CGS Baltic seed project (S81)

Project substance report

April 2017

EUSBSR
EU STRATEGY
FOR THE BALTIC
SEA REGION

Part-financed by
the European Union
EUSBSR
EU STRATEGY
FOR THE BALTIC
SEA REGION
SEED MONEY FACILITY

Preface:

The CGS Baltic seed project 18.2.2016-31.3.2017 was part-financed by the European Union seed money facility as part of the EU strategy for the Baltic Sea Region (EUSBSR). The partnership consisted of Geological Survey of Finland (coordinator), Institute of Geology at Tallinn University of Technology, Uppsala University, Nature Research Centre, Polish Geological Institute - National Research Institute and AGH University of Science and Technology in Krakow. The project goal was to develop a proposal for a CO2 storage project within the Baltic Sea Region (BSR), which addresses the horizontal action Climate and priority area Secure of the EUSBSR.

This report is structured so that the results of each subtask of the seed project are summarised within separate chapters, with chapter numbers corresponding to the subtask numbers in the seed project application. Some of the subtasks have also produced longer reports and other material, which are included as annexes to this report.

Contributing authors:

Nicklas Nordbäck, Geological Survey of Finland (coordinator)
Daniel Sopher, Auli Niemi & Chris Juhlin; Uppsala University, Sweden
Alla Shogenova & Kazbulat Shogenov; Institute of Geology at Tallinn University of Technology, Estonia
Saulius Šliaupa & Rasa Šliaupiene; Nature Research Centre, Vilnius, Lithuania
Adam Wójcicki; Polish Geological Institute - National Research Institute, Warsaw, Poland
Stanislaw Nagy & Lukasz Klimkovski; AGH University of Science and Technology, Krakow, Poland

Summary of the seed money project achievements

Based on the current knowledge, there is a large theoretical capacity to store CO2 in the Palaeozoic sedimentary succession of the Baltic basin. The most prospective areas of the Baltic basin borders several countries such as Sweden, Latvia, Lithuania, Poland and Russia but current estimates are mostly based on national studies. The goal of CGS Baltic is to enable a basin scale view of the storage potential and to identify the most promising CO_2 storage sites.

CGS Baltic seed project gathered geological CO_2 storage experts from around the Baltic basin. The situation of Carbon Capture and Storage (CCS) in the Baltic Sea Region (BSR) has been described by: exchange of information with relevant stakeholders, studying of existing regulatory frameworks, compiling of previous research results and by mapping of data availability. The ultimate aims of CGS Baltic is to map the potential CO_2 storage sites and capacity in the Baltic Sea region, characterize key reservoir and cap rock properties and to model relevant underground processes, aiming further to pilot testing and commercial CCS activities.

As the first post-seed step of CGS Baltic, a Concept Note for the third call of the Interreg Baltic Sea Region program will be prepared. This first proposal emerging from the CGS Baltic cooperation will map out prospective structures in the Baltic basin, suitable for a range of different subsurface storage options, including CO_2 storage.

Table of Contents

Output 1 - Assessment of the situation of CCS and the state of play in the BSR

1.1 Legal and regulatory framework

1.1.1 International Conventions

Major regulations that affect CCS are international conventions dealing with trans-boundary shipment of CO_2. Two such agreements are the **London Protocol** (**1996)** and the **OSPAR Convention (1992)**. All of the BSR countries are contracting parties of the **Helsinki Convention (1992)** (HELCOM) aiming to protect the Baltic Sea Area.

In 1996, Parties of the **London Convention (1972)** (LC) adopted a Protocol to the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, 1972 (**London Protocol (1996)**, LP) which entered into force in 2006. The LP restricts all dumping except for a permitted list (which still require permits). In order to enable sub-seabed storage the parties to the protocol adopted an amendment in 2006 where CO_2 sequestration in sub-seabed geological formations was added to the Protocol Annex 1, this entered into force on 10 February 2007 (Table 1). "Specific Guidelines for Assessment of Carbon Dioxide Streams for disposal into Sub-seabed geological Formations" were also adopted by the Protocol Parties in 2007. CO_2 streams from CO_2 capture processes are in the list of permitted substances. The amendments state that "carbon dioxide streams may only be considered for dumping, if disposal is into a sub-seabed geological formation; they consist overwhelmingly of carbon dioxide (they may contain incidental associated substances derived from the source material and the capture and sequestration processes used); no wastes or other matter are added for the purpose of disposing of them."

At the end of February 2017 there were 48 Parties to the LP, 87 parties to the LC and 99 parties in total (LC and LP). Poland, Finland, Russia and Belarus are parties to the LC, but have not ratified the LP. Latvia and Lithuania are not parties to either the LC or the LP, Denmark, Germany, Norway, Sweden and Estonia have ratified both the LC and LP. Finland, Poland, Latvia, Lithuania, Russia and Belarus are not parties to the LP. (Fig.1 - Annex1, Table 1).

An **Amendment to Article 6** of the LP was adopted in 2009. Article 6 prohibits "export of wastes or other matter to other countries for dumping or incineration at sea." The 2009 amendments to Article 6 enable - exclusively - the export of carbon dioxide streams for the purpose of sequestration in trans-boundary sub-seabed geological formations, it is not yet in force. By February 2017 it was only accepted by three countries (Norway, The Netherlands and UK), however, for an amendment to the LP to enter into force, acceptance by two-third of the Parties is required. Some options for trans-boundary storage of CO_2 regulated by Article 6 of the LP and CCS Directive are described in the Bastor2 Report.

The **OSPAR Convention 1992** includes 15 countries located on the western coast and catchments of Europe, together with the European Community (Fig. 2a, b, Annex 1), cooperating to protect the marine environment of the North-East Atlantic. This includes several BSR countries (**Denmark, Finland**, **Germany**, **Norway and Sweden**). The Convention permits dumping of carbon dioxide streams from carbon dioxide capture processes for storage, provided that its disposal is into a sub-soil geological formation and the streams consist overwhelmingly of carbon dioxide. They may contain incidental associated substances derived from the source material and the capture, transport and storage processes used; no wastes or other matter are added for the purpose of disposing of those wastes or other matter; they are intended to be retained in these formations permanently and will not lead to significant adverse consequences for the marine environment, human health and other legitimate uses of the maritime area.

The 1992 **Helsinki Convention** (**HELCOM**) entered into force in 2000, after the ratification by the European Economic Community, Germany, Latvia and Sweden (1994), Estonia and Finland (1995), Denmark (1996), Lithuania (1997), and Poland and Russia (1999) (http://helcom.fi/about-us/convention). The **HELCOM** Convention is applied to the protection of the marine environment of the Baltic Sea Area. The Contracting Parties shall prohibit dumping in the Baltic Sea Area. Each Contracting Party shall take all measures in order to prevent pollution of the marine environment of the Baltic Sea Area resulting from exploration or exploitation of its part of the seabed and the subsoil.

Table 1. Ratified international agreements and national CCS laws in the BSR countries

International agreements							National CCS laws (EU CCS Directive)				
Country	London Convention 1972	London Protocol 1996 (LP)	Amendments to LP		HELCOM 1992	OSPAR 1992	CO_2 storage permitted for Industrial Scale			Research	Exploration permit always required
			2006 (LP.1(1))	2009 (Article 6) (LP.3 (4))			Onshore	Off-shore	Temporal restriction		
Denmark	X	X	X		X	X	Forbid-den until 2020	Yes for EOR	Until 2020	X	X*
Estonia		X	X		X	EU sign.	No	No		X	
Finland	X				X	X	No	No		X	
Germany	X	X	X		X	X	Up to 4 Mt CO2 annually and maximum 1.3 Mt per one project.		Until 2018	X	X
Latvia					X	EU sign.	No	No		X	X
Lithuania					X	EU sign.	X	X		X	X
Poland	X				X	EU sign.	Not permitted, except for demo-projects		Until 2024	X	X
Sweden	X	X	X		X	X	No	X		X	X
Norway	X	X	X	X		X	No	X		X	
Russia	X				X	NA	NA	NA	NA	NA	NA
Belarus	X					NA	NA	NA	NA	NA	NA
		NA - not applicable				* - required when information is limited					

1.1.2 CCS Directive implementation

Public authorities of the BSR responsible for implementation of the EU CCS Directive (Table 2a,b - Annex 1,) reported to the EC with results from the *CCS Directive transposition* in 2013 and 2016. In the BSR only Lithuania allowed CO_2 geological storage both onshore and offshore. In Denmark, regulations have prohibited storage until 2020, except for offshore CO_2 enhanced oil recovery (EOR). CO_2 storage is prohibited in Poland until 2024 except for demonstration projects. The mass of CO_2 which can be stored is limited in Germany up until 2018 (where up to 4 Mt CO_2 can be stored annually and a maximum of 1.3 Mt for any individual project). CO_2 storage is prohibited except for research and development in Estonia, Finland and Latvia. Offshore CO_2 storage is permitted in Sweden and in Norway. The EU CCS Directive is applied only to CO_2 storage amounts of more than 100000 tonnes. Therefore CO_2 injection is permitted for research and pilot projects in all BSR countries, which are members of the EU (Table 1).

The CCS directive encourages bilateral agreements between countries to arrange for trans-boundary CO_2 transport in order to circumvent the London Protocol prohibiting the export of CO_2 as waste. Many countries addressed trans-boundary transport of CO_2 and trans-boundary storage sites or complexes in their regulations. However, only Germany, The Netherlands and the UK have experience of such trans-boundary cooperation within the North Sea Basin Task Force, who developed common principles for managing and regulating the transport, injection and sub seabed storage of CO2 in the North-Sea. In the BSR two pilot injections have already been made in Lithuania in 2013, investigating the potential of CO_2 to be used for EOR.

As a result of CCS Directive implementation CO_2 captured and transported for the purpose of geological storage is excluded from the national waste regulations. As well as this operators of combustion plants with a capacity of 300 MW or more should assess conditions and demonstrate that their plants are built “capture-ready” in all BSR countries, who are members of the EU.

The progress in EU CCS Directive implementation in 2013-2016 is presented in 2017 by the EC and reported in the Annex 1 to this report.

1.2 Political situation and stakeholder analysis

Though many experts have recognized CCS as a critical tool for deep emission reductions and while it would be important, for large-scale deployment in the 2020s, to demonstrate different CCS options at progressively larger scale, there has been a lack of support and progress in political and economic terms (IEA, 2014). Many past and present CCS projects have expressed a need for more clear and stable emissions reduction policies, economic incentives, together with comprehensive legal and regulatory arrangements.

According to GCCSI, 2015 the reasons for the slow development of CCS in Europe is that an explicit target for CCS deployment has never been set at the European level, whereas for other low-carbon solutions European binding targets were mandated by 2020. For renewable energy, it is instructive to look at how technology uptake driven by the 20 % renewable energy target at the European level, translated into nationally binding targets. A sharp fall in the carbon price has occurred since the announcement by the European Energy Programme for Recovery (EEPR) projects, do not support CCS uptake in the absence of other market drivers. The marked fall in the carbon price has cut the available revenues from the sales of 300 million allowances of the NER300. In addition, a combination of policy instruments is not effectively in place yet. While a number of policies to support R&D and deployment of the technology exist, many EU Member States have few or no policy frameworks in place that provide appropriate financial support for CCS deployment, help to close the commercial gap and attract private investments.

Generally, the main stakeholders of CCS are industry, states, public institutions and Non Governmental Organisations (NGOs). Based on general opinions, contacts and discussions during the CGS Baltic seed project there is currently low interest among CO2 producing companies to make investments in CCS technology. The attitude towards CCS is varying among NGOs in different countries. Opposition among green NGOs has been seen in Poland, Germany and Denmark while the opinion is more positive in Norway and Sweden.

To enhance actions in the field of CCS, governments would need to demonstrate a clear, long-term commitment to CCS, underpinned by detailed policy, legal and regulatory frameworks and economic incentives that would provide predictability for investors. In this sense, the Baltic Sea region is directly dependent on the policy laid out by the EU.

A more detailed description of the political situation and stakeholders is given in Annex 2 of this report. References are listed in annex 2.

1.3 Exchange of information with North Sea Basin Task Force/NORDICCS

The aim of subtask 1.3 was to exchange information with the North Sea Basin Task Force (NSBTF) and benefit from its experience in the deployment of the CCS technology. However, during the project it turned out that NSBTF activity has been suspended in recent years. As there is no active web page or new publications for the NSBTF, it was decided to focus on the reports prepared by the group in past years. Additionally, efforts were made to investigate the activity of NORDICS group, focusing on its report published in December 2016. The Swedish Geological Survey (NORDICCS partner) also participated in two CGS Baltic seed project meetings.

The experience of both the North Sea Basin Task Force and the NORDICSS project partners highlights that cooperation with partners strongly interested in a common goal is an extremely important element of a good network. The network should consists of both R&D partners and have significant involvement from industrial partners with the potential to execute CO2 projects.

The NSBTF and the NORDICCS project partners agreed that in order for CCS to be widely deployed in time to meet climate targets, actions must be taken urgently. These actions include:

- amending existing legal and regulatory frameworks to enable CCS (e.g. establishing a Measurement Reporting Guideline which allows ship transport of CO2 under EU ETS)
- establish incentives for CCS (e.g. capital grants for early CCS projects),
- ensure CCS is implemented in a manner acceptable to stakeholders.

A more detailed description of NSBTF and NORDICCS activities is given in Annex 3.

1.4 State of geological CO2 storage research in the Baltic Sea region

Different CO_2 geological storage research activities were performed in the Baltic Sea region since the year 2000, *e.g*. FP6 EU GeoCapacity (2006-2008), FP7 CGS Europe (2012-2013), FP7 CO2Stop, etc. The most important publications of the CGS Baltic project partners in the field of CCS are listed in Annex 4. The most important recent and ongoing research projects are listed by countries below:

POLAND

- In the National Programme (2008-2012/13) regional studies have been carried out investigating the Polish offshore Cambrian aquifer. This aquifer contains a number of hydrocarbon fields which were appraised and some of them developed (i.e. the B3 oil field, which is already depleted to a large extent, the B8 oil and gas field, which has been developed recently, the B6 and B4 gas fields have only been appraised so far). These can be potential storage sites of the CO_2 combined to the tertiary (CO_2) enhanced oil recovery activities.
- Environmental impact studies within the frames of the recently completed EU FP7 ECO2 project; where the Lotos B3 oil field was one of case studies (coordinator IFM-GEOMAR, DE; Polish partners: Univ. of Gdańsk and LOTOS).

- Pre-feasibility studies on CCS (full chain) in the frames of Norwegian Grant PRO_CCS; where one of the scenarios/case studies included the B3 oil field (Polish partners - Silesian and Częstochowa Universities of Technology).

SWEDEN

- The Bastor project where Uppsala University participated evaluated the Baltic Sea capacity at large. Results are presented in e.g. SLR (2014), Yang et al. (2015) and in Niemi (2015).

- Following on from the SwedSTORECO2 project, Uppsala University is actively trying to secure funding to establish a pilot CO2 injection site on Gotland. An application was submitted to the H2020 call for pilots.

- The Swedish Geological survey (SGU) has been participating in the NORDICCS project to map and assess CO2 storage potential in the Nordic countries.

- Uppsala University continues to analyse existing seismic data from the OPAB data set to gain an improved understanding of the geology below Swedish waters in the Baltic Sea.

- New 2D seismic data were acquired in the Swedish part of the Baltic Sea in March 2016. These data can potentially be used to better understand the Faludden reservoir, which has a large potential for CO_2 storage.

- Acquisition of additional marine seismic data is planned in the autumn of 2017.

- Uppsala University has had and is having a key role in developing the Heletz, Israel CO_2 injection site (see e.g. www.co2mustag.eu) and the associated experiments, in the frame of several recent EU projects on CO_2 (MUSTANG; PANACEA, CO2QUEST, TRUST) where Uppsala University has had a leadership role, either as coordinator or Work Package leader.

- A comprehensive book was recently published: Niemi et al, (Eds) (2017) 'Geological Storage of CO2 in deep saline aquifers' (http://www.springer.com/cn/book/9789402409949)

- Two CO_2 related PhD theses were recently competed at Uppsala University :

  - Farzad Basirat (2017) 'Process Models for CO2 Migration and Leakage - Gas Transport, Pore-Scale Displacement and Effects of Impurities'
  - Tian Liang (2016) *CO_2 storage in deep saline aquifers: Models for geological heterogeneity and large domains.*

- Four CO_2 related PhD Theses are presently underway

  - Kristina Rasmusson on residual trapping of CO_2 (expected defence on 2017)
  - Maria Rasmusson on dissolution trapping of CO_2 (expected defence on 2017)
  - Saba Joodaki on field characterization of CO2 trapping (expected defence on 2018)
  - Maryeh Hedayati on hydrogeochemistry of deep systems (including CO2 storage)

FINLAND

- The objective of the Finnish Carbon Capture and Storage Program (CCSP) 2011-2016, was to develop CCS-related technologies and concepts leading to essential pilot and demonstration projects by the end of the program. A further objective was to create a strong scientific basis for the development of CCS technology, concepts and frameworks, and to establish active, international CCS co-operation. Screening for prospective sites for geological storage of CO2 in the Southern Baltic Sea was performed and reported in 2013. The screening was performed as a collaboration between CCSP and Swedish CCS consortium.

- CARBON STORAGE IN THE BALTIC **–** Elforsk/CCSP Bastor2 study**.** The Bastor2 study estimated in 2015 some 16 Gt of CO_2 storage capacity in the Baltic Sea region along with assessments of environmental, social, legal and logistical conditions.

ESTONIA

- The storage capacity of Estonia in aquifers was estimated as zero, while economic modelling of an Estonian-Latvian scenario showed the prospects for storage of Estonian CO_2 emissions in Latvian structures. Options to store and/or use CO2 emissions in other BSR countries were estimated, while political and legislative agreements need to be implemented.

- CO_2 mineral carbonation using alkaline oil shale ash produced during oil shale combustion in Estonia is another prospective route for CO_2 storage studied in TTU and considered by Estonian stakeholders. Several PhDs in Chemical and Materials Technology were defended at TTU on CO_2 mineral carbonation and Oxyfuel combustion CO_2 capture in 2008-2016.

- In FP7 CO2Stop project TTUGI provided data on Latvian onshore structures (based on EU Geo Capacity database) and two offshore structures (E6 and E7) studied by TTUGI.

- The latest research direction is detailed modelling of CO_2 storage in some prospective Latvian structures onshore and especially offshore.

- PhD thesis "Petrophysical models of the CO_2 plume at prospective storage sites in the Baltic Basin" was defended in 2015 by K. Shogenov (supervisor A. Shogenova).

- The Oil-bearing E6 structure, offshore Latvia, was estimated as the largest prospective structure for CO_2 storage in the Cambrian Deimena Formation and prospective for storage and CO_2-EOR in Upper Ordovician Saldus Formation. The owner of this structure, the oil company Odin Energi Latvia took part at the final CGS Baltic meeting in Riga.

- At the present time TTUGI is working on data collection for basin-scale modelling of CO_2 storage, on synergy scenarios (CCS+ CO2-EOR+) within the E6 structure and other cross-cutting issues.

LATVIA

- Latvia has the largest CO_2 geological storage potential onshore and offshore in the region. The recent research activities were related FP7 CGS Europe project. No in-house projects were initiated lately.

LITHUANIA

- CO_2 EOR action was taken by "Minijos Nafta" to investigate exploitation of the ROZ (residual oil zone; otherwise not exploitable) in the Cambrian sandstones in three oil exploitation wells using CO_2 in 2013 and 2015. Results – estimated high oil recovery percentage using CO_2 and about 100 Mt CO_2 storage potential in west Lithuanian Gargzdai zone. The recoverable additional oil resources can reach 100 million barrels of oil.

- PhD thesis "Prospects of CO_2 geological storage in the Baltic Sedimentary Basin" was defended in 2014.

1.5. Mapping of available geological data

1.5.1 Introduction

According to the seed money project application the goal of this subtask is to assess the availability and ownership of all relevant seismic and deep bore hole data, and provide as a deliverable, a meta(data)base on the public, commercial and confidential data in question. The meta(data)base shall provide information on ownership of the data, whether these data are public (i.e. free or available for a small "token" fee) or owned exclusively by oil & gas companies (new data - might be accessed under confidentiality agreements). Such information helps to resolve the issues where negotiations with owners of the data such as geological surveys, government institutions and oil companies will be required and/or owners of the data are to be invited to become part of the main project consortium. The meta(data)base is elaborated in the form of a worksheet (*see Annex 5*) including input from questionnaires filled out by the seed project partners (and other available information in question) and supplemented with maps explaining the availability of the key datasets (*see Annex 5*).

1.5.2 The questionnaire

Basic information on the availability and ownership of relevant seismic and deep bore hole data within the area in question has been already gathered and published in the frames of BASREC & BASREC2 projects [1, 2]. However, the relevant scope, degree of detail and coverage was not sufficient for the needs of the CGS Baltic seed project or the proposed future project ideas. Consequently, additional information has to be gathered and collated.

In order to provide input to this task a questionnaire was issued to the project partners, requesting information on:

- Offshore seismic inventory and data ownership (field and processed data)

- Onshore (adjacent onshore areas of respective basins/formations) seismic inventory and data ownership

- Offshore wells inventory and data ownership (well logging data, results from laboratory analysis on drill core samples)

- Onshore wells inventory and data ownership

- Information on regional studies mapping CO2 storage potential

- Remarks (if applicable).

1.5.3 The meta(data)base

The meta-data base on availability/existence and ownership of (offshore and adjacent onshore) geological-geophysical data includes information on:

- Seismic 2-D (locally 3D) offshore and adjacent onshore data, imaging the Paleozoic formations;

- Deep borehole data – offshore and adjacent onshore wells penetrating the Paleozoic formations in question (especially the Cambrian aquifer and its caprock).

The meta(data)base is elaborated in the form of an Excel worksheet/table (*Availability and ownership of relevant seismic and deep bore hole data in the Baltic region - Metadatabase*) that includes information from the said questionnaires filled out by the project partners (using publicly available information, including websites & databases of relevant geological surveys and publications), and from other sources in case of countries not represented in CGS Baltic (publications, websites), supplemented with maps, if apply. The following information is collated in the meta(data)base:

- Denmark (Bornholm area) – after GEUS website (data.geus.dk);

- Estonia – after TTUGI questionnaire;

- Finland – after GTK questionnaire;

- Germany – omitted due to general lack of relevant Paleozoic aquifers;

- Lithuania – after GTC questionnaire;

- Latvia – after TTUGI questionnaire;

- Poland – after PGI-NRI questionnaire;

- Russia (Kaliningrad) – after BASTOR&BASTOR2 publications [1, 2];

- Sweden – after UU questionnaire.

