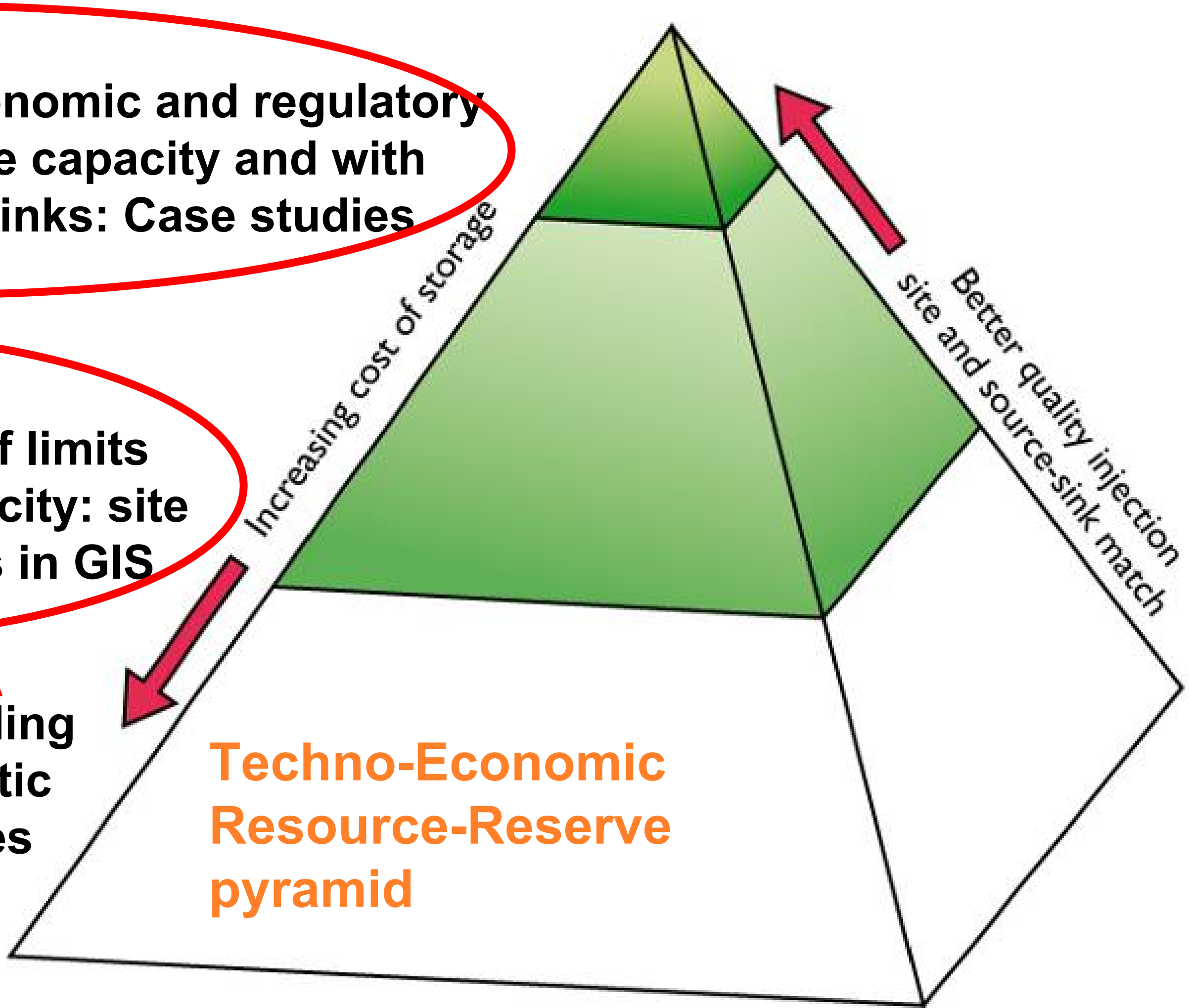
Higher capacities only when large aquifer volume can be used to accommodate pressure increase.
NOTE: numbers refer to trap, but depend on entire aquifer volume!