References:

[1] Vernon R., O'Neil N., Pasquali R. Nieminen M., 2013. Screening of prospective sites for geological storage of CO_2 in the Southern Baltic Sea. Espoo 2013. VTT Technology 101, 58 p. + app. 1 p. (final report of the BASTOR project).

[2] Vernon R., 2015. Cross-border collaboration essential for geological success in the Baltic Sea region. 2nd regional conference on CCS: Baltic Carbon Forum 2015, Tallinn, April 22-23, 2015.

[3] Niemi, A. (2015) 'Unlocking the potential for CCs in the Baltic Sea' Global CCS Institute Webinar (http://www.globalccsinstitute.com/insights/authors/WebinarOrganiser/ 2015/04/14/bastor2-unlocking-potential-ccs-baltic-sea?author=MTc1OTM%3D).

[4] SLR (2014) Prospective Sites for Geological Storage of CO2 in Southern Baltic Sea. Report prepared for the Energymyndigheten and released by Global CCS Institute. UU was responsible for the model simulations (http://www.globalccsinstitute.com/publications/final-report-prospective-sites-geological-storage-co2-southern-baltic-sea)

[5] Yang Z., L. Tian, B. Jung, S. Joodaki, F. Fagerlund, R. Pasquali, R. Vernon, N. O'Neill, and A. Niemi (2015), Assessing CO2 storage capacity in the Dalders Monocline of the Baltic Sea Basin using dynamic models of varying complexity. *International Journal of Greenhouse Gas Control* 43, 149-160. http://dx.doi.org/10.1016/j.ijggc.2015.10.024.

Output 2 – Plan for main project

2.1 CO2 storage atlas

There is significant technical potential for storing CO_2 in geological formations in the Baltic Sea region. Producing and abandoned hydrocarbon fields as well as saline aquifers are candidates for such storage. The mapping, qualification and verification of storage sites is indispensable for CCS planning.

Geological formations of the Baltic sedimentary basin are expected to be well-suited for storing large quantities of CO_2. It is therefore important to have the best possible understanding of the CO_2 storage potential.

The key objectives for the Atlas is to provide input on where it is possible to implement safe long-term storage of CO_2, and how much capacity there is for geological storage of CO_2. The Atlas should include the current and best available estimates of potential CO_2 storage resources determined by a common methodology applied across the whole region.

The work is substantiated by a number of previous studies as well as data from more than 70 years of deep drilling and industrial seismic activities in the Baltic sedimentary basin. Two geological formations (Cambrian and Lower Devonian) have been identified as potential sinks with regard to reservoir quality and presence of relevant sealing formations. Those aquifers should be considered in detail and accompanied by structural and thickness maps in the atlas to calculate storage volumes.

The Atlas is targeted to fulfil the objective that the information can be useful for future exploration for CO_2 storage sites.

CO_2 mineral carbonation (MC) using geological and alkaline waste materials is considered as a non-geological option for CO_2 storage both onshore and offshore (Sanna et al, 2014). Among possible in-situ and ex-situ MC options, mainly ex-situ MC options are available in many of the BSR countries. Considering that in Finland and Estonia geological storage capacity was estimated as close to zero, ex-situ MC options are very important for the region and should be included in the atlas.

The extensive research and technological development for carbonation of serpentinites and steel slag has already been done in Finland and for oil shale ash in Estonia. MC could be a good decision for small and medium CO2-emitters, especially suitable for industry, supporting transformation of the dangerous alkaline waste materials and waste water into the useful by-products. It is an additional environmentally friendly option for climate change mitigation, but still needing additional R&D activities to improve technology and decrease costs.

There are two alternative formats of the Atlas, i.e. the hard copy (printed) version and interactive (GIS) format. The most reasonable approach is seen in combination of the Atlas with the interactive Baltic Carbon Storage Database operated on Geographic Information System platform.

The following tentative structure of the Atlas is suggested:

1. Introduction

2. Stationary CO_2 sources and CO_2 emissions in the Baltic Sea region

3. Methodology

3.1 Geological storage principles

3.2 Data availability

3.3 Workflow and characterization

3.4 Methodology of the estimation of storage capacity

4. Geological description of the Baltic Sea region

5. Storage options

5.1 Saline aquifers

5.2 Hydrocarbon fields (EOR)

6. Non-geological storage options

6.1 CO_2 mineral carbonation using natural materials (Mg-bearing silicates – serpentine, olivine, etc)

6.2 CO_2 mineral carbonation using waste (oil shale ash, slags, cement and incremental ash and other alkaline wastes)

7. Risk assessment and monitoring

8. Conclusions

There is a high competence within the partner countries of the Baltic Sea region that can be employed to compile the GIS extension to the storage, describing the CO_2 geological storage potential in the region. The GIS data base can be permanently updated to incorporate new data. They can be also supplemented by the decision support systems (DSS).

References:

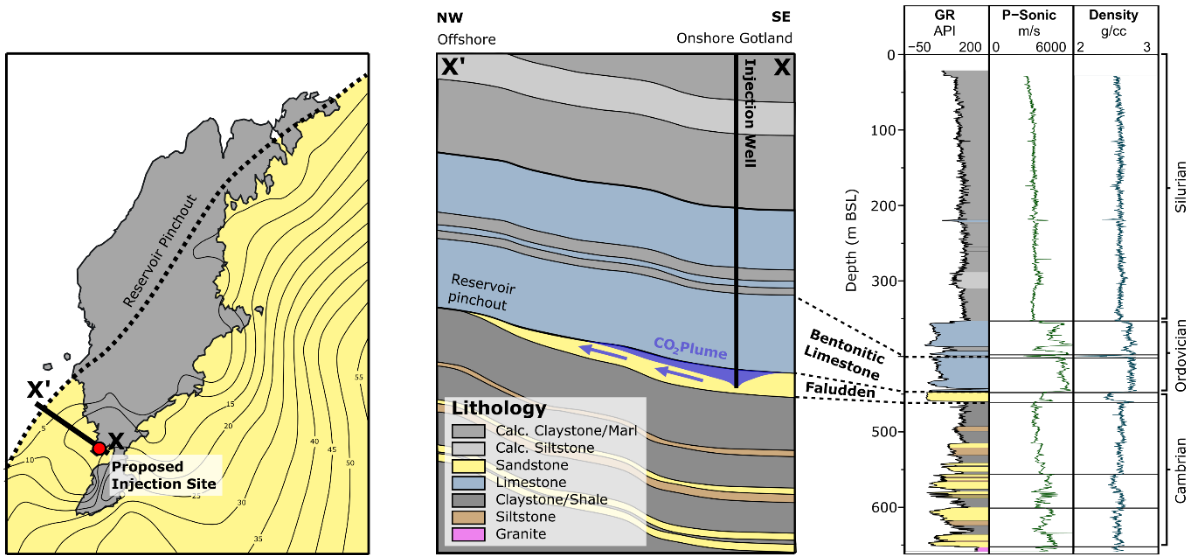
Sanna, A.; Uibu, M.; Caramanna, G.; Kuusik, R.; Maroto-Valer, M. M. (2014). A review of mineral carbonation technologies to sequester CO2. Chemical Society Reviews, 43 (23), 8049−8080, 10.1039/C4CS00035H.

2.2 Planning of pilot test CO2 injection site

Potential sites in the Baltic region

Pilot sites are an important way to test CO_2 storage in a real life environment and provide a crucial step in the development of the technology towards industrial scale storage operations. However, to date, relatively few pilot CO_2 storage projects have been established in Europe, none of which are located in the Baltic Sea region. In this section of the report a series of 4 potential test sites located in the Baltic Sea region are identified and described. A SWOT (Strengths Weaknesses Opportunities Threats) analysis is then performed to select a preferred pilot site. Finally, the preferred alternative is discussed in more detail and a scoping budget and timeline is presented. A more detailed summary of this part of the project is provided within Annex 6 of this report.

A **B** **C**



D

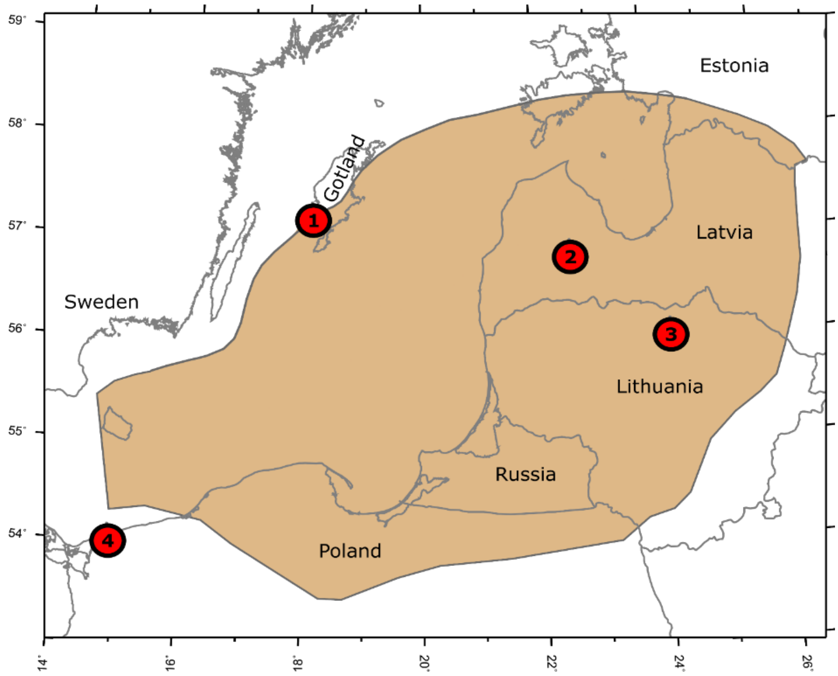


Fig. 1: A). Map of Gotland with contours denoting the Faludden reservoir thickness in meters. The location of the schematic profile in B) is shown as well as the location of the proposed injection site. B). Shows a schematic profile through the proposed injection site. C). Shows log data, Basic stratigraphy and lithology at the proposed test site. D). Map of the Baltic Sea region. The brown area indicates the approximate area where Cambrian reservoirs, suitable for storage, can be found. The locations of the four potential storage sites discussed in this report are shown.

The four test sites identified in this section are as follows: Site 1 (Southern Gotland) located on the island of Gotland, Sweden. Site 2 (South Kandava) located in Latvia. Site 3 (Vaškai structure) located in Lithuania and Site 4 (Kamień Pomorski) located in Poland (Fig. 1). Three of the four potential test sites (1, 2 and 3) target Middle Cambrian sandstone reservoirs, which provide an important storage option within the Baltic Sea area, while Site 4 targets a younger Zechstein Hauptdolomite reservoir. Based on the results from the SWOT analysis (see annex), Site 1 located on southern Gotland, was selected as the preferred pilot site location from the four alternatives. Major advantages of this pilot site are: 1. That the site provides a test of the regionally important Middle Cambrian Faludden reservoir. 2. The Site tests a somewhat novel stratigraphic trap scenario, thought to have a large potential capacity within the Baltic Sea region. 3. The level of practical, technical and economic maturity of this alternative is higher than the other pilot sites.

Geologically, Site 1 is situated on the NW flank of the Baltic Basin. The target reservoir is the well sorted, medium-grained quartz Faludden sandstone (Middle Cambrian). At the proposed test site, the reservoir is thought to have a thickness of 13m, to be located at a depth of 450m and to have relatively good reservoir properties (porosity 10-16% and permeability 200-400mD). The primary seal for the site is the Bentonitic limestone unit, which is thought to have a thickness of approximately 45m and a permeability of less than 1mD. It is thought that after injection CO_2 will migrate updip towards the stratigraphic pinchout of the reservoir, located to the NW of the injection site (Fig. 1).

The level of public acceptance of such a project on Gotland is currently unknown, but the site is located within a large wind farm, which indicates that the local population are somewhat open to industrial activity in the area. Small amounts of CO_2 from a biogas plant on Gotland could potentially be used in the experiment, however, the majority of the CO_2 would most likely have to be transported by truck and ferry from the mainland. An extensive monitoring plan would be employed at the site, which could include: repeat surface seismic surveys, Vertical seismic profiles, surface CO_2 flux measurements and real time downhole measurements of reservoir properties etc. A reasonable time plan for the project would be:

- Years 1-2: Baseline characterization of the site and drilling the injection well and monitor wells.
- Years 3-4: CO_2 injection.
- Years 5+ Decommissioning of site and long term monitoring.

A scoping budget for the southern Gotland site, based on the results from the SwedSTORECO2 project completed in 2013 is described in annex 6 to this report.

Based on the work in this study, it appears therefore, that of the sites considered, the southern Gotland site is the most viable and prospective pilot site opportunity in the Baltic Sea region. A proposal has been submitted by Uppsala University to the Horizon 2020 call for pilot sites in January 2017, which includes the southern Gotland test site. However this was performed outside the framework of the CGS Baltic SEED project.

2.3 Planning of modelling and risk assesment for storage in the BSR

The modeling work in future project consists of two part, namley (i) modeling of the CO_2 storage capacity in the Baltic Sea at large and (ii) modeling of the injection experiments at the pilot sites. Suggested work sequence for these is discussed below

2.3.1 Modeling of the CO_2 storage capacity in the Baltic Sea region at large

The work will in continue from the findings of the Bastor project (e.g. SLR (2014), Yang et al., 2015) where a geological model and estimation of the key properties of the main candidate formations, especially the Dalders Monocline, were presented and a more detailed dynamic modeling of the western-most part of the formation (Swedish sector) was carried out. The dynamic simulations and the resulting estimated dynamic capacities are presented in more detail in Yang et al. (2015). Basing on the finding of these studies the main points of the planned project are

- More detailed model analyses, including dynamic reservoir simulations also for the more eastern parts of the Dalders Monoclide where the capacity can be expected to be more extensive than in the western parts
- Modeling the effect of different injection geometries (vertical/horizontal wells, number of wells), pressure management techniques (such as withdrawal wells) as well as overall

optimization of injection-extraction strategies to achieve cost effective storage. This should be done for all parts of the formation

- The pressure limited capacity of the western part (Swedish sector) studied was sensitive to permeability, which is commonly a very poorly known parameter. Focus should therefore be in getting good estimates of permeability, for all parts of the formation. Acquiring additional data on hydromechanical properties is also a high priority, to allow a confident predicition of maximum allowable injection pressure.

2.3.2 Modeling of the CO2 injection and storage in the pilot site

For the selected pilot site/sites the following procedure is suggested, following e.g. the procedure used in modeling the Heletz, Israel CO2 injection site

- Site characterization, where all the available data is compiled and additional data is acquired from the injection area, concering the medium properties, layer thicknesses, bounding fracture zones etc. A good overview is given e.g. in Niemi et al., 2016a and exemplified in the Heletz case in Niemi et al., 2016b.
- Building a conceptual model of the site to be used as input for the model simulations
- Dynamic predicitive modeling of the CO_2 injection experiments. The injection experiments can have several differetn objectives. Firstly, smaller scale injections can be used to characterize different CO2 trapping characteristics of the site, such as residual trapping (see e.g. Rasmusson et al, 2014,2016). Then, larger scale injections should be used to investigate the plume spreading, capabaility to monitor the plume and the capability of the formation to hold the CO_2. All these experiments need to be carefully modelled prior to carrying out the experiments, by models such as TOUGH2 to investigate the actual CO2 injection and related processes (see e.g. Rasmusson, 2016) and models such as TOUGH2/FLAC (e.g. Figueiredo et al, 2015) to model the hydromechanical effects of injection.
- 4,2916he predicitive modeling and montioring programme should be closely inegrated and the experimental results then used for model validation and closer interpretation of site's properties for CO_2 storage.
- Predicitive modeling for actual storage on the site.
- Risk asssesment will be an essential component of both the predictive modeling of the injection experiments and the larger scale storage system. Main issues to be addressed in risk assesment are risks for unwanted hydromechanical and pressures effects as wells as risks for leakage.

2.3.3 The core partnership to carry out the modeling work

To carry out the work, the following core partnership is proposed, to be complemented as appropriate for the actual proposal to be submitted

Data collection and constructing the conceptual model

TTGUI will carry out data collection and construction of the static conceptual model of *Cambrian aquifer and Ordovician cap rock in the Latvian onshore and offshore* area using Schlumberger Petrel software. One Latvian geological offshore structure was already built in Petrel. Geological data for three structures in Latvian onshore (2) and Lithuanian offshore (1) were already analyzed and static models were built in Surfer software. Petrophysical data of about 200 wells from Latvia have been already collected. Geological data need to be collected and clarified.

PGI will carry out data collection and construction of the static conceptual model of *Cambrian aquifer in the Polish sector* using Schlumberger Petrel software. The area in question (eastern/north-eastern part of the Polish Baltic sector, south of Dalders anticline) includes several hydrocarbon fields with a good coverage of boreholes penetrating Middle Cambrian reservoir/aquifer as well as seismic data. Depending on future agreements with LOTOS Petrobaltic newest data of high quality might be available, at worst publicly available (older) regional and semi-detailed maps of Cambrian aquifer/reservoir and well-logging and petrophysical data could be used.

UU will focus on the data in the ***Swedish sector***, and will first collect all of the available well data and seismic data from the OPAB database. We would then re-process a grid of lines from the OPAB database across the area of the Faludden reservoir in the Swedish sector. We would combine this with data recently acquired by Hamburg University in 2016 and 2017 to generate an updated interpretation of the top reservoir structure. This would involve detailed mapping of potential faults across the area. We would then construct a reservoir model for the Faludden, using the updated structural interpretation and well data. We would generate several models, to take into account uncertainty in the pinch out location. We will use Gocad for the reservoir modelling and Opendtect / Claritas software for the interpretation / seismic processing.

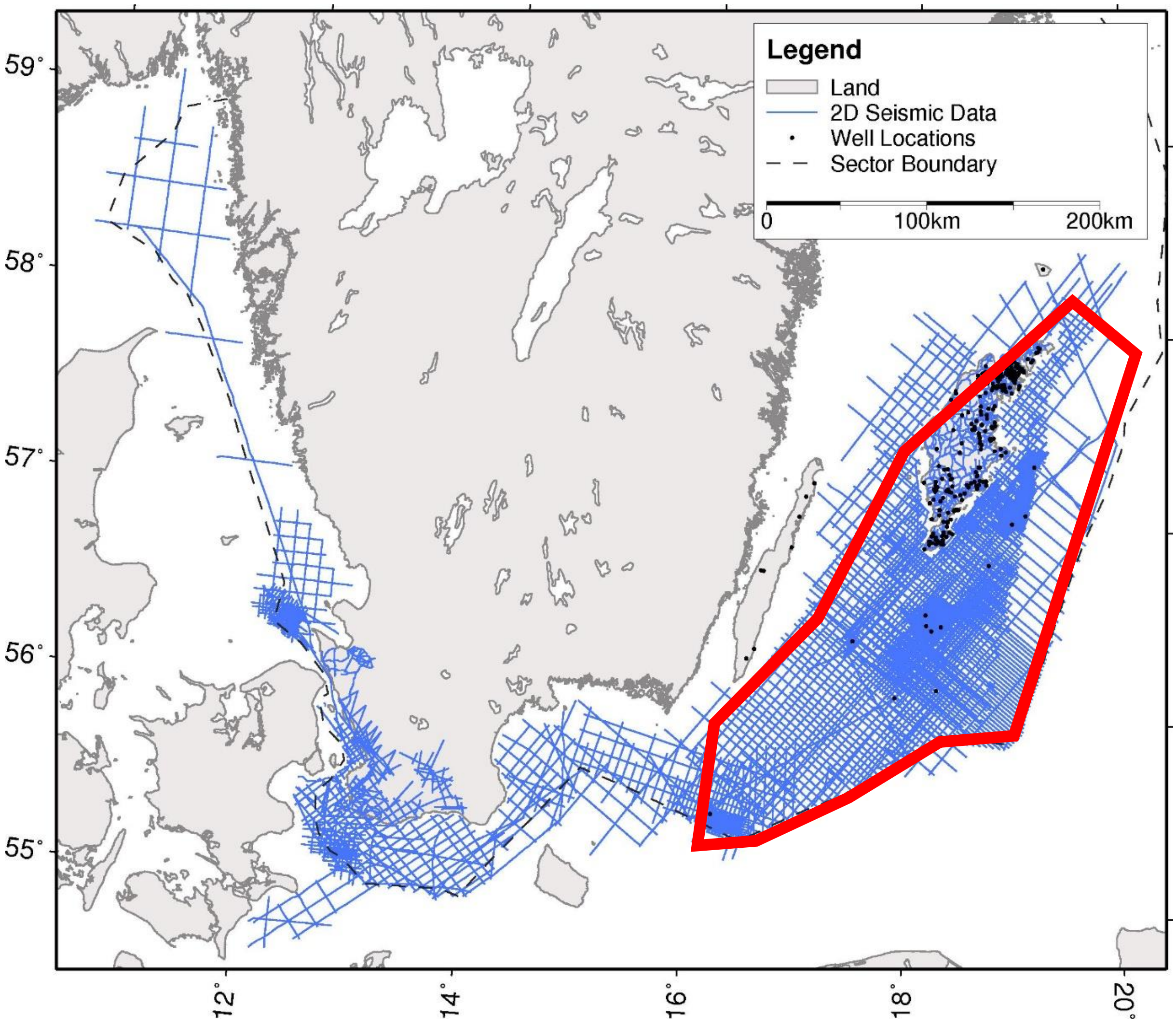


Figure 1. Map showing location of seismic and well data within the OPAB database. Red polygon indicates the approximate area of the large scale Dalders monocline model.

Furthermore, if the ***injection site is southern Gotland,*** UU will collect and re-process if necessary a fine grid of marine seismic lines around the southern part of the island of Gotland. These will be combined with land seismic (which has already been digitized by UU) and well data to generate a detailed top reservoir structure interpretation around the injection site. We will then use this updated structural interpretation to generate a reservoir model for the Faludden reservoir on southern Gotland. We will use Gocad for the reservoir modelling and Opendtect / Claritas software for the interpretation / seismic processing.

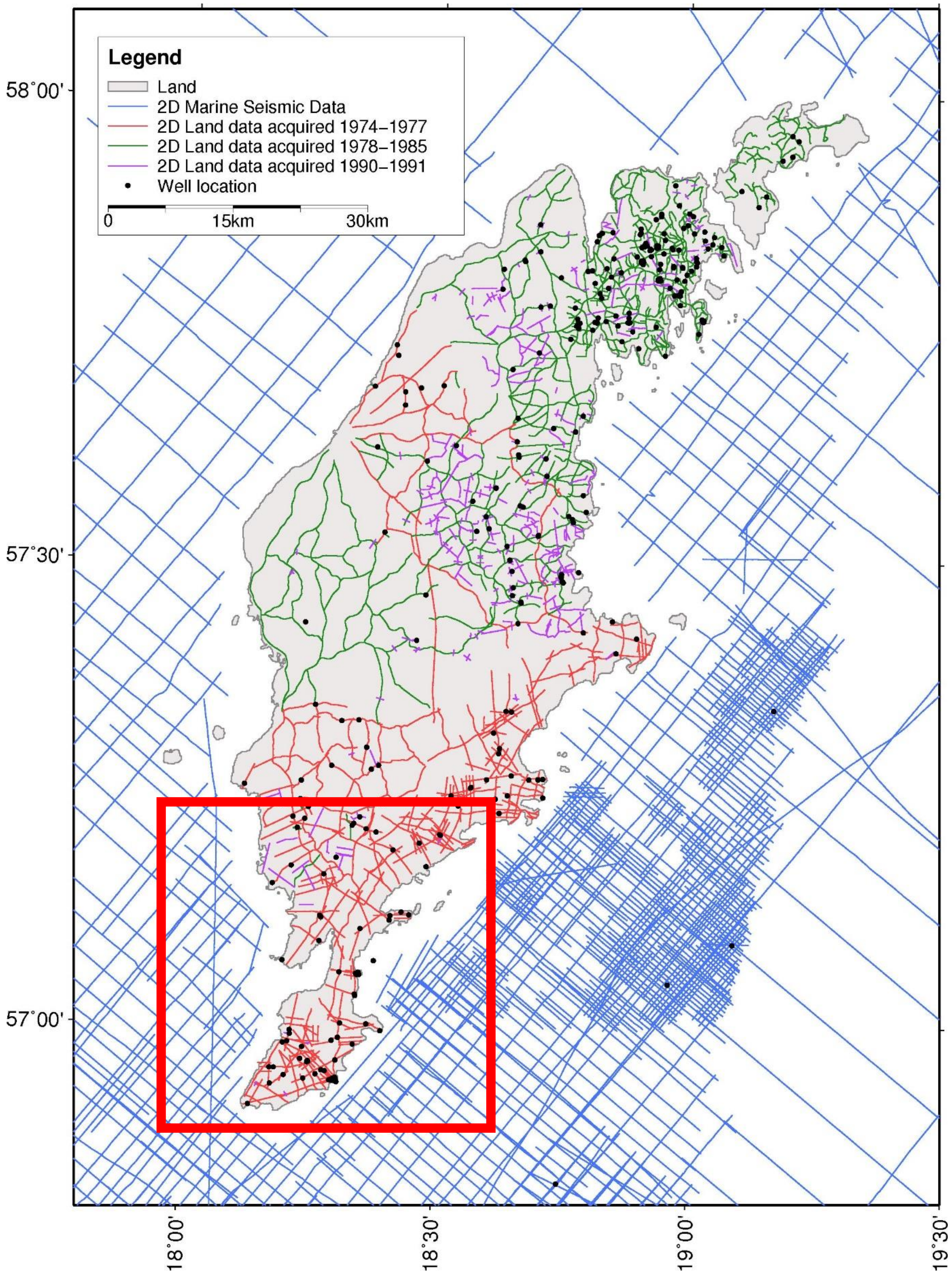


Figure 2. Map showing location of seismic and well data within the OPAB database. Red polygon indicates the approximate area of the detailed model around the injection site.

Dynamic simulations

The dynamic simulations will be carried out as described above, with **UU** as the main responsible organization. UU has extensive previous experience on similar modeling both concerning the large scale capacity estimates in the Baltic region and concerning injection experiment scale simulations, in particular at the Heletz site (for more details, see UU list of publications).

References related to 2.3

1. K. Rasmusson, M. Rasmusson, Y. Tsang, A. Niemi (2016) A simulation study of the effect of trapping model, geological heterogeneity and injection strategies on CO2 trapping. *International Journal of Greenhouse Gas Control*. Vol 52. pp. 52-72 DOI information: 10.1016/j.ijggc.2016.06.020.
2. Niemi, A., Katriona Edlmann, Jesus Carrera, Christopher Juhlin, Alexandru Tatomir, Iulia Ghergut, Martin Sauter, Jacob Bensabat, Fritjof Fagerlund, Kristina Rasmusson, Francois H. Cornet, Victor Vilarrasa and Christopher Ian McDermott (2016) Chapter 7: Site Characterization In: Niemi, A., Bear, J. and Bensabat, J. (Editors) (2016) GEOLOGICAL STORAGE OF CO2 IN DEEP SALINE FORMATIONS. In Press. Publisher Springer. 600p. Pp. 342-416 http://www.springer.com/gp/book/9789402409949.
3. Niemi, A. Bensabat, J, Shtivelman, V, Edlmann, K, Gouze, P., Luquot, L., Hingerl, F, Benson, S.M., Pezard, P.A, Rasmusson, K., Liang,T., Fagerlund, F., Gendler, M., Goldberg,I, Tatomir,A., Lange, T., Sauter, M., and Freifeld, B. (2016) Heletz experimental site overview, characterization and data analysis for CO2 injection and geological storage *Int. J. of Greenhouse Gas Control*. http://dx.doi.org/10.1016/j.ijggc.2015.12.030
4. Yang Z., L. Tian, B. Jung, S. Joodaki, F. Fagerlund, R. Pasquali, R. Vernon, N. O'Neill, and A. Niemi (2015), Assessing CO2 storage capacity in the Dalders Monocline of the Baltic Sea Basin using dynamic models of varying complexity. *International Journal of Greenhouse Gas Control* 43, 149-160. http://dx.doi.org/10.1016/j.ijggc.2015.10.024.
5. Figueiredo, B, Tsang, CF , Rutqvist, J, Bensabat, J and Niemi, A (2015) Coupled hydro-mechanical processes and fault reactivation induced by Co_2 Injection in a three-layer storage formation *Int Jour Greenhouse Gas Control,* Volume: 39, Pages: 432-448, DOI: 10.1016/j.ijggc.2015.06.008
6. Rasmusson, K., Rasmusson, M., Fagerlund, F., Bensabat,J., Tsang, Y. and Niemi, A. (2014) Analysis of alternative push-pull-test-designs for determining in-situ residual trapping of carbon dioxide. *Int Jour Greenhouse Gas Control,* Volume: 27 Pages: 155-168. Aug 2014

2.4 Communication and capacity building

This subtask refers to communication and capacity building in terms of (i) interaction and communication with and through the affiliated industry and regulatory partners that will form a key dissemination channel; (ii) education (affiliating PhD and MSc students, organizing training workshops etc); (iii) communicating with the policy makers and legal authorities and (iv) outreach and interaction with the local communities. The deliverable is a report on the above with a preliminary work plan and budget for the main project.

2.4.1 Interaction and communication with and through the affiliated industry and regulatory partners

The seed project partners are involved in the BASREC CCS initiative, which forms an important networking activity, involving respective governments and policy makers (e.g., ministries of energy or environment) as well as research community (research institutes & geological surveys, universities).

BASTOR and BASTOR2 projects were international initiatives on CCS scenarios in the Baltic region, financed by Swedish and Finnish industrial and energy companies, government organizations and the Global CCS Institute, the CGS Baltic seed project partners participated in these projects. The following industrial and energy companies were involved: SSAB, Jernkontoret, Svenska Petroleum Exploration, Cementa, Nordkalk, SMA Mineral, Minfo, Vattenfall, Fortum and Preem. Although some of them are no longer involved in CCS (e.g. Vattenfall) they can be approached through BASREC channels/events or directly, depending on the scope and priorities of the main project.

The seed project partners are in contact with a number of stakeholders - potential data providers to the main project and/or potential partners of the main projects, operating in the Baltic region:

- Polish Oil and Gas Company (onshore hydrocarbon operator, Poland);

- LOTOS Petrobaltic (offshore hydrocarbon operator, Poland);

- Svenska Petroleum Exploration AB (hydrocarbon operator, Sweden);

- AB LOTOS Geonafta (hydrocarbon operator, Lithuania);

- Odin Energy, Latvia (hydrocarbon operator, Latvia).

2.4.2 Education

The seed project partners participate in a number of international networks (e.g., CO2GeoNet, ENeRG, EERA CCS JP, EGS GEEG), involving the research/R&D community as well as, at least in some cases, education activities like affiliating PhD and MSc students and organizing training workshops. Among these especially, the CO2GeoNet network covers educational activities focused on PhD and MSc students. Additionally the university partners of the seed project include training on CCS related topics in their curricula, as well as hosting a number graduates who completed M.Sc. diploma and/or PhD examinations on CCS related issues. This includes the following institutions: IGTUT, Tallinn, Estonia; Uppsala University, Uppsala, Sweden; AGH University of Science and Technology, Cracow, Poland.

2.4.3 Communicating with the policy makers and legal authorities

In 1.1 government agendas responsible for the permitting process as well as their parent bodies (if applicable) responsible for defining policy have been identified in the respective countries of the Baltic region.

The permitting authorities can be various institutions: in Finland - a department of the Ministry of Employment and Economy, in Estonia – the Ministry of Environment (note that the Ministry of Economic Affairs and Communications is also involved in deciding policy), in Latvia – the Ministry of Economics, in Lithuania – the geological survey (parent body: Ministry of Environment), in Poland – the Ministry of Environment (the Ministry of Energy is also involved in deciding policy), in Denmark – the Danish Energy Agency (parent body: Ministry of Climate and Energy advised by the geological survey) and in Sweden – the geological survey (parent body: Ministry of Energy, Enterprise and Communication).

Persons responsible for the activities in question in particular countries are identified and are to be approached, depending on the scope of the main project.

2.4.4 Outreach and interaction with the local communities

Depending on the selection of the case study for the main project, local authorities and communities are to be approached.

Output 3 - Report on funding possibilities and steps to be taken after the seed money project is finalized

3.1 Funding possibilities

A wide range of different funding options have been discussed and analysed for the main project. A table of the most potential funding sources, including objectives, priorities, requirements and possible funding deadlines has been prepared for this output (Table 3.1). Any successful projects in CCS in 2015-2017 have also listed and analysed (Table 3.2).

The programs deemed as the most potential ones are:

- **Horizon 2020 Programme**
  http://ec.europa.eu/programmes/horizon2020/en/h2020-sections-projects
- **Interreg Baltic Sea Region**
  https://www.interreg-baltic.eu/
- **Nordic Energy Research**
  http://www.nordicenergy.org/

Horizon 2020 Program
Wide international consortiums, full CCS chain projects and the possibility to demonstrate high technological level (TRL5-TRL7). Two calls (LCE-30-2017: Geological storage pilots and LCE-29-2017: CCS in industry, including Bio-CCS) which had the deadline for submitting 5 January 2017, where devoted to CO2 storage pilots and CO2 capture pilots in industry. Both calls required high levels of TRL (technological development) and strong consortium of industrial and research partners.

In autumn 2016 it was decided that the CGS Baltic SEED project was not able to prepare an application for these calls. However, Uppsala University, a project partner has submitted a proposal to the LCE-30 call as part of another European consortium with wider spatial coverage than BSR. However, the Gotland storage site in Sweden was included by UU in this proposal as a proposed injection and research site.

At the end of 2016 Tallinn University of Technology (TTUGI) was invited by an Italian coordinator and took part in the LCE-29 call proposal for a CO2 capture pilot in the cement industry. TTUGI was included in the project to lead a work package on CO2 transport, use and storage. Techno-economic modelling of the BSR transport, use and storage scenario, use of the Estonian-Russian cluster of CO2 sources is planned in this proposal, together with experiments on CO2 mineral carbonation with oil shale ash produced at the cement plants.

During spring 2017 the new Horizon 2020 Program is under preparation, at the beginning of April 2017 the draft of the new Energy program for 2018-2020 is available for discussion by national stakeholders. The possible topics, suitable for the CGS Baltic Project and the BASRECCS Network available in the draft versions of the “Secure, clean and efficient energy” (Table 3.1.) are the following:

- Strategic planning for CCS (Call – 2018/CSA)
- Demonstrating the full CCS chain at commercial scale (2019: ERA-Net)

- Low carbon industrial production using full-chain CCU/CCS (2019: IA)

Interreg Baltic Sea Region
Third call: planned to be opened in autumn 2017 (https://www.interreg-baltic.eu/apply-for-funds/apply-for-funds.html). National and local authorities, associations and S&M enterprises should be included as partners. Geographical coverage of the programme is highly suitable for CGS Baltic. No CCS projects to date, CCS is not included as national priorities in the European INTERREG programmes but the programme offers funding for cleantech, energy (notably renewables) as a response to large societal challenges related to climate change.

Nordic Energy research
Nordic Energy Research is mostly fund Nordic Countries. In some calls cooperation with Baltic researchers are mentioned (Table 3.1). The next such calls will come in 2018.

3.2 Steps and planning after the seed project is finalised

During last project meeting in Riga it was decided that CGS Baltic will prepare a Concept Note for the third call of the Interreg Baltic Sea Region (Priority one: Capacity for Innovation) which will be opened mid 2017. The CGS Baltic partners agreed to appoint Jūlija Gušča, (Dr.sc.ing., Associate Professor, Head of the Environmental Science study department, Institute of Energy Systems and Environment, RTU) as coordinator of the new proposal, considering her successful experience in participation and leading of international projects, and also her existing positive experience in communication and cooperation with Latvian and Baltic stakeholders.

Based on the analysis of the INTERREG programme priorities and goals, it is sensible to prepare the main project proposal into Capacity and Innovation priority and to concentrate the proposal not only on CO2 storage, but to make more general mapping of the most prospective structures for a range of different subsurface storage options.

How to continue further networking?

The further networking will be continued through:
- Participation in BASRECCS Network, which have submitted a proposal for continuing their BSR CCS networking activities
- Cooperation with Horizon 2020 project ENOS – common workshop of ENOS project and CGS Baltic partners is planned for autumn 2018 for knowledge and information Exchange (responsible partner – TTUGI)
- Submitting application to Nordic Energy Research (2018 call)
- Preparation of Horizon 2020 proposal for full CCS chain strategy
- Cooperation between BASRECCS and CO2GeoNet: at the present time already 3 Baltic CGS partners are members of CO2GeoNet (TTUGI, PGI and UU)
- Cooperation between BASRECCS and ENeRG Network: (at the present time TTUGI, PGI and Lithuania are members).

How to continue project preparation if not yet ready, or negative results?

In case of a negative result in the INTERREG BSR programme, new proposals to Horizon 2020 and Nordic Energy Research Programme in 2018 will be developed.

In positive case, should we prepare more projects?

New projects should be prepared for piloting and demonstration of new technological developments and cross-cutting issues (CO_2 use, storage and synergy with renewable Resources), demonstration of full value chain CCS projects and for the development of the Baltic Sea Region Network of CO_2 emission clusters, transport and storage sites.

Table 3.1 Funding Sources

Funding Sources	Eligible countries and deadlines	Website	Area and priorities /topics	Objectives
Interreg BSR	Baltic Sea Region Countries ; *3rd call: Autumn 2017*	https://www.interreg-baltic.eu/	Capacity for Innovation: 1.1 Research & innovation infrastructures	Identifying challenges and introducing solutions in management of research and innovation infrastructures • Developing of incentive and funding schemes for commercial users • Assessing demand and adjusting supply for specific research capacities to support innovation potential of the BSR
Horizon 2020	EU and associated countries; *Autumn 2017-Winter 2018*	http://ec.europa.eu/programmes/horizon2020/en/h2020-sections-projects	**1) Secure, Clean and Efficient Energy:** LC-SC3-NZE-2-2018: Strategic planning for CCUS development LC-SC3-NZE-3-2019: Demonstrating the full CCS chain at commercial scale LC-SC3-NZE-4-2019-2020: Low carbon industrial production using CCUS	**NZE2 :** Elaboration of detailed plans for comprehensive CO2 gathering networks and industrial clusters linked to CO2 storage sites via hubs, pipeline networks and shipping routes, with due attention to border-crossing issues. Mapping and understanding the nature and longevity of emission sources, identification of transport corridors and performing initial impact assessments, and developing local business models for delivery of CO2 capture, transport, utilisation and/or storage; **NZE3:** The project will support the operation of a CO2 capture plant demonstrating the application of CCS technology to a commercial fossil fuel power plant with the subsequent transport and permanent geological storage of the CO2.; **NZE4:** Projects will address the full CCS chain, from demonstrating the capture of CO2 from industrial (non-power) installations to the detailed planning of its subsequent transport, utilisation and/or underground storage
Nordic Energy Research	Nordic and some times Baltic countries; *2018*	http://www.nordicenergy.org/	Energy Research	**Flagship Projects** Research projects involving three or more Nordic countries will be the largest instrument in the new period, accounting for approximately 80 % of Nordic Energy Research's direct research funding from member countries. Funding will be focussed on a small number of large projects, which will facilitate greater dissemination effects and achievement of the aforementioned goals. Projects will have a greater focus on delivering mid-term results, a focus that may be reinforced by a staggered funding format, the details of which will be determined when planning the programme. Industry involvement and co-financing will be sought. A share of Nordic Energy Research's direct research funding is earmarked **for the integration of researchers from the Baltic Sea region.** Half of these earmarked funds may be distributed through this instrument. The thematic focus of the Flagship Projects will be determined by the project proposals that successfully receive funding, not by the strategy or call text. In addition to criteria for scientific quality, the two-stage call text will require that pre-proposals fulfil detailed criteria based on the three principles of the strategy: Nordic added value; System perspective; and Politically relevant research results.

Table 3.2 Ongoing CCS Projects

Acronym	Title	Program and Funding	Duration	Website	Objectives	Partners and countries
Negative CO2	Enabling negative CO2 emissions in the Nordic energy system through the use of Chemical-Looping Combustion of biomass (bio-CLC)	***Nordic Energy Research***	November 2015 - October 2019	http://www.nordicenergy.org/flagship/negative-co2/about-negative-co2/	The goal of the Negative CO2 project is to develop a technology that enables CO2 capture and negative CO2 emissions with the lowest possible cost and energy penalty.	**Norway:** Chalmers University of Technology, The Bellona Foundation, Sibelco Nordic AB, SINTEF Energy Research SINTEF Materials and Chemistry, **Finland:** VTT Technical Research Centre of Finland Ltd, Åbo Akademi University, **Advisory Board:** Alstom Power AB, Andritz Oy, AKZO Nobel, Elkem AS, ON Sverige, AB Fortum Oyj, Foster Wheeler Energia, Göteborgs Energi, Titania A/S
CO2 Storage:				-		
STEMM-CCS	Strategies for Environmental Monitoring of Marine Carbon Capture and Storage	Horizon 2020	March 2016 - February 2020	http://projects.noc.ac.uk/stemm-ccs/	STEMM-CCS will deliver new insights, guidelines for best practice, and tools for all phases of the CO2 storage cycle at offshore CCS sites. The key objectives of the project are: To produce new tools and techniques for environmental monitoring as well as CO2 emission monitoring, quantification and assessment. To generate new knowledge of the reservoir overburden by direct investigation of natural geological and manmade features. To deliver the first CCS demonstration project level implementation of an ecological baseline, incorporating geochemical and biological variability. To promote knowledge transfer to industrial and regulatory stakeholders and local and international communities.	**UK:** Plymouth Marine Laboratory, Heriot-Watt University, **Norway:** Universitetet Tromsoe, Universitetet Bergen, Śhell Global Solutions International B.V., Seascape Consultants Ltd, Norsk Institutt For annforskning, **Germany:** Max Planck Gesellschaft Zur Foerderung, Helmholtz Zentrum Fur für Polar und Meeresforschung, **The Netherlands:** Der Wissenschaften E.V., **South Africa:** University Of Southampton, **Austria:** Technische Universitaet Graz, **Switzerlands**: Uni Research As
ENOS	Enabling Onshore CO2 Storage in Europe	Horizon 2020 - 12.58 M€	September 2016 - August 2020	https://enos-project.eu/	The demonstration of best practices through pilot-scale projects and field laboratories, integration of CO2 storage in local economic activities and creating a favourable environment for CCS onshore. The objective of the project is to enable the development of CO2 storage onshore in Europe by: 1) Developing, testing and demonstrating in the field, under “real-life conditions”, key technologies specifically adapted to onshore contexts (5 field sites). 2) Contributing to the creation of a favourable environment for onshore storage across Europe.	BRGM, France- coordinator, 30 partners from 17 countries involved (France, Germany, UK, Czech Republic, Spain, Norway, Italy, Slovakia, The Netherlands, Austria, Estonia, Croatia, Hungary, Romania, Denmark, Slovenia and Turkey)

CCS infrastructure						
GATEWAY	Developing a Pilot Case aimed at establishing a European infrastructure project for CO2 transport	Horizon 2020 0.79 M€	May 2015 - April 2017	https://www.sintef.no/projectweb/gateway/	Developing and defining a pilot case for European CO2 transport infrastructure: A comprehensive integrated project providing a model for establishing European CO2 infrastructure. Incorporating technology, policy-making, international law, regulatory aspects, business development, and tentative consortium. Make assessment of funding needs and resources. Follow the Berlin model to realize the Pilot case project.	SINTEF Energy Research (Coordinator), TNO (Netherlands), Forschungszentrum Julich (Germany) University of Leeds (UK), Progressive Energy Limited (UK), Ecofys (The Netherlands) Queen Mary - University of London (UK)
ERA-NET						
ACT	Accelerating CCS technologies as a new low-carbon energy vector	Horizon 2020 - 12,81 M€. In total 42.8 M€		http://www.act-ccs.eu/	The main objective of ACT is to facilitate the emergence of CCS by significant transnational joint calls that will stimulate **close cooperation between researchers and industry** in order to accelerate the deployment of CCS. The consortium will address the most relevant RD&D gaps in the CCS chain. **ACT will fund transnational R&D and innovation projects**, facilitate meeting places for knowledge sharing, ensure synergies with pilots and demonstration projects, and invite to discussions with stakeholders in the CCS field. ACT will also ensure dissemination of results from ACT funded projects as part of an extensive outreach program targeting the research community, policymakers and the public in general. The result will be new knowledge which in turn will close gaps and accelerate CCS deployment.	10 partners from **9 countries**: **Germany:** orschungszentrum Jülich GmbH Projektträger Jülich (FZJ/PtJ), **The Netherlands:** Ministry of Economic Affairs/Rijksdienst voor Ondernemend Nederland (RVO), **Norway:** The Research Council of Norway (RCN) and Gassnova SF (GN), **Romania:** Executive Agency for Higher Education, Research and Innovation Funding (UEFISCDI), **Spain:** Spanish Ministry of Economy and Competitiveness (MINECO), **Switzerland:** Swiss Federal Department for the Environment, Transport, Energy and Communications (DETEC), **Turkey:** The Scientific and Technological Research Council of Turkey (TUBITAK), **UK:** Department of Business, Energy and Industrial Strategy (BEIS)
CCS in industry						
CEMCAP	CO_2 capture from the cement industry	Horizon 2020 - 8.8 M€, Swiss government - 0.7 M CHF	May 2015 - September 2018	http://www.sintef.no/cemcap/	To prepare the ground for large-scale implementation of CO2 capture in the European cement industry	15 partners (industry, technology, research, academia) from 6 countries: Norway, Italy, Sweden, Germany, The Netherlands, Switherlands , SINTEFF - coordinator
LEILAC	Low Emissions Intensity Lime and Cement	Horizon 2020 - 11.93 M€	2016 - 2020	http://www.leilac.org.uk/	Carbon Capture is not yet included in the best available technologies for cement and lime. The approach to reducing emissions for the cement and lime industries has been to increase kiln efficiencies and utilise alternative fuels. Once tested in LEILAC and scaled up, Direct Separation should reduce the costs of CCS considerably and accelerate the deployment of CCS/U in both industries.	CALIX (EUROPE) LIMITED (Coordinator), 11 partners including Imperial College London
STEPWISE	Cost effective capturing of CO_2 in the iron and steel industry	Horizon 2020 - 12.97 M€		http://www.stepwise.eu/	The project aims at the demonstration of advanced pre-combustion CO2 removal technology within the framework of the Iron and Steel industry, aiming at lowering the CO2 footprint of steel production.	Kisuma Chemicals, ECN, Politecnico de Milano, Universitatea Babes-Bolyai, Swerea MEFOS , SSAB,Tata Steel Consulting (**The Netherlands, Italy, Romania, Sweden, UK**)

Annexes:

Annex 1: Output 1.1 Legal and regulatory framework

Annex 2: Output 1.2 Political situation and stakeholder analysis

Annex 3: Output 1.3 Exchange of information with North Sea Basin Task Force/NORDICCS

Annex 4: List of most important publications of CGS Baltic project partners.