- **From Filip Neele, TNO**

Top:
Practical capacity with economic and regulatory barriers applied to effective capacity and with matching of sources and sinks: Case studies

Middle:
Effective capacity with technical/geological cut-off limits applied to theoretical capacity: site specific/regional estimates in GIS

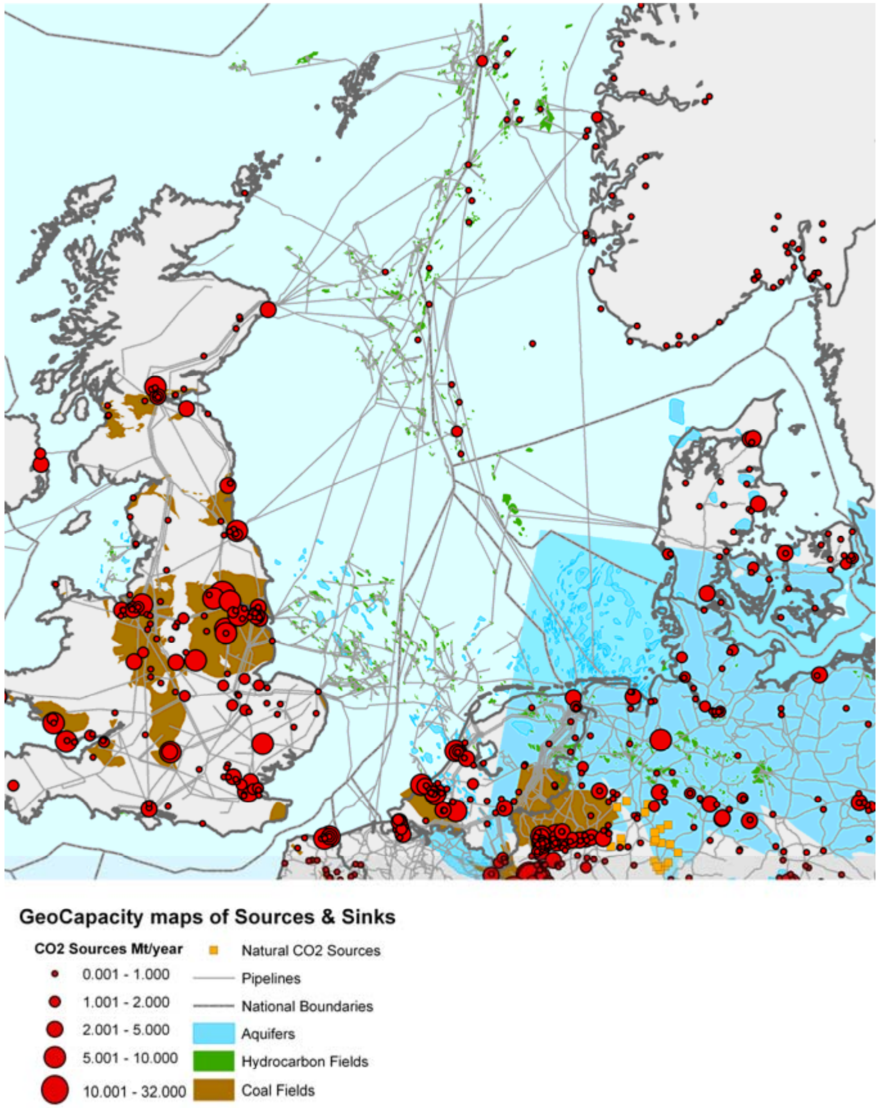
Bottom:
~~Theoretical capacity including large uneconomic/unrealistic volumes: regional estimates without storage efficiency~~