Annex 5: Output 1.5 Mapping of available geological data

Annex 6: Output 2.2. Planning of a pilot test CO2 injection site

Annex 1 Legal and regulatory framework

1.1.1 International agreements

When international treaties are signed by ministers from a given country they will only be binding after being ratified by the parliament of that country. They enter into force when a certain percentage of the contract parties ratify and are only binding for parties that have ratified. International agreements are outclass national law, incl. Constitution. Disputes between parties are solved by an international court.

Multilateral environmental agreements

At the international level, major regulations that affect CCS are international conventions dealing with transboundary shipments of CO_2. Two such agreements are the Protocol to the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (**London Protocol**) and the Convention for the Protection of the Marine Environment of the North-East Atlantic (**OSPAR Convention**). All BSR countries are contracting parties of Helsinki Convention 1992 (**HELCOM**) aiming on the protection of the Baltic marine environment, including regulation of dumping, pollution as well as exploration and exploitation activities of the seabed and its subsoil in the Baltic Sea.

1.1.1.1 London Protocol

The Inter-Governmental Conference entitled "The Convention on the Dumping of Wastes at Sea", which occurred in London in November 1972 at the invitation of the United Kingdom, agreed on a set of guidelines, generally known as the **London Convention** (LC). The London Convention, one of the first international conventions for the protection of the marine environment from human activities, came into force on 30 August 1975. Since 1977, it has been administered by IMO (The International Maritime Organization http://www.imo.org/en/About/Pages/Default.aspx). Currently, 87 States are Party to the London Convention 1972 (Fig.1).

The London Convention contributes to the international control and prevention of marine pollution by prohibiting the dumping of certain hazardous materials. In addition, a special permit is required prior to dumping of a number of other identified materials and a general permit for other wastes or matter.

"Dumping" has been defined as the deliberate disposal at sea of wastes or other matter from vessels, aircraft, platforms or other man-made structures, as well as the deliberate disposal of these vessels or platforms themselves. Annexes list wastes which cannot be dumped and others for which a special dumping permit is required.

Amendments adopted in 1993 (which entered into force in 1994) banned the dumping into the sea of low-level radioactive wastes. In addition, the amendments phased out the dumping of industrial wastes by 31 December 1995 and banned the incineration at sea of industrial wastes.

In **1996,** Parties adopted a Protocol to the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, 1972 (known as the **London Protocol (**LP)) which entered into force in **2006**. At end of February 2017 there were **48 Parties** to the London Protocol 1996, 87 parties to the London Convention 1972 and 99 parties in total (LC and LP) (Fig.1).

Poland, Finland, Russia and Belarus are parties to the London Convention 1972, but have not ratified the London Protocol 1996. Latvia and Lithuania are not parties to either the London Convention or the London Protocol (Table 1).

In the BSR (Fig.1,Table 1): Denmark, Germany, Norway, Sweden and Estonia have ratified both the LC and LP. Finland, Poland, Latvia, Lithuania, Russia and Belarus are not party to the LP. Among the Nordic Countries only Finland has not yet ratified the London Protocol 1996.

The Protocol, which is meant to eventually replace the 1972 Convention, represents a major change of approach to the question of how to regulate the use of the sea as a depository for waste materials. Rather than stating which materials may not be dumped, it prohibits all dumping, except for possibly acceptable wastes on the so-called "reverse list", contained in an annex to the Protocol.

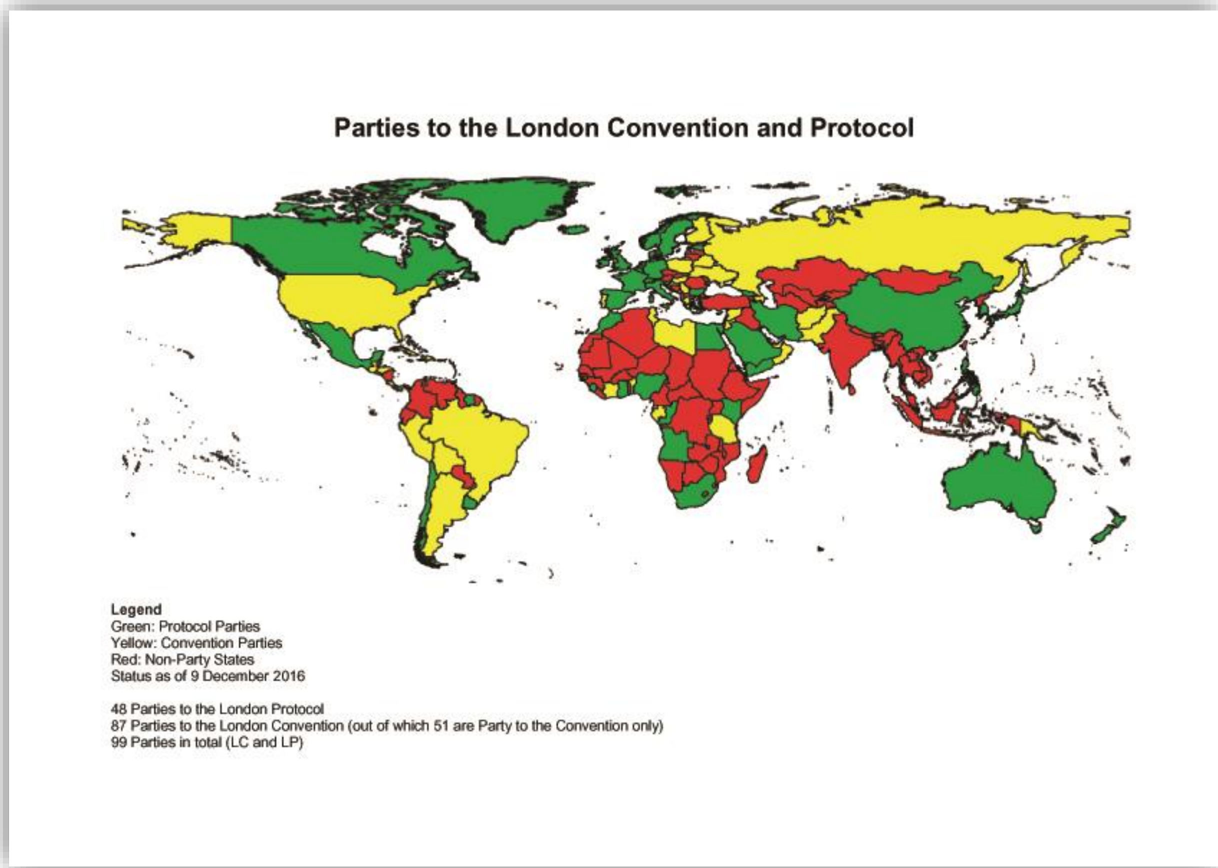


Figure 1. Parties of London Convention 1972 and London Protocol 1996 (IMO, 9 December, 2016).

The London Protocol stresses the “precautionary approach”, which requires that “appropriate preventative measures are taken when there is reason to believe that wastes or other matter introduced into the marine environment are likely to cause harm even when there is no conclusive evidence to prove a causal relation between inputs and their effects”.

It also states that "the polluter should, in principle, bear the cost of pollution" and emphasizes that Contracting Parties should ensure that the Protocol should not simply result in pollution being transferred from one part of the environment to another.

The Contracting Parties to the London Convention and Protocol have recently taken steps to mitigate the impacts of increasing concentrations of CO_2 in the atmosphere (and consequently in the marine environment) and to ensure that new technologies that aim to engineer the climate, and have the potential to cause harm to the marine environment, are effectively controlled and regulated.

The instruments have, so far, been the most advanced international regulatory instruments addressing carbon capture and sequestration in sub-sea geological formations and marine climate engineering such as ocean fertilization. The 1996 Protocol restricts all dumping except for a permitted list (which still require permits). In order to enable sub-seabed storage the parties to the protocol adopted **an amendment in 2006** where CO_2 sequestration in sub-seabed geological formations was added to the Protocol Annex 1 (LP.1(1)). This amendment entered into the force on 10 February 2007 (Table 1). Also in 2007 “Specific Guidelines for Assessment of Carbon Dioxide Streams for disposal into Sub-seabed geological Formations” were adopted by the Protocol Parties.

Article 4 states that Contracting Parties "shall prohibit the dumping of any wastes or other matter with the exception of those listed in **Annex 1**:
CO_2 streams from CO_2 capture processes are in the list of the permitted substances.
The amendments state that:

- carbon dioxide streams may only be considered for dumping, if:
- disposal is into a sub-seabed geological formation;
- they consist overwhelmingly of carbon dioxide (they may contain incidental associated substances derived from the source material and the capture and sequestration processes used);
- No wastes or other matter are added for the purpose of disposing of them.

Amendment to Article 6 of the LP was adopted **in 2009**. Article 6 prohibits “export of wastes or other matter to other countries for dumping or incineration at sea.” 2009 amendments to Article 6 (LP.3(4)) enabling - exclusively - the export of carbon dioxide streams for the purpose of sequestration in trans-boundary sub-seabed geological formations, is not yet in force. By February 2017 it is accepted only by three countries (**Norway**, The Netherlands and UK), while amendment to the LP requires acceptance by two-third of the Parties to enter into force [1].

Some options for trans-boundary storage of CO_2 regulated by Article 6 of the LP and CCS Directive are described in [2].

1.1.1.2 OSPAR Convention

OSPAR is the mechanism by which fifteen Governments of the western coasts and catchments of Europe, together with the European Community, cooperate to protect the marine environment of the North-East Atlantic. It started in 1972 with the Oslo Convention against dumping. It was broadened to cover land-based sources and the offshore industry by the Paris Convention of 1974. These two conventions were unified, up-dated and extended by the 1992 OSPAR Convention. The new annex on biodiversity and ecosystems was adopted in 1998 to cover non-polluting human activities that can adversely affect the sea www.ospar.org.

Under the Rules of Procedure the OSPAR Commission consists of representatives of each of its 16 Contracting Parties (Fig.2a, b, Table 1). The Contracting Parties are Belgium, **Denmark, Finland**, France, **Germany**, Iceland, Ireland, Luxembourg, The Netherlands, **Norway**, Portugal, Spain, **Sweden**, Switzerland and United Kingdom, together with the European Union. **Finland** is not on the western coasts of Europe, but some of its rivers flow to the Barents Sea and historically it was involved in the efforts to control the dumping of hazardous waste in the Atlantic and the North Sea. Luxembourg and Switzerland are Contracting Parties due to their location within the catchments of the River Rhine.
Annex II on the prevention and elimination of pollution by dumping or incineration:
ARTICLE 1. This Annex shall not apply to any deliberate disposal in the maritime area of: (a) wastes or other matter from offshore installations; (b) offshore installations and offshore pipelines.
ARTICLE 2. Incineration is prohibited.
ARTICLE 3.

1. The dumping of all wastes or other matter is prohibited, except for those wastes or other matter listed in paragraphs 2 and 3 of this Article.
2. The list referred to in paragraph 1 of this Article includes the following:

(f) carbon dioxide streams from carbon dioxide capture processes for storage, provided: i. disposal is into a sub-soil geological formation; ii. the streams consist overwhelmingly of carbon dioxide. They may contain incidental associated substances derived from the source material and the capture, transport and storage processes used; iii. no wastes or other matter are added for the purpose of disposing of those wastes or other matter; iv. they are intended to be retained in these formations permanently and will not lead to significant adverse consequences for the marine environment, human health and other legitimate uses of the maritime area.

Figure 2 a.
OSPAR maritime area – the Arctic (I), the Greater North Sea II), the Celtic Seas, the Bay of Biscay/Golfe de Gascogne (III) and Iberian waters (IV), and the Wider Atlantic

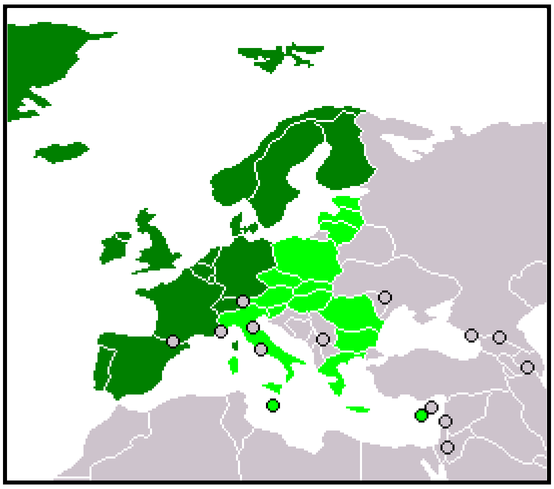


Figure 2 b. Parties of OSPAR Convention

Signatory states

European Union

1.1.1.3 Helsinki Convention 1992 (HELCOM)

Convention on the Protection of the Marine Environment of the Baltic Sea Area

The 1992 Helsinki Convention entered into force on 17 January 2000, after the ratification instruments were deposited by the European Economic Community, Germany, Latvia and Sweden in 1994, by Estonia and Finland in 1995, by Denmark in 1996, by Lithuania in 1997, and by Poland and Russia in November 1999 (http://helcom.fi/about-us/convention).

The Convention covers the whole of the Baltic Sea area, including inland waters as well as the water of the sea itself and the sea-bed. Measures are also taken in the whole catchment area of the Baltic Sea to reduce land-based pollution.

The Convention is amended when deemed necessary, thus following, e.g., the developments in international environmental and maritime laws. The latest amendment entered into force on 15 November 2008.

HELCOM Convention is applied to the **Baltic Sea Area**. For the purposes of this Convention the "Baltic Sea Area" shall be the Baltic Sea and the entrance to the Baltic Sea bounded by the parallel of the **Skaw in the Skagerrak at 57° 44.43'N**.

The Contracting Parties shall individually or jointly take all appropriate legislative, administrative or other relevant measures to prevent and eliminate pollution in order to promote the ecological restoration of the Baltic Sea Area and the preservation of its ecological balance.

This Convention shall apply to the protection of the marine environment of the Baltic Sea Area which comprises the water-body and the seabed including their living resources and other forms of marine life.

Without prejudice to its sovereignty each Contracting Party shall implement the provisions of this Convention within its territorial sea and its internal waters through its national authorities.

Whenever an environmental impact assessment of a proposed activity that is likely to cause a significant adverse impact on the marine environment of the Baltic Sea Area is required by international law or supra-national regulations applicable to the Contracting Party of origin, that Contracting Party shall notify the Commission and any Contracting Party which may be affected by a transboundary impact on the Baltic Sea Area.

Where two or more Contracting Parties share transboundary waters within the catchment area of the Baltic Sea, these Parties shall cooperate to ensure that potential impacts on the marine environment of the Baltic Sea Area are fully investigated within the environmental impact assessment referred to in paragraph 1 of this Article. The Contracting Parties concerned shall jointly take appropriate measures in order to prevent and eliminate pollution including cumulative deleterious effects.

The Contracting Parties shall prohibit dumping in the Baltic Sea Area. Dumping of dredged material shall be subject to a prior special permit issued by the appropriate national authority.

Each Contracting Party shall take all measures in order to prevent pollution of the marine environment of the Baltic Sea Area resulting from exploration or exploitation of its part of the seabed and the subsoil thereof or from any associated activities thereon as well as to ensure that adequate preparedness is maintained for immediate response actions against pollution incidents caused by such activities.

The Contracting Parties shall ensure that information is made available to the public on the condition of the Baltic Sea and the waters in its catchment area, measures taken or planned to be taken to prevent and eliminate pollution and the effectiveness of those measures. For this purpose, the Contracting Parties shall ensure that the following information is made available to the public:

a) permits issued and the conditions required to be met;

b) results of water and effluent sampling carried out for the purposes of monitoring and assessment, as well as results of checking compliance with water-quality objectives or permit conditions; and

c) water-quality objectives.

Each Contracting Party shall ensure that this information shall be available to the public at all reasonable times and shall provide members of the public with reasonable facilities for obtaining, on payment of reasonable charges, copies of entries in its registers.

Table 1. Ratified international agreements, national CCS laws in the BSR countries and their GCCSI assessment

Country	International agreements						National CCS laws (EU CCS Directive)							
	London Convention 1972	London Protocol 1996 (LP)	Amendments to LP		HELCOM 1992	OSPAR 1992	CO_2 storage permitted for				Exploration permit always required	GCCSI Assessment Score (2015)		
							Industrial Scale			Research				
			2006 (LP.1(1))	2009 (Article 6) (LP.3 (4))			Onshore	Off-shore	Temporal restriction			A	B	C
Denmark	X	X	X		X	X	Forbid-den until 2020	Yes for EOR	Until 2020	X	X*	62		
Estonia		X	X		X	EU sign.	No	No		X				31
Finland	X				X	X	No	No		X			44	
Germany	X	X	X		X	X	Up to 4 Mt CO2 annually and maximum 1.3 Mt per one project.		Until 2018	X	X		56	
Latvia					X	EU sign.	No	No		X	X			32
Lithuania					X	EU sign.	X	X		X	X		50	
Poland	X				X	EU sign.	Not permitted, except for demo-projects		Until 2024	X	X		45	
Sweden	X	X	X		X	X	No	X		X	X		51	
Norway	X	X	X	X		X	No	X		X			40	
Russia	X				X	NA	NA	NA	NA	NA	NA			33
Belarus	X					NA	NA	NA	NA	NA	NA			

NA - not applicable; * - required when information is limited

1.1.2 CCS Directive

1.1.2.1 EU CCS Directive implementation in the BSR countries by 2013

Public authorities of the BSR which were responsible for implementation of´the EU CCS Directive (Table 2a,b) in their countries reported to EC in 2013 about results of the *CCS Directive transposition* by 2013 [3, 4]. While many Member States allow CO_2 geological storage, governments have applied at least temporary restrictions on CO_2 storage in several countries (Table 1). In Denmark, regulations have prohibited storage until 2020, with the exception of offshore CO_2 - enhanced oil recovery (EOR). CO_2 storage is prohibited in Poland until 2024 except for demonstration projects. The volume of exploration area for CO_2 storage is limited in Germany, only limited CO_2 storage will be permitted until 2018 (up to 4 Mt CO_2 annually and maximum 1.3 Mt per one project). CO_2 storage is prohibited except for research and development in Estonia, Finland and Latvia. Offshore CO_2 storage is permitted in Sweden according to the new law which came into effect from March 2013, and in Norway regulated by existing petroleum exploration laws. New CCS regulations in Norway are based on existing petroleum legislation and the EU CCS Directive.

Amendment of existing EU Directives and transboundary issues

The CCS Directive has amended six existing EU Directives in order to protect the environment and human health from the risks connected to geological storage of CO_2. All EU Member States, communicated the EC for their transposing measures, made amendments in four of their existing instruments regulated by the (1) EIA (Environmental Impact Assessment) Directive, (2) Waste Framework Directive, (3) Industrial Emission Directive and (4) Large Combustion Plant Directive. Member States which allow CO_2 storage in their countries also amended laws regulated by (5) Water Framework Directive and (6) Environmental Liability Directive (Articles 31-35 and 37, [4] and [3].

The CCS directive encourages bilateral agreements between countries to arrange for transboundary CO_2 transport in order to circumvent the London Protocol prohibiting the export of CO_2 as waste [2].

Many countries addressed in their regulations transboundary transport of CO_2 and transboundary storage sites or complexes, but only three countries (Germany, The Netherlands and the UK) have experience of such transboundary cooperation. Here, the North Sea Basin Task Force, developed common principles for managing and regulating the transport, injection and CO2 storage in the North-Sea sub-seabed [6]. Two pilot injections have been already made in Lithuania in 2013, investigating potential of CO_2 to be used for EOR [7].

As a result, capture and transport of CO_2 stream is covered by national instruments regulated by (1) and (3); CO_2 captured and transported for the purpose of geological storage is excluded from the national waste regulations (2), and operators of combustion plants with capacity of 300 MW or more should assess conditions and demonstrate that the plant is built “capture-ready” (4) in all the Member States. CO_2 is allowed for injection into saline reservoirs according to instruments regulated by (5) and operation of CO_2 storage sites is allowed according to amendments made in instruments regulated by (6) in countries permitting CO_2 storage [3].