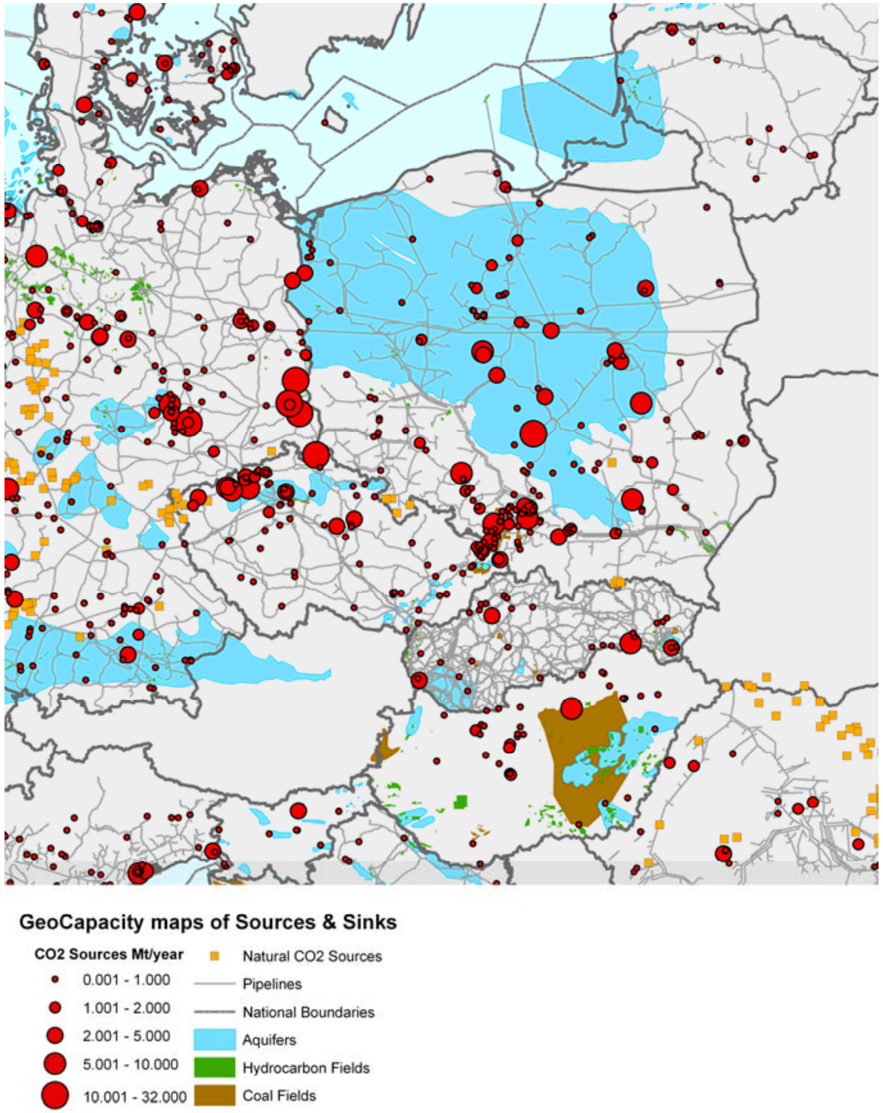
Preliminary pan-European storage capacity estimate

Emissions from big stationary sources (Gt CO2)	Storage capacity (Gt CO2)					
	Aquifers		Hydrocarbon fields		Coal measures	
	Effective capacity	Conservative estimate	Effective capacity	Conservative estimate	Effective capacity	Conservative estimate
2	350	100	30	25	1.5	1.0