Public acceptance

Local public protests against CCS which have had an impact on adoption of the directive have occurred at several proposed storage sites in Germany [4]. Strong resistance to CCS by Green NGOs is apparent in Germany, Denmark and Poland. The influence of Green NGOs on public opinion is high in Germany and Poland, and is thought to be at least partially responsible for the long lasting debates in these countries [5]. In Denmark the opposition of the local environmental NGOs was so high that it resulted in prohibition of CO_2 storage onshore until at least 2020.

Table 2a. Public authorities of the BSR responsible for implementation of the EU CCS Directive

MS	Competent Authorities	Roles
	Minister for Climate and Energy	Retains the authority to issue and withdraw permits.
	Danish Energy Agency	Competent authority, as the Minister for Climate and Energy has delegated the implementation of CCS Directive to them.
Estonia	Ministry of the Environment	Only competent authority, except in the case of construction of a transboundary transport pipeline, which requires a permit from the Government.
	Regional State Administrative Agencies (AVI)	Issue environmental permits for carbon capture installations.
	Centres for Economic Development, Transport and the Environment (ELY)	Monitor compliance with permits and the conditions of use. They are also responsible for supervision and environmental legislation.
	Energy Market Authority	Responsible for the implementation and surveillance of the emissions trading provisions of Directive 2003/87/EC, and for settling disputes related to third party access to pipelines.
	Finish Ministry of Employment and the Economy.	Negotiate transboundary cooperation with the authorities of another state.
	Land (federal state) authorities	Responsible for fulfilling the duties under the KSpG.
	Federal Network Agency	Responsible for tasks involved in connection and third party access to carbon dioxide pipelines or storage reservoirs.

	Federal Institute for Geo-sciences and Natural Resources	Is compiling and operating the register for information on CO_2 pipelines and storage reservoirs
	German Emissions Trading Authority (DEHSt)	Approve monitoring plans to ensure consistent enforcement in Germany.
	Federal Ministry of the Environment, Nature Conservation and Reactor Safety	
	Federal Environment Agency	
	Ministry of Environmental Protection and Regional Development	Coordinates the implementation of the CCS Directive and cooperates with the Ministry of Justice in matters concerning the determination of jurisdiction.
	State Office of Environmental Monitoring	Ensures that the capture and storage for plants greater than 300 MW are evaluated.
	State Environmental Service	Incorporates "capture readiness" requirements for combustion plants in their permits and is responsible for setting the requirements for CO2 stream composition.
	A Court of General Jurisdiction	Responsible for dispute settlement.
	Geological Survey of Lithuania	Competent authority which performs most of the tasks referred to in the Directive.
	Lithuanian Government	Determines the cases under which the decision to transfer responsibility shall be agreed with the Commission.
	Ministry of Environment	Makes decisions on the transfer of responsibility.

Table 2b. Public authorities of the BSR responsible for implementation of the EU CCS Directive

MS	Competent Authorities	Roles
	Head of the State Mining Authority	Responsible for underground carbon dioxide storage; approving the storage site management plan, the monitoring plan, corrective measures plan, provisional post-closure plan and the mining plant operation schedule.
	Head of the Energy Regulatory Office	Conducts tasks related to regulation of the provision of carbon dioxide transmission services and the access to transmission and underground carbon dioxide services.
	Competent borough/commune leader (wójt), mayor or president of a city	Responsible for issuing decisions on environmental conditions (based upon environmental impact assessment and public consultations). Also cooperates in issuing concessions
	Environmental protection authorities, including regional environmental protection directorates	Authorities cooperating in issuing concessions include the minister of economy, maritime administration authority, competent borough/commune leader (*wójt*), mayor or president of a city and the EC.
	National Fund for Environmental Protection and Water Management	Manage financial security funds, including funds for financing of tasks related to transfer of responsibility for underground carbon dioxide storage sites).
	Polish Geological Institute — National Research Institute (PIG–PIB)	Maintain the register of mining areas and closed underground carbon dioxide storage sites, as well as fulfilment of tasks of the National Administrator of Carbon Dioxide Storage Sites — KAPS CO_2).
	Competent authority for emission trading.	Responsible for emission settlement.

Sweden	Mark- och miljödomstol (Land and Environment Court)	The Land and Environment Courts are responsible for granting a permit for CO2 storage on land and on the continental shelf if the storage exceeds 100 000 tons. There are five Land and Environment Courts (situated i Växjö, Vänersborg, Nacka, Östersund och Umeå) with different territorial jurisdiction. Which Land and Environment Court the application should be sent to depends on where the site will be located. (see Förordning (2010:984) om mark- och miljödomstolars domsområden).
	Regeringskansliet (Government Offices)	If CO2 storage is to take place on the continental shelf, a permit is necessary according to the continental-sockellagen (Continental Shelf Act) regardless of the amount of CO2 that will be stored. The Government Offices must also decide on the permissibility of the project unless the project is for research purposes and the amount of CO2 is less than 100 000 tons.
	Länsstyrelse (County Administrative Board)	Granting permits for storage that is less than 100 000 tons of CO2.
	SGU (Swedish geological survey)	Providing expert advice to the Land and Environment Courts and/or the Government Offices, if they so require, during the processing of an application. If permission is granted SGU will be the supervisory authority (regulatory authority) and will oversee that the operation is conducted in accordance to the permit.
	Ministry of Transport	Energy Act/Land Planning Act
	Ministry of Petroleum & Energy	
	Ministry of Labour & Social Affairs	
	Ministry of Environment and Climate	Pollution Control Act/Regulations

1.1.2.2 CCS Directive Review 2015

Article 38 of the CCS Directive requires the Commission to assess the CCS Directive in a report to be transmitted by 31 March 2015 to the European Parliament and to the Council and to present a proposal for revision of the Directive if appropriate [9]. In the Report of the EC to the EU Parliament, published in December 2015 it was stated that "it is important to maintain support for commercial-scale demonstration projects both in the power and industry sectors, as this is essential to gain experience, bring down costs and demonstrate safe and reliable underground storage of CO2. At the EU level, the Innovation Fund, which should be endowed with 450 million allowances under the EU ETS, should support CCS besides innovative renewable energy and energy-intensive industry."

Power generation and other industrial projects have long investment cycles, so it is important that Member States consider CCS as part of their long-term planning (ideally up to 2050) to be developed under the future Governance for the Energy Union.

With a view to future CCS deployment, it is important to plan adequate CO2 transport and storage infrastructure, and consider sharing infrastructure to reduce costs. Advancing knowledge of CO2 storage capacity and mapping the location of key storage sites and clusters of CO2 sources would help with the planning of the future transport and storage network. The Connecting Europe Facility can play a role in supporting cross-border transport networks and regional cooperation in this area.

Stepping up research and innovation activities in this area is one of the ten actions identified in the new Strategic Energy Technology Plan to accelerate energy system transformation and create jobs and growth."

Based on the evaluation study, the European Commission found that the CCS Directive is fit for purpose. However, the lack of practical experience of projects going through the regulatory process precludes a robust judgement of the performance of the Directive. There is clear stakeholder concern that reopening the Directive now could be counterproductive as it would bring a period of uncertainty for CCS, which would not be helpful in a sector where investor confidence is already low [9].

1.1.2.3 Progress in EU CCS Directive implementation in 2013-2016

All EU Member States have notified transposition measures to the Commission. To date, the Commission considers that the legislation of sixteen Member States is fully conforming to the Directive. Exchanges are still ongoing with the remaining Member States to bring their legislation fully in line with the requirements of the Directive [10].

Specific implementation issues in the BSR States

Selection of storage sites

Among BSR countries only Poland and Germany have determined new areas from which storage sites may or may not be selected.

Five German federal states[1] are preparing decisions or have passed laws limiting or banning underground storage of CO_2, including for research purposes. The underpinning reasons span from prioritising uses of the underground such as for geothermal energy, storage of energy or mining to giving special emphasis on the public interest such as environmental and tourism concerns.

Poland has determined one storage area - the Cambrian reservoir within the Polish Exclusive Economic Zone (EEZ) - deep geological formations of exhausted hydrocarbon deposits and the surrounding area.

New assessments of the available storage have been carried out, or are ongoing in Germany and Sweden. In the period 2011-2015, the Swedish Geological Survey participated in the Nordic CCS Competence Centre NORDICCS. One of the most important results of this is a web-based Nordic CO_2 storage atlas, which provides a comprehensive overview of storage sites in the Nordic countries – Denmark, Norway, Sweden and Iceland. Reservoir simulations indicate a storage capacity of 250 Mt CO_2 for each of two modelled storage units within Sweden's economic zone.

Germany is doing a further assessment of CO_2 storage capacity in deep saline aquifers using the methodology of the North American storage atlas for the purposes of an expert comparison of methods.

The majority of current assessments done in the Member States are static and do not include aspects such as flow calculations, migration pathways and dissolution effects. Studying these parameters would be necessary for choosing the most appropriate monitoring techniques and for the optimisation of potential CO_2 storage projects. Cost models would also improve the usefulness of CO_2 storage assessments.

Feasibility for CCS retrofitting for new large scale combustions plants

The CCS Directive requires that when applying for licence, operators assess the technical and economic feasibility of carbon capture, transport and storage. If the assessment is positive, space on the installation site must be set aside for the equipment necessary to capture and compress CO_2.

In the BSR assessments were carried out in Germany (five) and Poland (ten). Assessments found that CCS is not economically feasible. Some further difficulties were found for some of the plants – no suitable storage sites in Estonia.

However, even if the assessments were not positive, many of the permitted power plants are setting aside land for the equipment to remove and compress CO_2 and are designed in such a way that CCS can be connected later on without major layout modifications, e.g. in the Estonia, Germany and Poland.

[1] Lower Saxony, Schleswig-Holstein, Mecklenburg-Western Pomerania, Saxony-Anhalt, Bremen.

Five BSR Member States (Germany, Finland, Norway, Poland and Sweden) participate in Action 9 of the SET-Plan - 'Renewing efforts to demonstrate CCS in the EU and developing sustainable solutions for carbon capture and use (CCU)'.

Research projects with relevance to the CCS Directive

Even if demonstration and commercialisation of CCS has not advanced during 2013-2016, Germany and Lithuania continue to support or plan to further support research activities to improve the technology and knowledge of underground storage of CO2. Estonia and Poland report exploring alternatives to geological storage of CO_2 through various CO_2 utilisation options.

Five BSR Member States (Germany, Finland, Norway, Poland and Sweden) participate in Action 9 of the SET-Plan - 'Renewing efforts to demonstrate CCS in the EU and developing sustainable solutions for carbon capture and use (CCU)'.

CO_2 transport and storage networks

Two active CCS regional networks working to develop common, transboundary solutions for the transport and geological storage of CO2 - the North Sea Basin Task Force with the UK, the Netherlands, Norway, Germany and Belgium and the Baltic Sea Region CCS network with Estonia, Germany, Finland, Norway and Sweden are reported by EC in 2017 [10]. These networks may facilitate the transparent and non-discriminatory access to CO_2 transport networks and CO_2 storage sites for operators in BSR countries where there is no possibility of underground storage [10] (Estonia and Finland).

1.1.3 Assessment of national CCS regulations by GCCSI

In 2015 the Global Carbon Capture and Storage Institute (GCCSI) estimated national legal and regulatory regimes for carbon capture and storage in 55 countries.

Among the BSR countries assessed, only regulations implemented in Denmark were assigned into Band A (Table 1) estimated by GCCSI as representing "advanced and comprehensive frameworks, which are largely capable of addressing many of the critical legal and regulatory aspects throughout the CCS-project lifecycle. These findings reflect an extensive and sustained national commitment to the development of law and regulation for the technology, which is perhaps unsurprising considering the leadership role some of these nations have adopted with regard to the technology" [11] .

Six BSR countries (Table 1) were assigned into Band B (CCS-specific laws or existing laws that are applicable across parts of the CCS project cycle). Estonia, Latvia and Russia were assigned into Band C (very few CCS-specific or existing laws that are applicable across parts of the CCS project cycle).

1.1.4. Conclusions (gaps and needs)

- The enabling legislation for CCS in the BSR is regulated by national laws and international conventions (London Protocol, OSPAR and HELCOM). These have been adopted in different extent at national levels (CCS Directive), but have not been implemented yet in all the BSR countries (as London Protocol).
- As several BSR countries have not yet ratified the London Protocol (Finland, Poland, Latvia, Lithuania and Russia), bilateral and international agreements and local permits will be needed for transboundary offshore CO_2 storage, which could be regulated also by HELCOM for the Baltic Sea.
- As not all BSR countries implemented CCS legislation fully in line with the requirements of the Directive, their exchanges with EC are still ongoing.

- Improved estimation of CO_2 storage capacity and mapping the location of key storage sites and clusters of CO_2 sources is needed for planning of CO_2 transport and storage infrastructure in the BSR. Sharing infrastructure will reduce costs.
- Banning of CO_2 storage by some countries (like in some Federal States of Germany) explained by higher priority for other resources (geothermal energy or energy storage) could/need to be replaced by synergy of CCS with geothermal energy and use of CO_2 for energy storage.
- The most developed and full framework for CCS was estimated and scored by GCCSI in Denmark, while other BSR countries demonstrate limited or very few CCS-specific or existing laws applicable across aspects of the CCS project lifecycle.
- EC reported that several challenges still remain for the large-scale implementation of CCS projects in Europe. These include high investment costs and lack of public and consequently political support for onshore storage.
- More economic technological developments are needed to decrease CCS costs.
- Lack of onshore CCS demonstration projects in Europe was one of reasons to ban CO_2 storage in Latvia with available storage capacity, while the bans in Estonia and Finland were motivated by absent storage capacity.
- Offshore storage is successfully demonstrated in Norway, where significant storage capacity has been estimated. However, it is more expensive offshore than onshore, where implementation of international agreements, like the amendment to Article 6 of the London Protocol (enabling transboundary CO2 storage), still needs to be implemented.
- The most promising driving force for CCS implementation is to combine it with CO_2 use (CCUS), including EOR-CCS, mineral carbonation options and geothermal-CCS, which will hopefully lead to a greater sense of trust among Green NGOs and the general public.
- At least six BSR countries are active in CCUS research. Additional European and national regulations are needed to consider CO_2 used as CO_2 stored and to include CO_2 used for enhanced recovery of various resources (oil, gas, coal bed methane, geothermal energy, saline water, CO_2 energy storage) into CO_2 storage and monitoring planning and activities.

References:

[1] Status of multilateral Conventions and instruments in respect of which the International Maritime Organization or its Secretary-General performs depositary or other functions. IMO. *13 June 2016, 512-528.*

[2] Rydberg N. and Langlet D. 2014. CCS in the Baltic Sea Region – Bastor 2. Work Package 4 – Legal & Fiscal aspects. Elforsk report 14:48, 90 pp.

[3] Shogenova, A., Piessens, K., Holloway, S., Bentham, M., Martínez, R., Flornes, K.M., Poulsen, N.E., Wójcicki, A., Sliaupa, S., Kucharič, L., Dudu, A., Persoglia, S., Hladik, V., Saftic, B., Kvassnes, A., Shogenov, K., Ivask, J., Suárez, I., Sava, C., Sorin, A., Chikkatur, A. 2014. Implementation of the EU CCS Directive in Europe: results and development in 2013 . Elsevier, The Netherlands. *Energy Procedia* 63, 6662-6670. | **DOI** |

[4] Report from the Commission to the European Parliament and the Council on the implementation of Directice 2009/31/EC on the geological storage of carbon dioxide. Brussels: European Commission; 2014. p.1-8.

[5] Rütters H and the CGS Europe partners. State of play on CO2 geological storage in 28 European countries. CGS Europe report No. D2.10; 2013. p.1-89.

[6] One North Sea: A study into North Sea cross-border CO2 transport and storage. 2010. http://www.npd.no/no/Publikasjoner/Rapporter/Samarbeider- om-CO2-lager/.

[7] Haselton T M. Exploiting the ROZ in Lithuania. 19th Annual CO2 Flooding Conference, Midland, Texas; 2013. http://www.co2conference.net/wp-content/uploads/2013/12/15-Haselton-Exploiting-the-ROZ-in-Lithuania-new-new.pdf.

[8] Report from the Commission to the European Parliament and the Council. On the implementation of The European Energy Programme for Recovery. Brussels: European Commission; 2013. p.1-14.

[9] *EC 2015. Report on review of Directive 2009/31/EC on the geological storage of carbon dioxide. 18.11.2015 Brussels.*

[10] Report from the Commission to the European Parliament and the Council on the Implementation of Directice 2009/31/EC on the Geological Storage of Carbon Dioxide. Brussels: European Commission; 2017. p.1-7, http://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:52017DC0037&from=EN
[11] GCCSI 2015. Global CCS Institute CCS Legal and Regulatory Indicator. A global assessment of national legal and regulatory regimes for carbon capture and storage. Global Carbon Capture and Storage Institute Ltd. 27 pp.

Annex 2 Political situation and stakeholder analysis

Introduction

There is strong evidence that anthropogenic activities during the last centuries, such as burning of fossil fuels and land use, are disturbing the natural carbon cycle (e.g. NASA data). Parts of the increased CO2 emissions is absorbing in vegetation and some is dissolving in the oceans, the latter causing acidification and negative effects on marine life. The remainder has accumulated in the atmosphere where it contributes to the greenhouse effect. Today the concentration in the atmosphere is 402 ppm and experts believe that 450 ppm (corresponding to a temperature increase of about 2°C (2DS)) is a limit beyond which drastic environmental consequences are inevitable (IPCC 2007).

There are multiple mitigation pathways likely to limit warming to below 2°C relative to pre-industrial levels. These pathways would require substantial emissions reductions over the next few decades and near zero emissions of CO2 and other long-lived greenhouse gases by the end of this century. To achieve the mitigation goal of limiting warming to below 2DS, several tools and technologies are required. Most of the scenarios indicate that in order to reach a full decarbonisation of society, at lowest cost, Carbon Capture and Storage (CCS) should be deployed at large scales (IPCC, 2014).

Currently there is 39 large-scale projects in various stages (planned or in operation) in the world. The number of CCS project would need to rise substantially to help meet longer-term climate goals. The International Energy Agency (IEA), in modelling its 2°C Scenario (2DS), has CCS capturing around four gigatonnes (Gt) of CO2 emissions per annum by 2040, today (Figure 1).

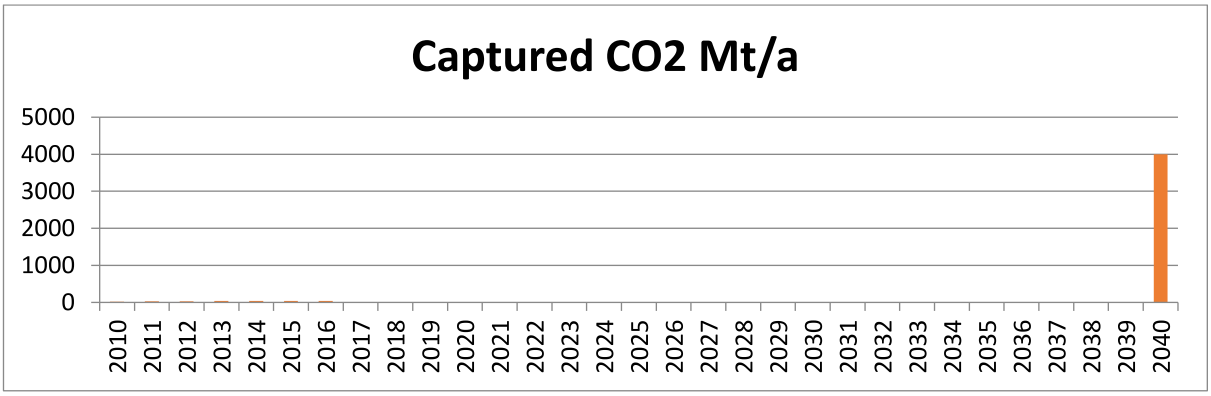


Figure 1. Captured CO2 per annum globally with the IEA target for 2040.

The development of CCS been stalled by lacking economic incentives, missing political support and in some regions also by public opposition. To enhance actions in the field of CCS, governments would need to demonstrate a clear, long-term commitment to CCS underpinned by detailed policy, legal and regulatory frameworks that would provide predictability for investors.

EU Climate strategies and targets

The EU emissions trading system is the EU's key tool for cutting greenhouse gas emissions from large-scale facilities in the power and industry sectors, as well as the aviation sector. The system works according to the cap and trade principle. The EU also supports the development of low carbon technologies for example through the NER300 programme for renewable energy technologies and carbon capture & storage and Horizon 2020 funding for research & innovation.

The EU has set itself targets for reducing its greenhouse gas emissions progressively up to 2050. Key climate and energy targets are set in the 2020 climate and energy package and 2030 climate and energy framework. The 2020 package sets three key targets for 2020: 20 % cut in greenhouse gas emissions (from 1990 levels), 20 % of EU energy from renewables and 20 % improvement in energy efficiency. Targets were set in 2007 and entered into force in 2009. The 2030 climate & energy framework sets three key targets for 2030: at least 40 % cuts in greenhouse gas emissions (from 1990 levels), at least 27 % share of renewables and at least 27 % improvement in energy efficiency. The 2030 framework was adopted in October 2014 and builds on the 2020 package.

These current EU targets are defined to put the EU on the way to achieve the transformation towards a low- carbon economy as detailed in the 2050 low-carbon roadmap, which suggests that by 2050: the EU should cut emissions by 80 % below 1990 levels (40 % by 2030 and 60 % by 2040). To reach this goal all sectors would need to contribute according to their technological and economic potential.

The power sector has the biggest potential for cutting emissions, since low-emission energy sources can replace fossil fuels in power generation, transport and heating. Fossil fuel power stations could also be equipped with CCS technology, which according to Ea Energy analyses (2012), could become necessary in Poland and Germany from 2035 onwards. For the industry, it is foreseen that up to 2030 CO_2 emissions will fall gradually through energy efficiency measures but after 2035 CCS technology would need to be applied in sectors where industries are unable to make cuts in any other way (e.g. steel, cement). The 2050 low-carbon roadmap concludes that the transition to a low-carbon society is feasible and affordable, but requires innovation and investments. To make the transition it is estimated that the EU would need to invest an additional 270 billion € (on average 1.5 % of its GDP annually) over the next 4 decades.

BSR Climate policies and targets

The EU proposals for reducing CO2 emissions recognizes different capacities of Member States to take action by differentiating targets according to GDP per capita across Member States. In general, higher income Member States will take on more ambitious targets than lower income Member States. There is also differences in e.g. the availability of renewable energy, biomass etc. that provide different starting points for different states.

Finland

Finland has adopted EU level targets for reducing emissions by 2020 and 2050. The national targets for Finland for 2020 are specified in the National Energy and Climate Strategy and the longer-term objectives in the Energy and Climate Roadmap 2050 –. Finland aims for 38 % renewable energy by 2020 and to have an emission free energy system by 2050

According to current scenarios, some industrial processes in Finland will require CCS technology. Should the central biomass fuels not remain zero-emission or CCS not be commercialized the reduction targets by 2050 cannot be reached.

Sweden

In 2008/2009 governmental bills were passed in Sweden stating among other things aims of 40 % GHG reduction by 2020 compared to 1990 levels and 50 % renewable energy. Sweden also has a vision to have a vehicle fleet independent of fossil fuels by 2030 and to have zero net greenhouse gas emissions by 2050. The aims in Sweden are planned to be reached with the help of carbon dioxide tax, international emission trading and renewable energy certificates.

Estonia

Estonia is aiming to keep emissions of GHG by 2020 within the limit of 11 percent, compared to the level of 2005 and to bring the share of renewable energy to 25 %, 10 % renewable in transport and not to exceed 2010 level of total consumption.

Latvia

The Latvian target for 2020 is a limited increase in GHG emissions of 17 % (compared to 2005). Latvia’s Energy Strategy 2030, in force since March 2013, sets long-term actions to ensure energy supply, competitiveness, energy efficiency and use of renewable energy.

Lithuania

The goal for 2020 is to achieve that the national economy growth is faster than the increase of GHG emissions (GHG/GDP tCO2e/1 mln. Lt GDP). EU ETS emissions not exceeding 8.53 MtCO2e. Non EU ETS emissions not exceeding 16.584 MtCO2e.

Poland

The goal for 2020 is that non-ETS missions may increase no higher than 14 % above 2005 level (original Kyoto target was 6 % below 1988 level), 15 % renewables in energy (20 % by 2030), 9 % energy savings.

Russia

The goal for 2020 is to decrease emissions by 25 % from 1990 level (30 % by 2030) as stated in Russia Energy strategy.

Germany

Germany aims to cut greenhouse gas emissions (GHG) by 40 percent by 2020 and up to 95 percent in 2050, compared to 1990 levels. The share of renewables in gross final energy consumption is to rise to 60 percent by 2050. Renewables are to make up a minimum of 80 percent of the country's gross power consumption by the middle of the century.

Denmark

Denmark aims for 20 % reduction by 2020 and to have 30 % renewable in total energy consumption. The Danish reduction obligations for 2030 have not yet been negotiated but Denmark aims to be independent of fossil fuels by 2050.

Norway

The goal for 2020 is a 30 % reduction from 1990 levels (40 % by 2030 and carbon neutral by 2050, in case of ambitious global agreement is reached Norway is ready to become carbon neutral already by 2030). Norway has planned to reach the goals with ETS and carbon tax, reductions in transport sector, development of low-emission technologies for the industry, renewable energy and carbon capture and storage.

Baltic Sea region Key CCS Stakeholders

Information on Key CCS stakeholders were gathered in a survey among CGS Baltic participants.

Table 1. Key CCS Stakeholders in the BSR.

Key CCS stakeholders			
Country	Geological R&D	Energy and Industry	Legal authorities
Finland	GTK, VTT & Universities	Power sector (Finnish Energy, Fortum, Helsingin energia, etc.), Industry sector include steel (SSAB etc.), cement (Finnsementti, Nordkalk etc.) and pulp and paper (UPM, Metso, Stora Enso etc.)	Ministry of the Environment. Ministry of Employment and the Economy.
Sweden	SGU, Universities, Elforsk	Vattenfall, LKAB, Boliden, SSAB, Svenska Petroleum Exploration, Jernkontoret, SMA Mineral, Cementa, Nordkalk, Fortum, Preem, MinFo, Stora Enso, SCA, Södra, Holmen AB and BillerudKorsnäs	SGU, The Swedish Energy Agency (Energimyndigheten), Swedish Environmental Protection Agency (Naturvårdsverket), Ministry of the Environment and Energy
Estonia	Estonian Geological Survey. Tallinn Universiy of Technology.	Eesti Energia AS, Viru Keemia Grupp AS, AS Kunda Nordic Tsement etc.	Ministry of the Environment. Ministry of Economic Affairs and Communications.
Latvia	LEGMC, Faculty of Geography and Earth Sciences, University of Latvia	Oil industry (Odin Energi Latvia)	Ministry of Environmental Protection and Regional Development
Lithuania	NRC	Oil industry (Minijos Nafta)	Ministry of environment, Lithuanian Geological Survey
Poland	PGI-NRI, AGH-UST, CMI, MEERI PAS, OGI, Silesian Univ. of Technology	Ministry of Energy; Power & Fuel Sector (PGE, Tauron, Enea, Energa, POGC, PKN Orlen, LOTOS), Industry sector: chemical (Grupa Azoty), steel (ArcelorMittal PL) etc.	Ministry of Environment
Russia	VNIGRI, Gubkin University	Ministry of energy, oil industry	Russian subsoil licensing authorities
Germany	GFZ, BRG	The Voice of German Industry, Federal associate of German Energy and Water Utilities, German Lignite Association, Mining, Chemistry and Energy Industrial Union	Competent authorities of Länder
Denmark	GEUS	Oil industry	Danish Energy Agency
Norway	NPD, SINTEF	Statoil	Ministry of Petroleum and Energy

References:

Ea Energy Analyses, 2012. Energy Policy Strategies of the Baltic Sea Region for the Post Kyoto Period. Prepared for BASREC. 86 p.

GCCSI, 2015. The Global Status of CCS: 2015.

IEA, 2014. CCS 2014 - What lies in store for CCS?. Insight series 2014. 108 p.

IPCC 2007. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. IPCC, Geneva, Switzerland.

IPCC, 2014. Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.

Annex 3 Exchange of information with North Sea Basin Task Force/NORDICCS

1.3.1 Introduction

The aim of subtask 1.3 was to exchange information with the North Sea Basin Task Force (NSBTF) and benefit from its experience in the deployment of the CCS technology. However, during the project it turned out that NSBTF activity in recent years seems to be suspended. As there is not active web page and new publications, it was decided to focus on the reports prepared by the group in past years. Additionally, it was decided to compensate by investigating activity of NORDICS group, based on its report published in December 2016. Swedish Geological Survey (NORDICCS partner) did also participate in two CGS Baltic seed project meetings.

1.3.2 The North Sea Basin Task Force

The North Sea Basin Task Force was established by the agreement between Norway and the United Kingdom in November 2005. The purpose of the agreement was a collaboration on issues related with transport and storage of CO2 beneath the North Sea which was agreed the best geological opportunity for storing both countries' CO2 emissions. The Task Force was composed of public and private bodies (from governments and industry) from countries on the rim of the North Sea (Table 2).

Table 2 The North Sea Basin Task Force members

UK	Norway
DTI DEFRA The Crown Estate BGS AEA BP Shell	The Ministry of Petroleum and Energy The Ministry of the Environment Det Norske Veritas Statoil Hydro

At the beginning of cooperation Task Force members cooperate intensively and prepared two noteworthy reports:

Storing CO_2 under the North Sea Basin - a key solution for combating climate change, 2007

and

Development of a CO_2 transport and storage network in the North Sea: report to the North Sea Basin Task Force, 2007

Unfortunately, its activity in recent years seems to be suspended. As there is no active web page and new publications, authors focused on the above mentioned reports.

The Task Force activities were divided into two phases. Activities in Phase I was mainly concentrated on a gap analysis on issues related to legal and regulatory frameworks, public acceptance, emission accounting, monitoring, verification and risk management. The most significant barriers to deployment of the CCS technology presented in Table 2 was classified as international (I), regional (R) or national (N) and traffic lights system indicates expected time until barrier is solved: red – long term barrier, amber – short term, green – already solved.

Table 3 Barriers to deployment of CCS technology – results of gap analysis [1]

Potential barriers or enablers	International (I), Regional (R), National (N)	Expected time until solved	
		< 2 years	2-5 years
UNFCC-IPCC National Inventories	N, I	green	green
Kyoto Protocol (CDM and JI)	I	red	amber
UNCLOS	I	green	green
London Convention and Protocol	I	green	green
OSPAR	R	amber	green
Trans-boundary movement and/or damage	I	amber	amber
The Aarhus Convention	I	green	green
EU ETS	R	amber	green
EU enabling legal framework	R	red	green
UK regulations and CCS	N	amber	green
Norway regulations and CCS	N	amber	green
Long-term liability	N, R, I	red	red
Risk assessment methods	I	amber	green
Risk acceptance, including site approval criteria	I	red	amber
Monitoring and verification	I	red	amber
Public support	I	amber	amber
Accounting and certification of credits	I	amber	green
Costs and economics	I	red	amber
Incentives	I/R/N	red	amber
Technology maturity	I	green	green

The Task Force recognized the following critical issues to be resolved [1]:

- amending existing legal and regulatory frameworks to enable CCS (viable approach to long-term responsibility, criteria for risk acceptance and site qualification (risk-based process), remove barriers to CCS in international conventions),
- establishing incentives for CCS,
- ensuring CCS is implemented in a manner acceptable to stakeholders .

Phase II had to rely on addressing the issues identified in first phase, sharing the knowledge between both countries and following up the results of the UK-Norway infrastructure study.

The NSBTF suggested that the North Sea Basin regulatory framework for the geological storage of CO2 should [1]:

- enable the sub-sea geological storage of substantial quantities of anthropogenic CO2,

- be soundly based, publicly stated, instil public confidence and provide predictability for stakeholders,
- be consistent within national borders and across national borders,
- regulate the CO2 cycle, building on existing legislation for transport, storage and disposal of commodities or waste,
- adopt a science-based approach to site evaluation ,
- address other potential environmental impacts of CCS activities,
- manage CO2 injection and storage through a licensing and regulatory regime

1.3.3 The NORDICCS project

The Nordic CCS competence centre (NORDICCS) was established in 2012 in order to address Pan-Nordic issues in CCS. It involved major CCS stakeholders from Top-level Research Initiative - the largest joint Nordic research and innovation initiative for climate, energy and the environment (11 R&D partners and 6 industry partners). The aim of the project was very similar to the objective of the NSBTF – to boost the deployment of CCS, in this case in the Nordic countries. NORDICCS activities were organized in three categories: 1) integrating activities, 2) spreading excellence, and 3) joint R&D activities and divided into six work-packages: 1) Assumptions and premises, 2) Communication, 3) Case studies, 4) CO2 Capture, 5) CO2 Transport, 6) CO2 Storage. Each work-package had its own WP leader responsible for planning and executing the work in accordance with approved plans. Leaders of each WPs were members of the management group administrated by the Centre Leader. The structure of the management of NORDICCS project is presented in Figure 1.

Important part of the project was establishing and operating networks of partners according to identified needs. During the first year of activity the NORDICCS Roadmap was developed providing the strategic framework for the centre and formalizing and integrating NORDICCS as the Nordic CCS platform and community. The most important for the interactive work were networks for CO_2 capture, CO_2 transport and CO_2 storage and exchange of the information between them. The activity “Feasibility study” were recognized as very important for coordination between work-packages. Knowledge and recommendations regarding framework conditions were collect and discussed on special seminars, also with subcontracted specialists (in case of topics outside the competence of the partners). NORDICCS seminar were open and the results were made publicly available. During the annual conventions all partners shared results and discussed common issues.

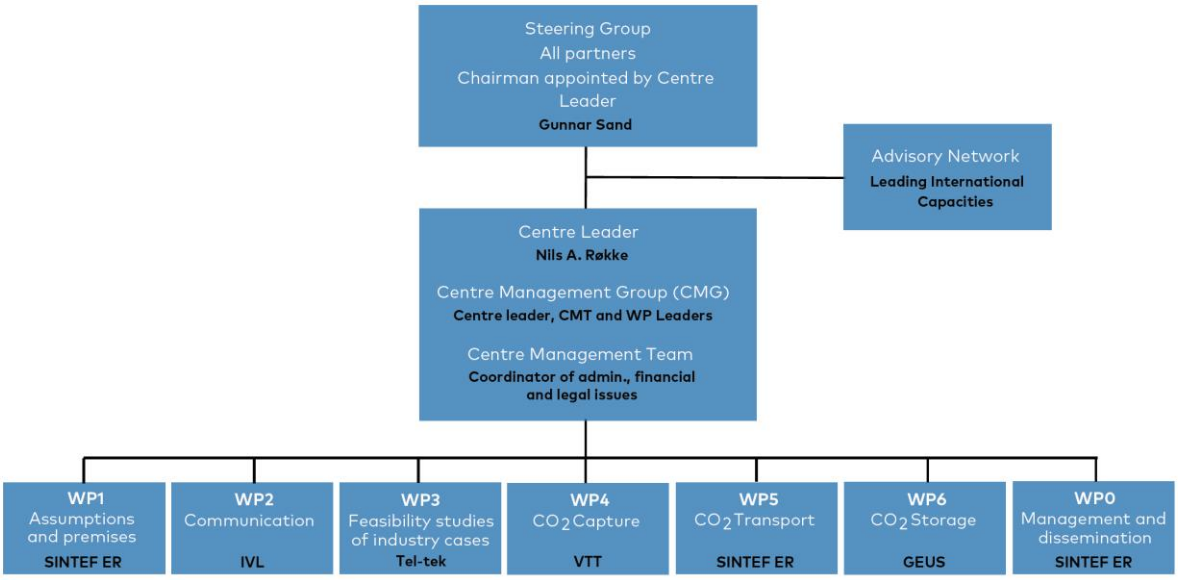


Figure 2 Management structure of NORDICCS [3]

Key findings from the Nordic CCS Roadmap:

- Ship transport of CO_2 is most the most effective one for the 80% of the CO_2 capture cases in the Nordic region,
- Good solution (from the point of view of economy of scale) is to build a joint storage site in the North Sea to which CO_2 can be transported by the ship from an onshore hub collecting CO_2 from all the Nordic countries (additionally the CO_2 hub could be used to kick-start CO_2-EOR and reduce costs) ,
- The most cost-effective CO_2 capture projects are located a relatively short distance away from the Utsira formation and CO_2 hub.
- Urgently required is establishing a Measurement Reporting Guideline which allows ship transport of CO_2 under EU Emission's Trading System.

1.3.4 Summary

According to the experience of both The North Sea Basin Task Force as well as the NORDICSS it can be summarized that the cooperation of partners strongly interested in common goal is extremely important element of good network. The network should consists of R&D partners and significant industrial partners with potential to execute CO_2 project.

The NSBTF and the NORDICCS agreed that in order for CCS to be widely deployed in time to meet climate targets, actions must be taken urgently. These includes:

- amending existing legal and regulatory frameworks to enable CCS (e.g. establishing a Measurement Reporting Guideline which allows ship transport of CO_2 under EU ETS)

- establishing incentives for CCS (e.g. capital grants for early CCS projects),
- ensuring CCS is implemented in a manner acceptable to stakeholders .

1.3.5 References

[1] *Storing CO_2 under the North Sea Basin - a key solution for combating climate change*, NSBTF 2007

[2] *Development of a CO_2 transport and storage network in the North Sea: report to the North Sea Basin Task Force*, NSBTF 2007

[3] *Building Nordic Excellence in CCS: NORDICCS – the Nordic CCS Competence Centre*, TRI, December 2016

Annex 4 List of most important publications by CGS Baltic project partners

Geological Survey of Finland

1. CCSP, 2016. CCSP Final report. http://ccspfinalreport.fi/reports/CCSP_Final_report.pdf
2. **Korhonen, K., Ahonen, L., & Nordbäck, N.** 2016. Geothermal and geochemical constraints of liquid CO2 storage in rock. CCSP research report D416. https://portal.cleen.fi/_layouts/IWXmlPublications.aspx?Source=CCSP&FileId=1017
3. Kujanpää, L., Ritola, J., **Nordbäck, N., &** Teir, S**. 2014.** Scenarios and new technologies for a North-European CO2 transport infrastructure in 2050. 16 s. http://www.sciencedirect.com/science/article/pii/S1876610214021122
4. **Nordbäck. N.** 2014. Report on status and capacities of geological CO2 storage in the surrounding regions to Finland. CCSP report D534. https://portal.cleen.fi/_layouts/IWXmlPublications.aspx?Source=CCSP&FileId=662
5. **Nordbäck, N. & Virtasalo, J.** 2014. Report on the prospective areas for CO2 storage in western Russia. CLEEN CCSP research report D518, 28 p. https://portal.cleen.fi/_layouts/IWXmlPublications.aspx?Source=CCSP&FileId=561
6. **Solismaa, L.** 2009. The suitability of carbon geological storage in main sedimentary formations in Finland. Archive report K2.142/2009/56, Geological Survey of Finland, 23 p. In Finnish.
7. Teir, S., Pikkarainen, T., Kujanpää, L., Tsupari, E., Kärki, J., Arasto, A. & **Aatos, S. 2011.** Carbon Capture and Storage (CCS). VTT, Espoo. 103 p. + app. 6 p. VTT Working Papers: 161 (in Finnish).

Institute of Geology at Tallinn University of Technology

Articles in Thomson & Reuters WOS:

1. Shogenov, K., Forlin, E. & Shogenova, A. (2017, in press) 3D geological and petrophysical numerical models of E6 structure for CO_2 storage in the Baltic Sea. Elsevier. Energy Procedia. **DOI**

2. Shogenov, K., Shogenova, A., Gei, D. & Forlin, E. (2017, in press) Synergy of CO_2 storage and oil recovery in different geological formations: case study in the Baltic Sea. Elsevier. Energy Procedia. **DOI**
3. Shogenov, K., Gei, D., Forlin, E. and Shogenova, A. 2016. *Petrophysical and numerical seismic modelling of CO_2 geological storage in the E6 structure, Baltic Sea, Offshore Latvia*. Petroleum Geoscience, 22, 153−164.
4. Shogenov, K., Shogenova, A., Vizika-Kavvadias, O. and Nauroy J.-Fr. 2015. Reservoir quality and petrophysical properties of Cambrian sandstones and their changes during the experimental modelling of CO2 storage in the Baltic Basin. Estonian Academy Publishers, Tallinn. *Estonian Journal of Earth Sciences* **64**(3), 199-217. **DOI**
5. Shogenov, K., Shogenova, A., Vizika-Kavvadias, O., Nauroy J.-Fr. 2015. Experimental modeling of CO2-fluid-rock interaction: The evolution of the composition and properties of host rocks in the Baltic Region. AGU Publications, John Wiley & Sons, USA. *Earth and Space Science* **2**(7), 262–284. **DOI**
6. Shogenova, A., Piessens, K., Holloway, S., Bentham, M., Martínez, R., Flornes, K.M., Poulsen, N.E., Wójcicki, A., Sliaupa, S., Kucharič, L., Dudu, A., Persoglia, S., Hladik, V., Saftic, B., Kvassnes, A., Shogenov, K., Ivask, J., Suárez, I., Sava, C., Sorin, A., Chikkatur, A. 2014. Implementation of the EU CCS Directive in Europe: results and development in 2013 . Elsevier, The Netherlands. *Energy Procedia* 63, 6662-6670. **DOI**
7. Shogenov, K., Shogenova, A., Vizika-Kavvadias, O. 2013. Petrophysical properties and capacity of prospective for CO2 geological storage Baltic offshore and onshore structures. Elsevier. *Energy Procedia* **37**, 5036-5045. **DOI**
8. Shogenov, Kazbulat; Shogenova, Alla; Vizika-Kavvadias, Olga. 2013. Potential structures for CO2 geological storage in the Baltic Sea: case study offshore Latvia. *Bulletin of the Geological Society of Finland.* **85**(1), 65-81.
9. Shogenova, A., Piessens, K., Ivask, J., Shogenov, K., Martínez, R., Suáres, I., Flornes, K.M., Poulsen, N.E., Wójcicki, A., Sliaupa, S., Kucharic, L., Dudu A., Persoglia, S., Holloway S., and Saftic, B. 2013. CCS Directive transposition into national laws in Europe: progress and problems by the end of 2011. Elsevier. *Energy Procedia* **37**, 7723-7731. **DOI**
10. Šliaupa, S., Lojka, R., Tasáryová, Z., Kolejka, V., Hladík, V., Kotulová, J., Kucharič, L., Fejdi, V., Wójcicki, A., Tarkowski, R., Uliasz-Misiak, B., Šliaupienė, R., Nulle, I., Pomeranceva, R., Ivanova, O., Shogenova, A., Shogenov, K. 2013. CO2 Storage Potential of Sedimentary Basins of Slovakia, The Czech Republic, Poland, and Baltic States. *Geological Quarterly* **57**(2), 219-232. **DOI**
11. Shogenova, A.; Shogenov, K.; Vaher, R.; Ivask, J.; Sliaupa, S.; Vangkilde-Pedersen, T.; Uibu, M.; Kuusik, R. (2011). CO2 geological storage capacity analysis in Estonia and neighbouring regions. Energy Procedia, 4, 2785 - 2792.
12. Shogenova, A.; Shogenov, K.; Pomeranceva, R.; Nulle, I.; Neele, F.; Hendriks, C. (2011). Economic modelling of the capture–transport–sink scenario of industrial CO2 emissions: the Estonian–Latvian cross-border case study. Energy Procedia, 4, 2385 - 2392.
13. Shogenova, A.; Sliaupa, S.; Shogenov, K.; Sliaupiene, R.; Pomeranceva, R.; Vaher, R.; Uibu, M.; Kuusik, R. (2009). Possibilities for geological storage and mineral trapping of industrial CO2 emissions in the Baltic region. Energy Procedia, 1(S1), 2753 - 2760.
14. Shogenova, A.; Sliaupa, S.; Vaher, R.; Shogenov, K.; Pomeranceva, R. (2009). The Baltic Basin: structure, properties of reservoir rocks and capacity for geological storage of CO2. Estonian Journal of Earth Sciences, 58(4), 259 - 267.
15. Sliaupa, S.; Shogenova, A.; Shogenov, K.; Sliaupiene, R.; Zabele, A.; Vaher, R. (2008). Industrial carbon dioxide emissions and potential geological sinks in the Baltic States. Oil Shale, 25(4), 465 - 484.
16. Raidla, V.; Kirsimäe, K.; Bityukova, L.; Jõeleht, A.; Shogenova, A.; Šliaupa, S. (2006). Lithology and diagenesis of the poorly consolidated Cambrian siliciclastic sediments in the northern Baltic Sedimentary Basin. Geological Quarterly, 50(4), 11 - 22.