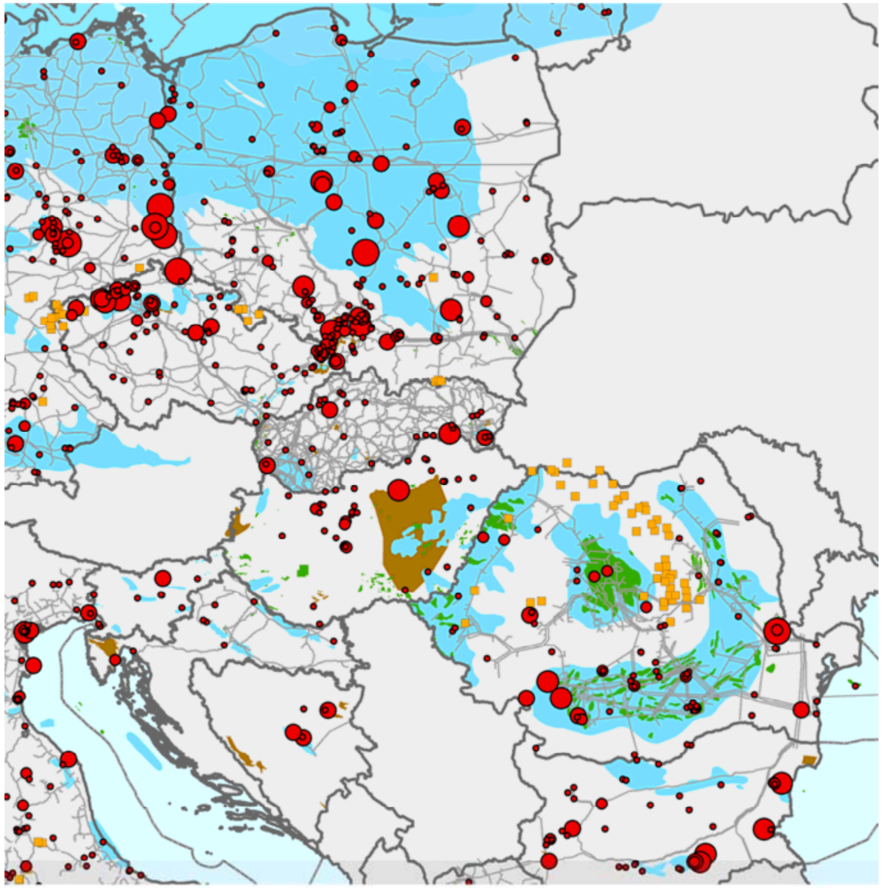
North Sea area



North East Europe

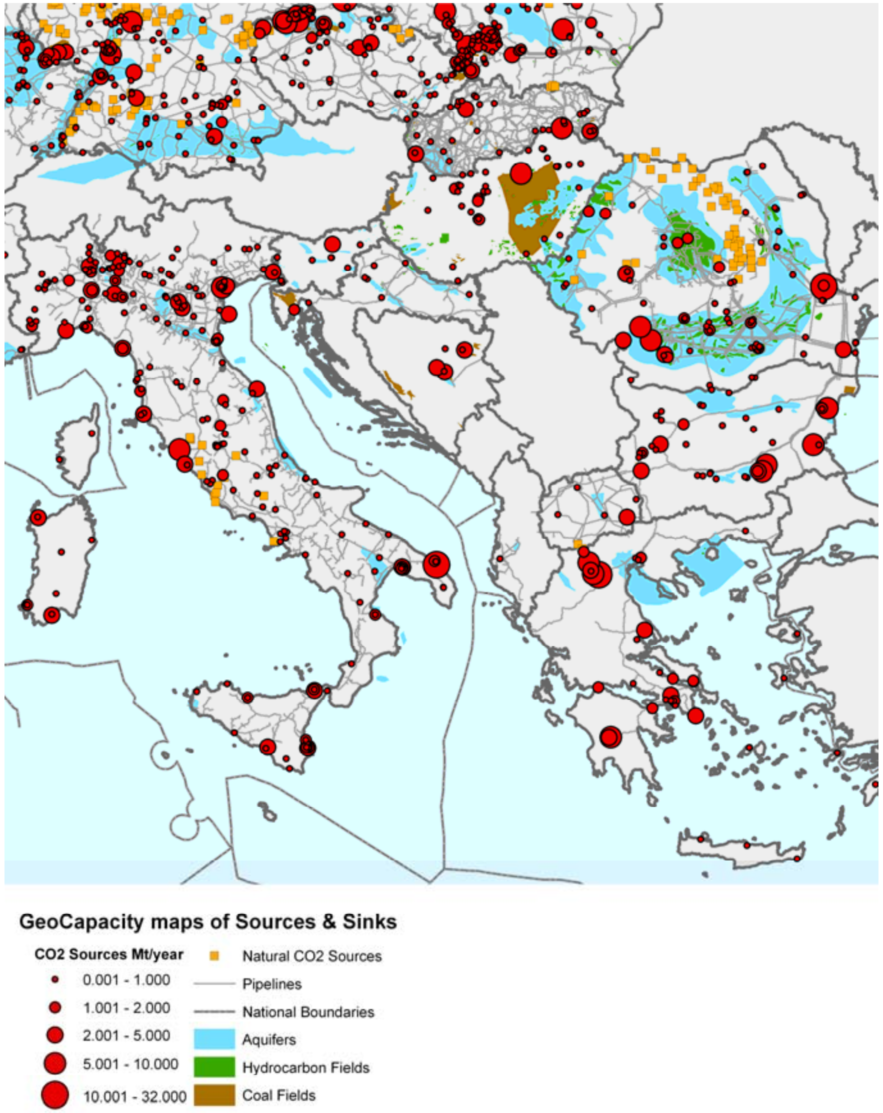


Central East Europe

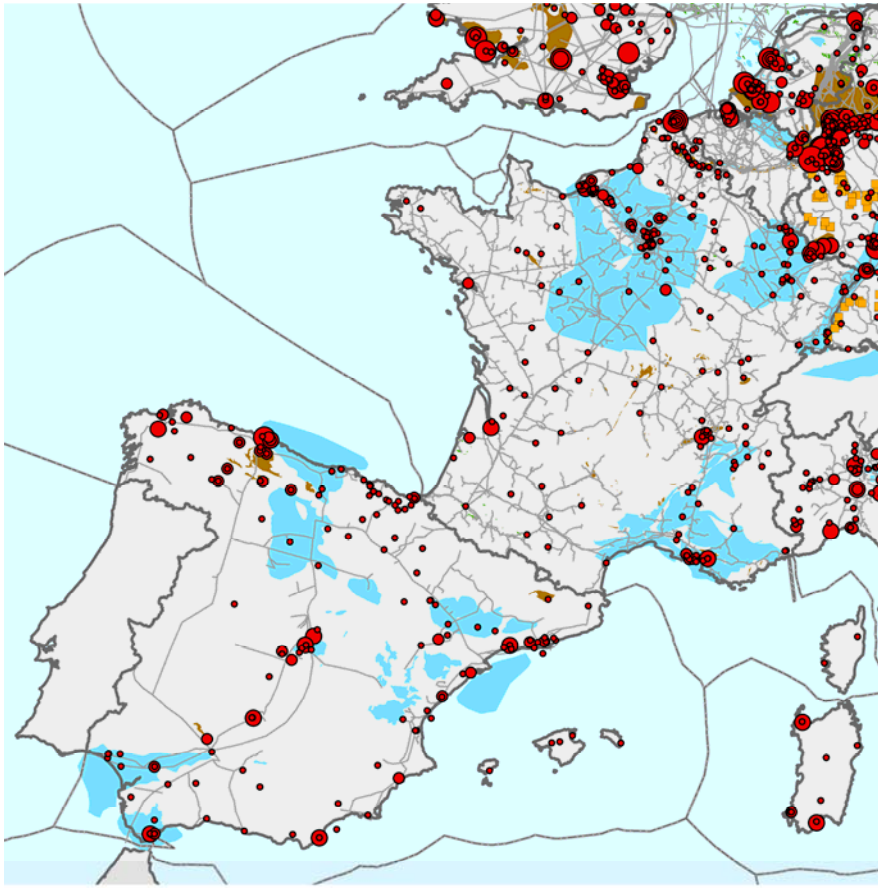


GeoCapacity maps of Sources & Sinks

South East Europe



South West Europe



GeoCapacity maps of Sources & Sinks

CO2 Sources Mt/year	
0.001 - 1.000	Natural CO2 Sources
1.001 - 2.000	Pipelines
2.001 - 5.000	National Boundaries
5.001 - 10.000	Aquifers
10.001 - 32.000	Hydrocarbon Fields
	Coal Fields

Case studies

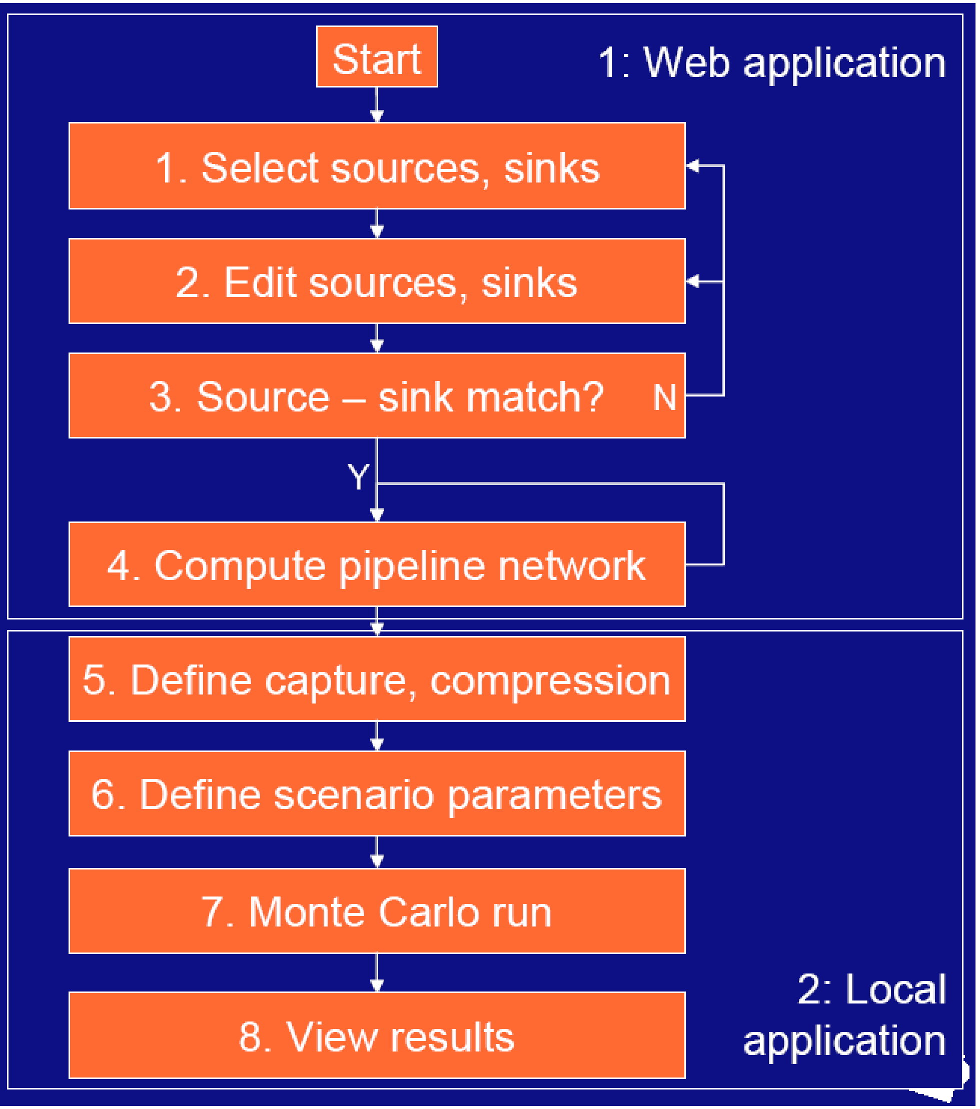
Geological part

- selected structures with potential for pilot / demonstration projects

Economic part

- utilisation of Decision Support System (DSS)

Economic tool Overview



WP 6.1
Initiation of technology transfer to China

Focusing on one province with large CO_2 point sources and investigate the storage potential

WP 6.2
Framework for international cooperation

Establish communication links between GeoCapacity and CSLF countries to initiate the technology transfer

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Main project achievements:

- CCS inventory of Europe incl. GIS (base for future CO_2 storage atlas of Europe ?)
- Contribution to guidelines for assessment of geological storage capacity, site selection criteria and methodology for ranking
- Pioneering CCS work in many countries

Project website:

http://www.geocapacity.eu