Public reports:

1. Rütters, H. and the CGS Europe partners (2013) - State of play on CO2 geological storage in 28 European countries. CGS Europe report No. D2.10, June 2013, 89 p. http://www.cgseurope.net/UserFiles/file/News/CGS%20Europe%20report%20_D2_10_State%20of%20play%20on%20CO2%20storage%20in%2028%20European%20countries%281%29.pdf
2. Rütters, H. , Möller, I., Flornes, K., Hladik, V., Arvantis, A., Gulec, N., Bakiler, C., Dudu, A., Kucharic, L., Juhojuntti, N., Shogenova, A., Georgiev, G., 2013. State-of-the-Art of Monitoring Methods to evaluate Storage Site Performance. CGS Europe report no D3.3, Korre, A., Stead, R., Jensen, N.B.(Eds.), July 2013, 109 p. http://repository.cgseurope.net/Download.ashx?url=/media/71787/cgs_europe_kr_1_monitoring___d3.3_public.pdf
3. Vangkilde-Pedersen, T. et al. 2009 a. FP6 EU GeoCapacity Project, Assessing European Capacity for Geological Storage of Carbon Dioxide, Storage Capacity, WP2, D16 report, 166 pp, http://www.geology.cz/geocapacity/publications/D16%20WP2%20Report%20storage%20capacity-red.pdf
4. Vangkilde-Pedersen, T. et al. 2009 b. FP6 EU GeoCapacity Project, Assessing European Capacity for Geological Storage of Carbon Dioxide, Inventories & GIS, D8, WP1 Report, 84 pp, http://www.geology.cz/geocapacity/publications/D8%20WP1%20Report%20inventories%20and%20GIS-red.pdf

5. Shogenova A., Vaher R., Shogenov K., Ivask J. 2009a. CO_2 geological storage in Estonia and neighbouring regions: analysis of options and storage recommendations. Institute of Geology, Tallinn University of Technology. 67 pp. (Report to Eesti Energia Company, **confidential report)**

Uppsala University

1. Basirat, F., Yang, Z., Niemi, A. (2017) Pore-scale modeling of wettability effects on CO_2–brine displacement during geological storage. *Advances in Water Resources*. Accepted with revision.

2. Tian, L., Richard Wilkinson, Zhibing Yang, Henry Power, Fritjof Fagerlund and Auli Niemi (2017) 'Gaussian Process Emulators for Quantifying Uncertainty in CO2 Spreading Predictions in Heterogeneous Media' Computers & Geosciences. Accepted with revision, revision submitted.

3. Basirat, F., Fagerlund, F., Denchik, N., Pezard, P. and Niemi, A. (2016) Numerical modelling of CO2 injection at small-scale field experimental site in Maguelone, France. *International Journal of Greenhouse Gas Control*, 2016. 54: 200-210.

4. K. Rasmusson, M. Rasmusson, Y. Tsang, A. Niemi (2016) A simulation study of the effect of trapping model, geological heterogeneity and injection strategies on CO2 trapping. *International Journal of Greenhouse Gas Control*. Vol 52. pp. 52-72 DOI information: 10.1016/j.ijggc.2016.06.020.

5. Wolf, J.L., Niemi, A., Bensabat, J. and Rebscher, D. (2016) Benefits and restrictions of 2D reactive transport simulations of CO_2 and SO_2 co-injection into a saline aquifer using TOUGHREACT V3.0-OMP.I*nternational Journal of Greenhouse Gas Control.* http://dx.doi.org/10.1016/j.ijggc.2016.07.005. Volume: 54 Pages: 610-626 Part: 2 Published:

6. Tsang, C-F and Niemi, A. (2016) Chapter 2: Overview of the Processes Occurring during Geological Storage of CO_2. In: Niemi, A., Bear, J. and Bensabat, J. (Editors) GEOLOGICAL

STORAGE OF CO2 IN DEEP SALINE FORMATIONS. In Press. Publisher Springer. 600p. Pp. 415-519. http://www.springer.com/gp/book/9789402409949.

7. Niemi,A., Zhibing Yang, Jesus Carrera, Henry Power, Christopher Ian McDermott, Dorothee Rebscher, Jan Lennard Wolff, Franz May, Bruno Figuieredo and Victor Vilarrasa (2016) Chapter 4
Mathematical Modeling – Approaches for Model Solution. IN: Niemi, A., Bear, J. and Bensabat, J. (Editors) (2016) GEOLOGICAL STORAGE OF CO2 IN DEEP SALINE FORMATIONS. In Press. Publisher Springer. 600p. pp. 149-207
http://www.springer.com/gp/book/9789402409949

8. Niemi, A., Jacob Bensabat, Peter Bergmann, Christopher Juhlin, Alexandru Tatomir, Iulia Ghergut, Martin Sauter, Barry Freifeld, Larry Myer, Christine Doughty, Axel Liebscher, Stefan Lüth, Sonja Martens, Fabian Möller, Cornelia Schmidt-Hattenberger and Martin Streibel (2016) Chapter 8: Field Injection Operations and Monitoring of the Injected CO_2 (2016) In: Niemi, A., Bear, J. and Bensabat, J. (Editors) GEOLOGICAL STORAGE OF CO2 IN DEEP SALINE FORMATIONS. In Press. Publisher Springer. 600p. Pp. 415-519.
http://www.springer.com/gp/book/9789402409949.

9. Niemi, A., Katriona Edlmann, Jesus Carrera, Christopher Juhlin, Alexandru Tatomir, Iulia Ghergut, Martin Sauter, Jacob Bensabat, Fritjof Fagerlund, Kristina Rasmusson, Francois H. Cornet, Victor Vilarrasa and Christopher Ian McDermott (2016) Chapter 7: Site Characterization In: Niemi, A., Bear, J. and Bensabat, J. (Editors) (2016) GEOLOGICAL STORAGE OF CO2 IN DEEP SALINE FORMATIONS. In Press. Publisher Springer. 600p. Pp. 342-416 http://www.springer.com/gp/book/9789402409949.

10. Fagerlund, F., Hellman, F., Målqvist, A. and Niemi, A. (2016) Multilevel Monte Carlo methods for computing failure probability of porous media flow systems. *Advances in Water Resources*. Volume: 94 Pages: 498-509. AUG 2016.

11. Niemi, Auli, Gouze, Philippe and Bensabat, Jacob (2016) 'Characterization of formation properties for geological storage of CO2 - Experiences from the Heletz CO2 injection site and other example sites from the EU FP7 project MUSTANG'. Editorial for a Special Issue to *International Journal of Greenhouse Gas Control*, 2016. Doi: 10.1016/j.ijggc.2016.02.007

12. Niemi, A. Bensabat, J, Shtivelman, V, Edlmann, K, Gouze, P., Luquot, L., Hingerl, F, Benson, S.M., Pezard, P.A, Rasmusson, K., Liang,T., Fagerlund, F., Gendler, M., Goldberg,I, Tatomir,A., Lange, T., Sauter, M., and Freifeld, B. (2016) Heletz experimental site overview, characterization and data analysis for CO2 injection and geological storage *Int. J. of Greenhouse Gas Control*. http://dx.doi.org/10.1016/j.ijggc.2015.12.030

13. Luquot, L., Gouze, P., Niemi, A., Bensabat, J. and Carrera, J. (2016) Laboratory CO2-rich brine percolation experiments through Heletz samples (Israel): Role of the flow rate and brine composition. *International Journal of Greenhouse Gas Control*, DOI:10.1016/j.ijggc.2015.10.023

14. Zhang, F., Juhlin C., Niemi A., Huang F., Bensabat J. (2016). A feasibility and efficiency study of seismic waveform inversion for time-lapse monitoring of onshore CO2 geological storage sites using reflection seismic acquisition geometries. *International Journal of Greenhouse Gas Control*, doi:10.1016/j.ijggc.2015.11.015

15. Tatomir, A., Halisch, M., Duschl, F., Peche, A., Wiegand, B., Schaffer, M., Licha, T., Niemi, A., Bensabat, J., Sauter, M., (2016). An integrated core-based analysis for the characterization of flow, transport and mineralogical parameters of the Heletz pilot CO2 storage site reservoir. *International Journal of Greenhouse Gas Control.* doi:10.1016/j.ijggc.2016.01.030.

16. Edlmann K., Niemi A., Bensabat J., Haszeldine R.S. and McDermott C.I. (2016) Mineralogical properties of the caprock and reservoir sandstone of the Heletz field scale experimental CO_2 injection site, Israel; and their initial sensitivity to CO_2 injection. *Int. J. of Greenhouse Gas Control*, 2016. http://dx.doi.org/10.1016/j.ijggc.2016.01.003

17. Edlmann, K., Bensabat, Niemi, A., R.S. Haszeldine, C.I. McDermott (2016) Lessons learned from using expert elicitation to identify, assess and rank the potential leakage scenarios at the Heletz pilot CO2 injection site *Int. J. of Greenhouse Gas Control*, 2016. http://dx.doi.org/10.1016/j.ijggc.2016.02.018

18. Porter, RTJ, Mahgerefteh, H, Brown, S, Martynov, S, Collard, A, Woolley, RM, Fairweather, M, Falle, SAEG, Wareing, CJ, Nikolaidis, IK, Boulougouris, GC, Peristeras, LD, Tsangaris, DM, Economou, IG, Salvador, C, Zanganeh, K Wigston, A, Najafali, JN, Shafeen, A, Beigzadeh, A, Farret, R, Gombert, P, Hebrard, J, Proust, C, Ceroni, A, Flauw, Y, Zhang, YC, Chen, SY, Yu, JL, Talemi, RH, Bensabat, J, Wolf, JL, Rebscher, D, Niemi, A, Jung, BJ Mac Dowell, N, Shah, N, Kolster, C, Mechleri, E, Krevor, S (2016) Techno-economic assessment of CO2 quality effect on its storage and transport: CO(2)QUEST An overview of aims, objectives and main findings . *International Journal of Greenhouse gas Control.* Vol: 54 Pp. 662-681. Part: 2. DOI: 10.1016/j.ijggc.2016.08.011

19. Tian, L., Z. Yang, B. Jung, S. Joodaki, M. Erlström, Q. Zhou, and A. Niemi (2015). Integrated simulations of CO2 spreading and pressure response in the multilayer saline aquifer of South Scania Site, Sweden. *Greenhouse Gases: Science and Technology,* http://dx.doi.org/10.1002/ghg.1583.

20. Yang Z., L. Tian, B. Jung, S. Joodaki, F. Fagerlund, R. Pasquali, R. Vernon, N. O'Neill, and A. Niemi (2015), Assessing CO2 storage capacity in the Dalders Monocline of the Baltic Sea Basin using dynamic models of varying complexity. *International Journal of Greenhouse Gas Control* 43, 149-160. http://dx.doi.org/10.1016/j.ijggc.2015.10.024.

21. Tian, L, Yang, Z, Fagerlund, F. and Niemi, A. (2015) Effects of permeability heterogeneity on CO2 injectivity and storage efficiency coefficient. *Greenhouse Gases: Science and Technology.* http://dx.doi.org/10.1002/ghg.1540.

22. Basirat, F., Niemi, A., Sharma, P. and Fagerlund, F. (2015) Experimental and Modelling Investigation of CO2 Flow and Transport in a Coupled Domain of Porous Media and Free Flow. *International Journal of Greenhouse Gas Control.* 42: 61-470. http://dx.doi.org/10.1016/j.ijggc.2015.08.024

23. Rasmusson, M., Fagerlund, F., Tsang, Y., Rasmusson, K., Niemi, A. (2015) On the prerequisites for density-driven instabilities and convective mixing under broad geological CO2 storage conditions Advances. *Advances in Water Resources*, 84: 136-151. doi:10.1016/j.advwatres.2015.08.009

24. Figueiredo, B, CF. Tsang, A. Niemi, J. Rutqvist and J. Bensabat (2015) Study of the Potential

Fault Reactivation induced by CO2 injection in a three-layer storage formation. Proceedings ISRM International Society of Rock Mechanics

25. Figueiredo, B, Tsang, CF , Rutqvist, J, Bensabat, J and Niemi, A (2015) Coupled hydro-mechanical processes and fault reactivation induced by Co_2 Injection in a three-layer storage formation *Int Jour Greenhouse Gas Control,* Volume: 39, Pages: 432-448, DOI: 10.1016/j.ijggc.2015.06.008

26. Rasmusson, K., Tsang, C.-F., Tsang, Y., Rasmusson M., Pan, L., Fagerlund, F., Bensabat, J., Niemi, A. (2015) Distribution of injected CO2 in a stratified saline reservoir accounting for coupled wellbore-reservoir flow. *Greenhouse Gases: Science and Technology*.Volume 5, Issue 4, August 2015, Pages: 419–436

27. Yang, Z., A. Niemi, L. Tian, Saba Joodaki, and M. Erlström (2015), Modeling of pressure buildup and estimation of maximum injection rate for geological CO2 storage at the South Scania site, Sweden, *Greenhouse Gases: Science and Technology.* Volume: 5, Issue: 3, Pages: 277-290 DOI: 10. http://dx.doi.org/10.1002/ghg.1466.

28. Rasmusson, K., Rasmusson, M., Fagerlund, F., Bensabat,J., Tsang, Y. and Niemi, A. (2014) Analysis of alternative push-pull-test-designs for determining in-situ residual trapping of carbon dioxide. *Int Jour Greenhouse Gas Control,* Volume: 27 Pages: 155-168. Aug 2014

29. O'Neill, N., Pasquali, R., Vernon, R. and Niemi, A. (2014) Geological Storage of CO2 in the Southern Baltic Sea. *Energy Procedia*, 2014. Vol 59 (pp. 443-439)

30. Behrens, H., Ghergut,J., Bensabat, J., Niemi, A. and Sauter, M. (2014) Merging single-well and inter-well tracer tests into one forced gradient dipole test, at the Heletz site within the MUSTANG project. *Energy Procedia*, 2014. 59 (pp. 249 – 255)

31. Brown, S., Martynov, S., Mahgerefteh, H., Fairweather, M., Woolley, R.M., Wareing, C.J., Falle, S., Rutters, H. Niemi, A., Zhang, Y.C. Chen, S., Bensabat, J., Shah, N., Dowell, N.M., Proust, C. Regis Farret, R., Economou, I.G., Tsangaris, D.M. Boulougouris, G.C., Wittenbergh, J.V (2014) CO2QUEST: Techno-economic Assessment of CO2 Quality Effect on Its Storage and Transport *Energy Procedia*, 2014. 63 (2622-2629)

32. Kühn, M., Andreas Busch, Auli Niemi, Alexandra Amann-Hildenbrand, Thomas Kempka, Stefan Lüth (2013) Preface: CO2 storage is feasible and further demonstration projects are needed. *Int Jour Greenhouse Gas Control* 19 (2013) 606–608

33. Yang, Z, Tian, L., Niemi, A. and Fagerlund, F. (2013) Upscaling of the constitutive relationships for CO2 migration in multi-modal heterogeneous formations. *Int Jour Greenhouse Gas Control* 19 (2013) 743–755

34. Fritjof Fagerlund, Auli Niemi, Jacob Bensabat, Vladimir Shtivelman (2013) Design of a two-well field test to determine in situ residual and dissolution trapping of CO2 applied to the Heletz CO2 injection site. *Int Jour Greenhouse Gas Control* 19 (2013) 642–651

35. Tong, Niemi et al (2013) A numerical model of tracer transport in a non-isothermal two-phase flow system for CO2 geological storage characterization. *Transport in Porous Media* doi: 10.1007/s11242-013-0138-x. 98(1):173-192.

36. Basirat,F., Niemi,A., Perroud,H. Lofi,J. , Denchik,N., Lods, G., Pezard,P., Sharma, P. and Fagerlund, F. (2013) Modeling CO2 Gas Transport in the Shallow Subsurface in Maguelone Field Experiment. *Energy Proc* 40 (2013)337 – 345. 1876-6102.

37. Saba Joodaki, Auli Niemi, Christopher Juhlin, Daniel Sophera, Monika Ivandica, Mikael Erlström (2013) Simulation of CO2 injection into a Baltic Sea saline aquifer and seismic monitoring of the plume. *Energy Proc* 40, 355 – 364.

38. Zhibing Yang, Auli Niemi, Liang Tian, Mikael Erlström (2013) Modelling of far-field pressure plumes for carbon dioxide sequestration. *Energy Proc* 40, 472 – 480.

39. Fritjof Fagerlund, Auli Niemi, Jacob Bensabat, Vladimir Shtivelman (2013) Interwell field test to determine in-situ CO2 trapping in a deep saline aquifer: Modelling study of the effects of test design and geological parameters. *Energy Proc*40, 554 – 563.

40. Niemi et al. (2012). Small-scale CO2 injection into a deep geological formation at Heletz, Israel. *Energy Proc*. Volume 23 (504-511)

41. Huang, F., Bergmann, P., Juhlin, C**.**, Ivandic, M., Lüth, S., Ivanova, A., Kempka, T., Henninges, J., Sopher, D. and Zhang, F., 2016. The First Post-injection Seismic Monitor Survey at the Ketzin Pilot CO2 Storage Site: Results from Time-lapse Analysis. *Geophysical Prospecting*. Accepted Author Manuscript. doi:10.1111/1365-2478.12497

42. Huang, F., Juhlin, C., Han, L., Sopher, D. and Ivandic, M., 2017. Feasibility of utilizing wavelet phase to map the CO2 plume at the Ketzin pilot site, Germany. *Geophys. Prosp.* 65, 523-543.

43. Huang, F., Juhlin, C**.,** Han, L., Kempka, T., Lüth, S. and Zhang, F., 2016. Quantitative evaluation of thin-layer thickness and CO2 mass utilizing seismic complex decomposition at the Ketzin CO2 storage site, Germany. *Geophys. J. Int.,* 207, 160-173.

44. Sopher, D**.**, Erlström, M., Bell, N., and Juhlin, C., 2016. The structure and stratigraphy of the sedimentary succession in the Swedish sector of the Baltic Basin: New insights from vintage 2D marine seismic data. *Tectonophysics,* 676, 90-111.

45. Bergmann, P., Diersch, M., Götz, J., Ivandic, M., Ivanova, A., Juhlin, C., Kummerow, J., Liebscher, A., Lüth, S., Meekes, S., Norden, B., Schmidt-Hattenberger, C., Wagner, F.M. & Zhang, F., 2016. Review on geophysical monitoring of CO2 injection at Ketzin, Germany. *Journal of Petroleum Science and Engineering,* 139, 112-136.

46. Huang F., Juhlin, C., Kempka, T., Norden, B., and Zhang, F., 2015. Modeling 3D time-lapse seismic response induced by CO2 by integrating borehole and 3D seismic data - a case study at the Ketzin pilot site, Germany. *International Journal of Greenhouse Gas Control,* 36, 66-77.

47. Ivandic, M., Juhlin, C**.**, Lueth, S., Bergmann, P., Kashubin, A., Sopher, D., Ivanova, A., Baumann, G. and Henninges, J., 2015. Geophysical monitoring at the Ketzin pilot site for CO2 storage: New insights into the plume evolution. *International Journal of Greenhouse Gas Control,* 32, 90-105.

48. Zhang, F., Juhlin, C. and Sopher, D., 2014. Passive Seismic Ambient Noise Correlation: An Example from the Ketzin Experimental CO2 Storage Site, Germany. *Energy Procedia,* 59, 90-96.

49. Sopher, D., Juhlin, C., Erlstrom, M., 2014. A probabilistic assessment of the effective CO2 storage capacity within the Swedish sector of the Baltic Basin. *International Journal of Greenhouse Gas Control*, 30, 148-170.

50. Bergmann, P., Kashubin, A., Ivandic, M., Lüth, S. and Juhlin, C., 2014. Time-lapse difference static correction using prestack crosscorrelations: 4D seismic image enhancement case from Ketzin. *Geophysics,* 79, B243-B252.

51. Sopher, D., Juhlin, C., Huang, F., Ivandic, M. and Lueth, S., 2014. Quantitative assessment of seismic source performance: Feasibility of small and affordable seismic sources for long term monitoring at the Ketzin CO2 storage site, Germany, *J. Applied Geophysics,* 107*,* 171-186.

52. Alcalde, J. Marzán, I., Saura, E., Martí, D., Ayarza, P., Juhlin, C., Pérez-Estaún, A., Carbonell, R. 2014. 3D geological characterization of the Hontomín CO2 storage site, Spain: Multidisciplinary approach from seismic, well-log and regional data. *Tectonophysics*, 627, 6-25.

53. Bergmann, P., Ivandic, M., Norden, B., Rücker, C., Kiessling, D., Lueth, S., Schmidt-Hattenberger, C. and Juhlin, C., 2014. Combination of seismic reflection and constrained resistivity inversion with an application to 4D imaging of the Ketzin CO_2 storage site, Germany. *Geophysics,* 79, B37-B50.

54. Ivanova, A., Bergmann, P., Kummerow, J., Yang, C., Lüth, S. and Juhlin, C., 2013. Seismic modeling of the AVO/AVA response to CO2 injection at the Ketzin site, Germany. *Energy Procedia*, 40, 490-498.

55. Ivanova, A., Juhlin, C., Lengler, U., Bergmann, P., Lüth, S., and Kempka, T., 2013. Impact of temperature on CO2 storage at the Ketzin site based on fluid flow simulations and seismic data. *International Journal of Greenhouse Gas Control,* 19, 775-784.

56. Sopher, D. and Juhlin, C., 2013. Processing and Interpretation of vintage 2D marine seismic data from the outer Hanö Bay Area, Baltic Sea. *J. Applied Geophysics,* 95, 1-15.

57. Alcalde, J., Martí, D., Calahorrano, A., Marzan, I., Ayarza, P., Carbonell, R., Juhlin, C., and Pérez-Estaún A., 2013. Active seismic characterization experiments of the Hontomín research facility for geological storage of CO2, Spain. *International Journal of Greenhouse Gas Control,* 19, 785-795.

58. Zhang, F., Juhlin, C., Ivandic, M. and Lüth, S., 2013. Application of seismic waveform tomography to monitoring of CO2 injection: modeling and a real data example from the Ketzin site, Germany. *Geophysical Prospecting,* 61, 284-299.

59. Alcalde, J., Martí, D., Juhlin, C., Malehmir, A., Sopher, D., Saura, E., Marzan, I., Ayarza, P.,Calahorrano, A., Pérez-Estaún A. and Carbonell, R., 2013. 3-D reflection seismic imaging of the Hontomín structure in the Basque-Cantabrian Basin (Spain). Solid Earth, 4, 481-496.

60. Ivandic, M., Yang, C., Lüth, S., Cosma, C. and Juhlin, C., 2012. Time-lapse analysis of sparse 3D seismic data from the CO2 storage pilot site at Ketzin, Germany, *J. Applied Geophysics*, 84, 14-28.

61. Xu, Z., Juhlin, C., Gudmundsson, O., Zhang, F., Yang, C., Kashubin, A. and Lüth, S., 2012. Reconstruction of subsurface structure from ambient seismic noise: an example from Ketzin, Germany. Geophysical Journal International, 189: 1085–1102.

62. Zhang, F., Juhlin, C., Cosma, C., Tryggvason, A., and Pratt , G., 2012. Crosswell seismic waveform tomography for monitoring CO2 injection: a case study from the Ketzin site, Germany. *Geophys. J. Int.*, 189, 629–646.

63. Ivanova, A., Kashubin, A., Juhojuntti, N., Kummerow, J., Henninges, J., Juhlin, C., Lüth, S. and Ivandic, M., 2012. Monitoring and volumetric estimation of injected CO2 using 4D seismic, petrophysical data, core measurements and well logging: a case study at Ketzin, Germany. *Geophysical Prospecting,* 60*,* 957-973.

64. SLR and Uppsala University., 2014. Final report on prospective sites for the geological storage of CO2 in the southern Baltic Sea. Elforsk report 14:53. 99pp.

65. Yang Z, Tian L , Jung B, Joodaki S, Fagerlund F, Pasquali R., 2015. Assessing CO_2 storage capacity in the Dalders Monocline of the Baltic Sea Basin using dynamic models of varying complexity. International Journal of Greenhouse Gas Control. 2015; 43:149-60.

Annex 5 Availability and ownership of relevant seismic and deep bore hole data in the Baltic region – Maps and metabase

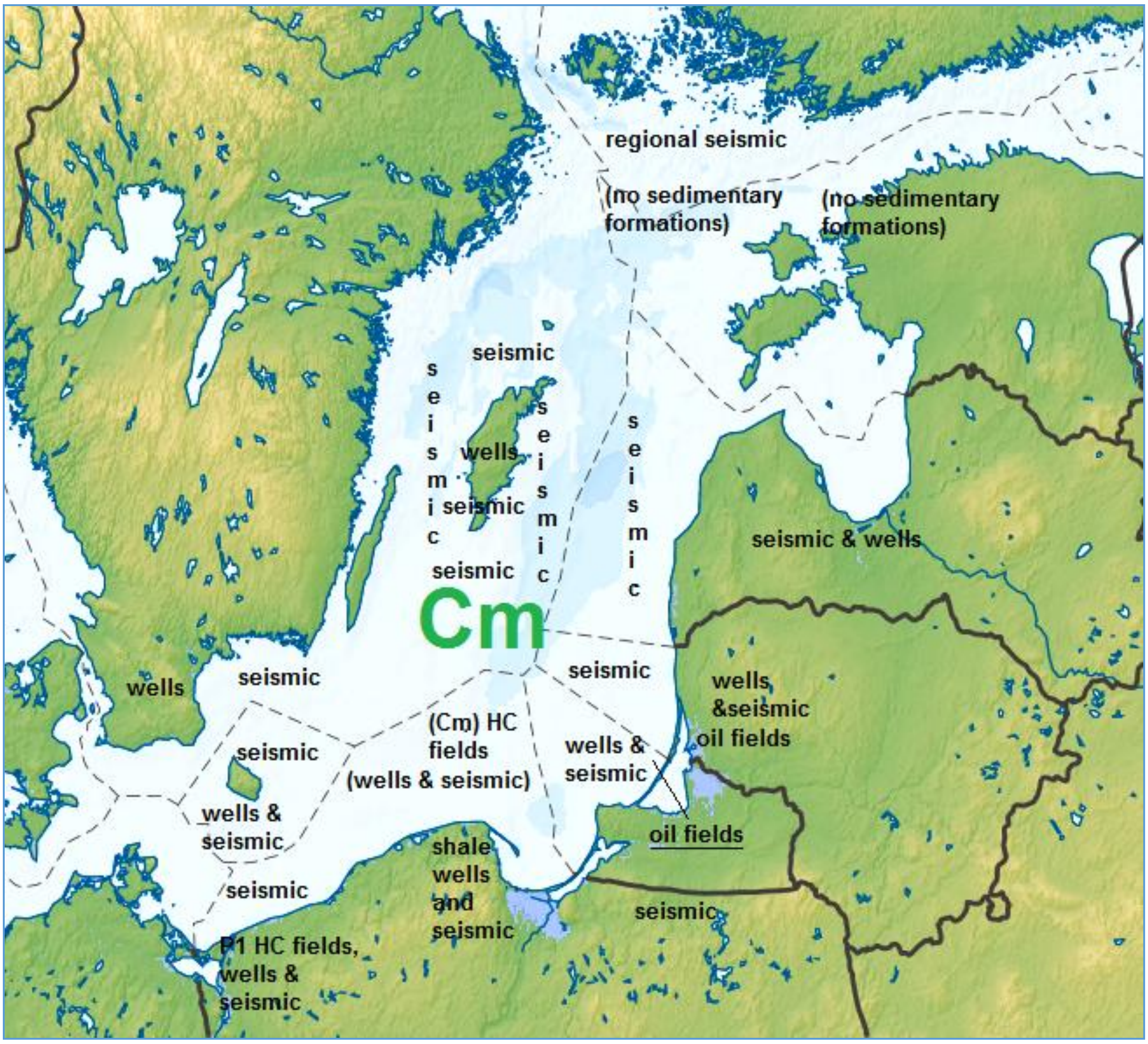


Fig. 1 General information on the data coverage for the (southern) Baltic region.

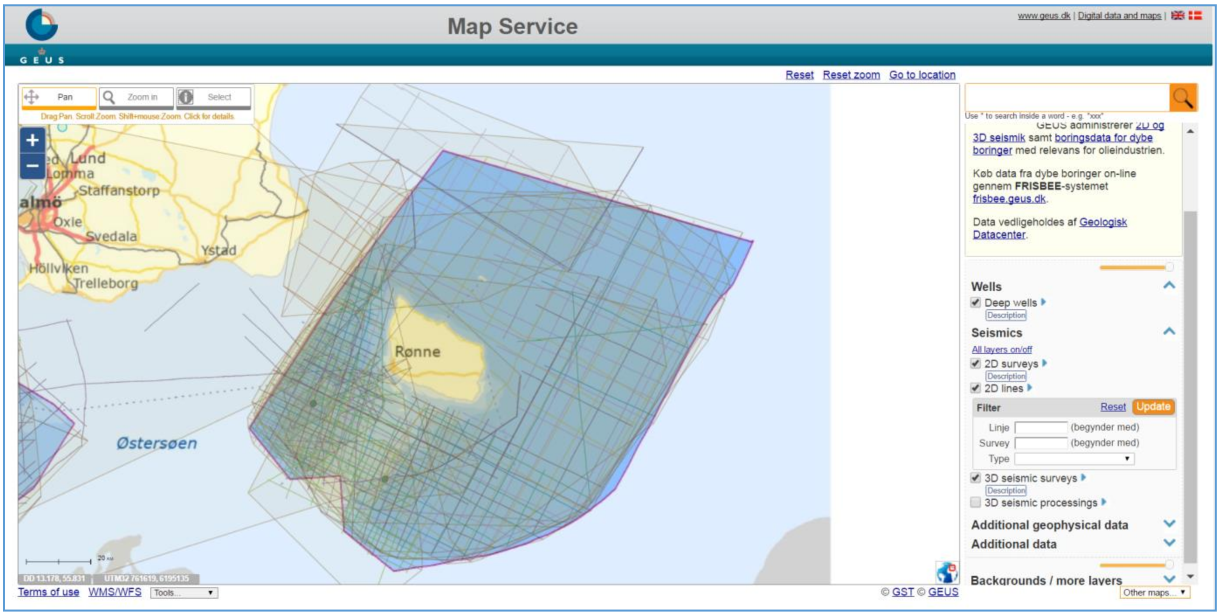


Fig. 2 Data coverage for the Bornholm area, Denmark (http://data.geus.dk/).

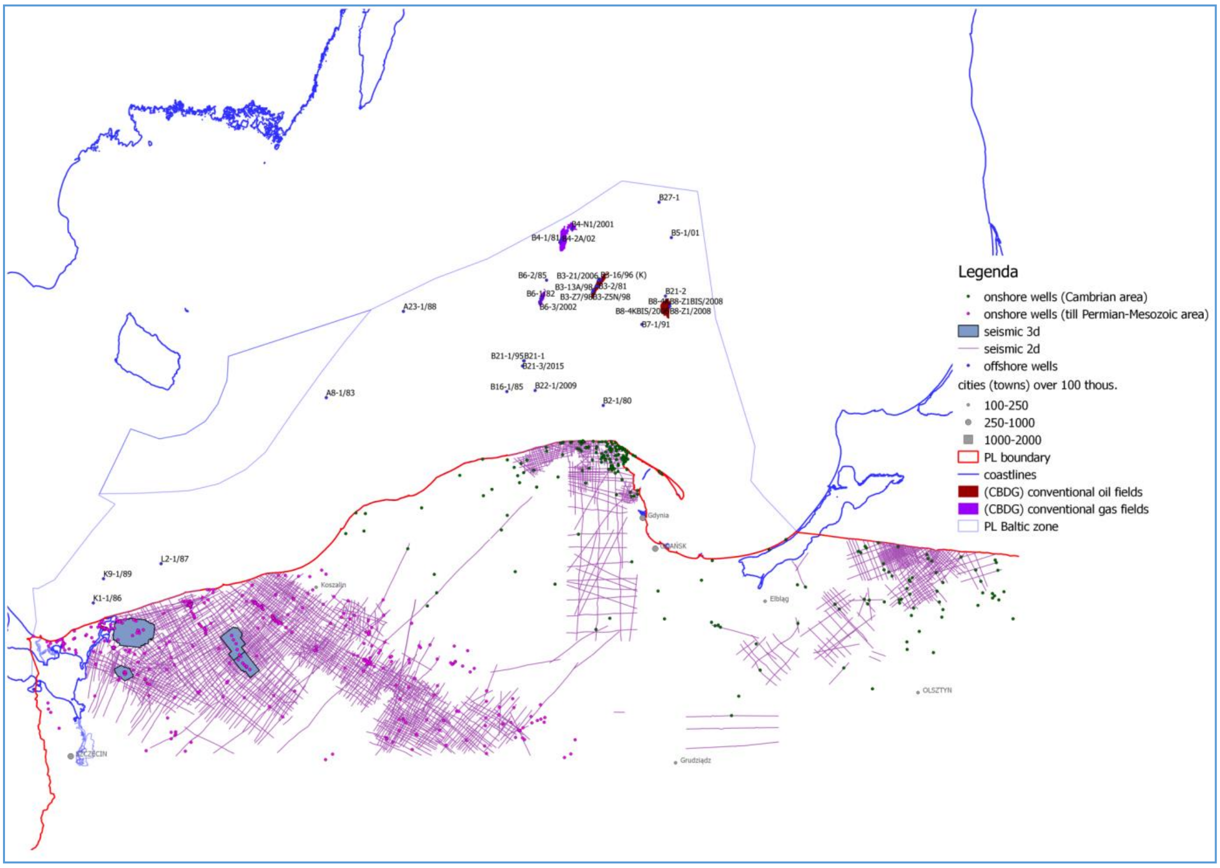


Fig. 3 Data coverage for the Polish sector and offshore area of Poland (http://baza.pgi.gov.pl/).

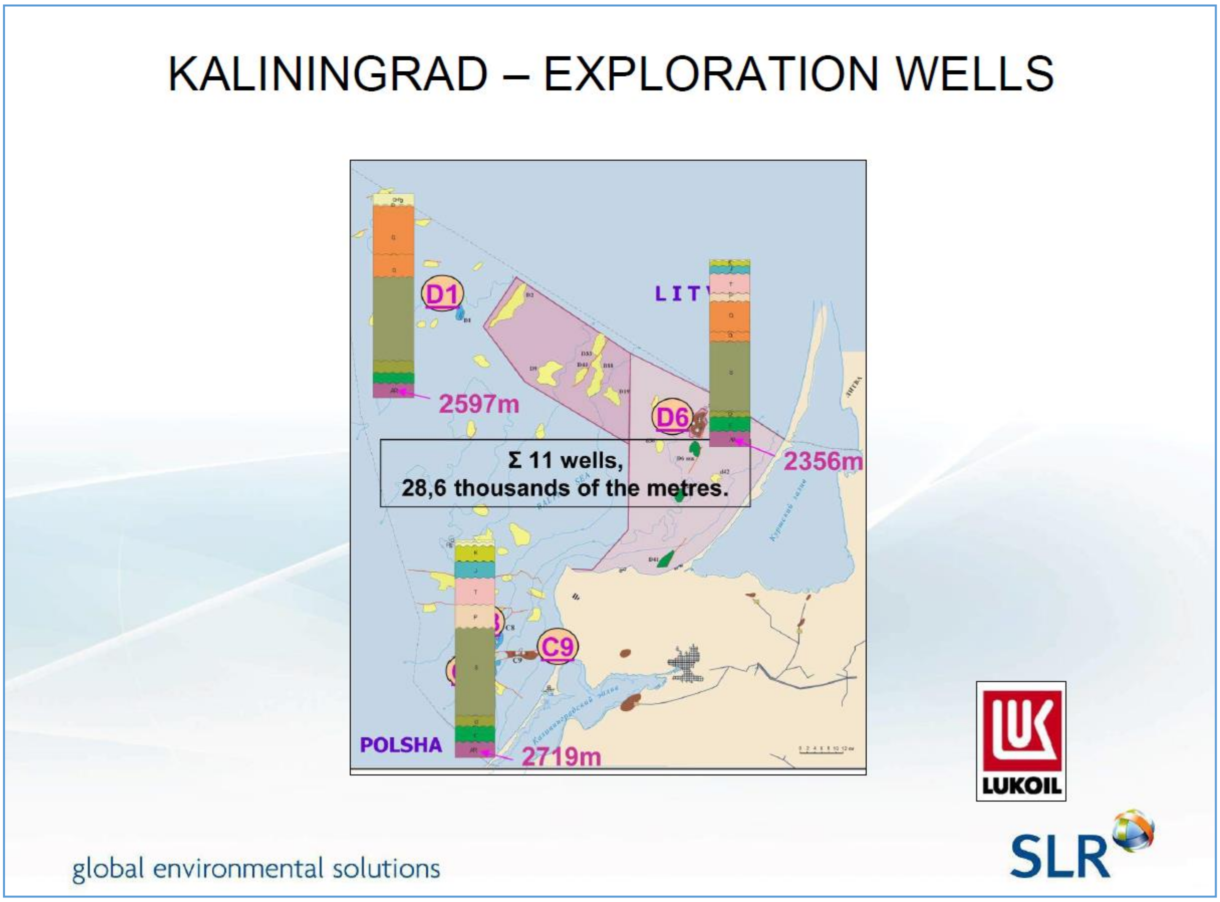


Fig. 4 Data coverage for the Russian sector (Vernon, 2015).

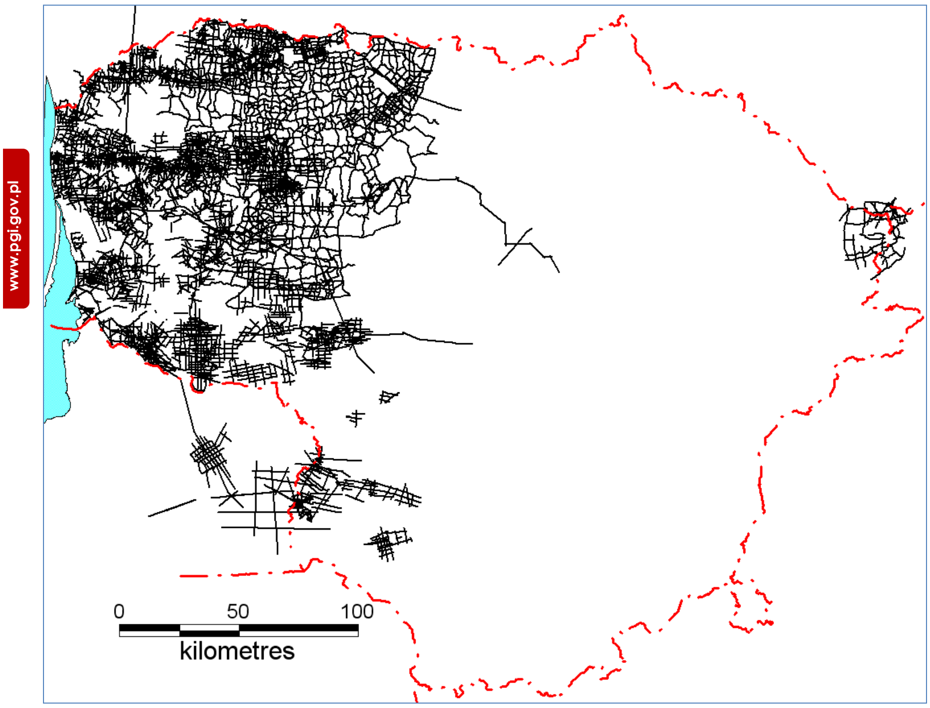


Fig. 5 Data coverage for the onshore area of Lithuania (GTC/LGT).

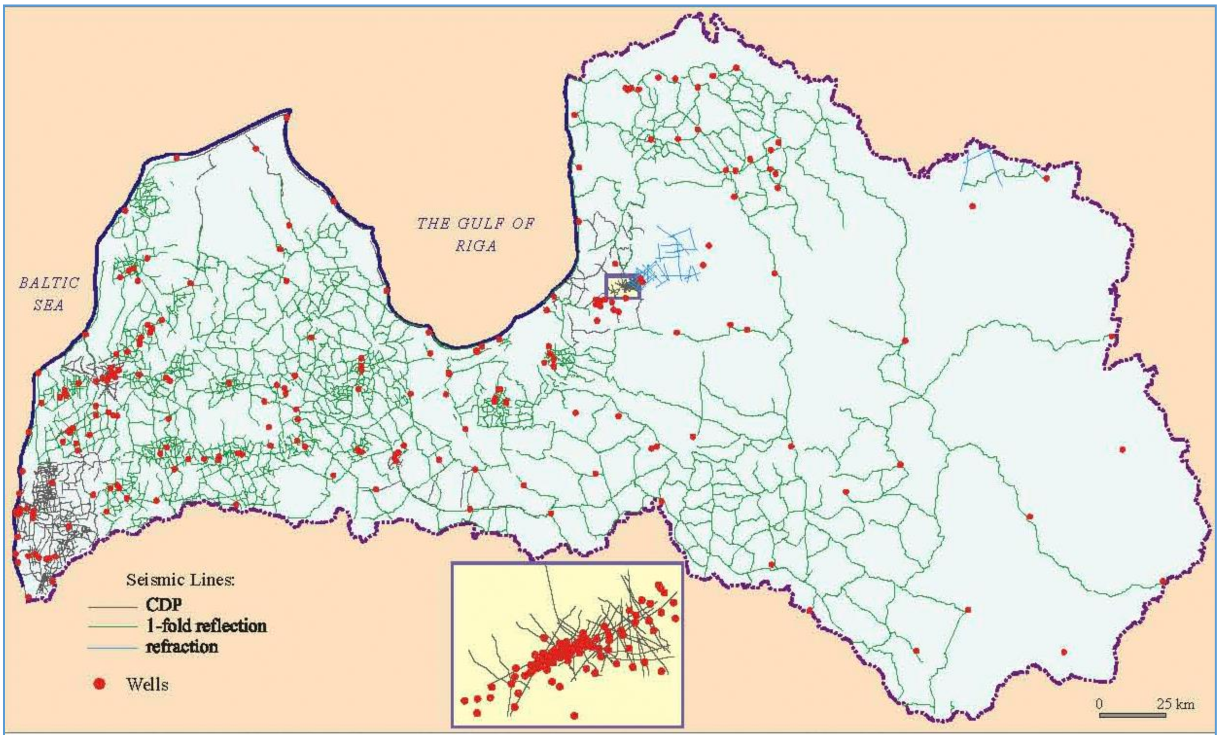


Figure 5. **Seismic and well database for lower part of sedimentary cover (LEGMA 2007)**

Fig. 6 Data coverage for the onshore area of Latvia (LEGMA).

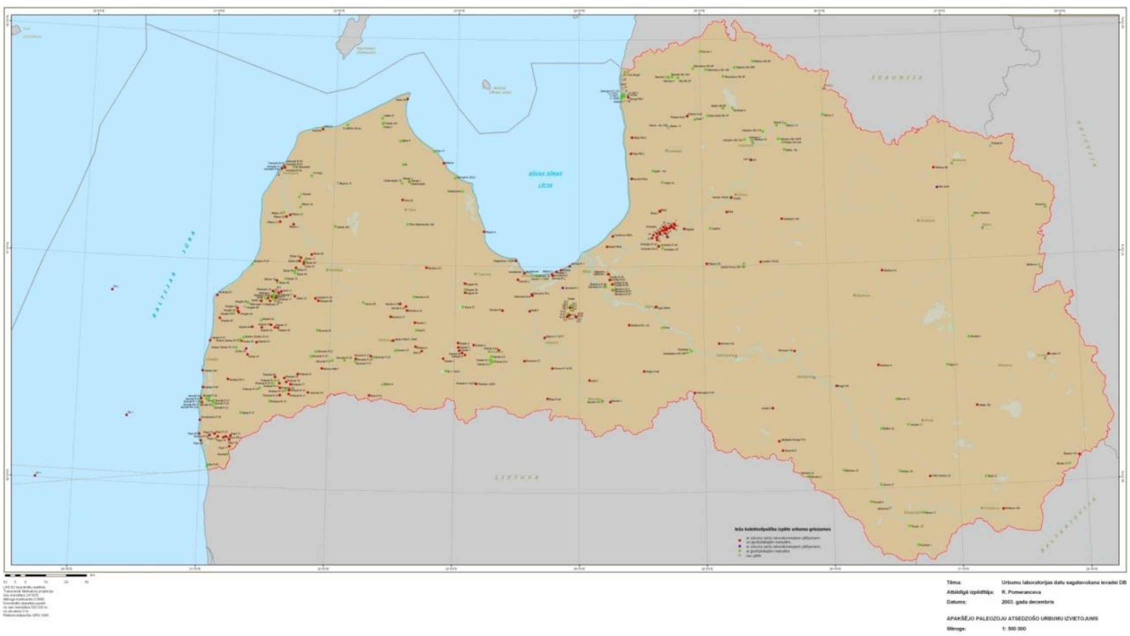


Fig. 7 Deep wells in the onshore and offshore areas of Latvia (LEGMA).

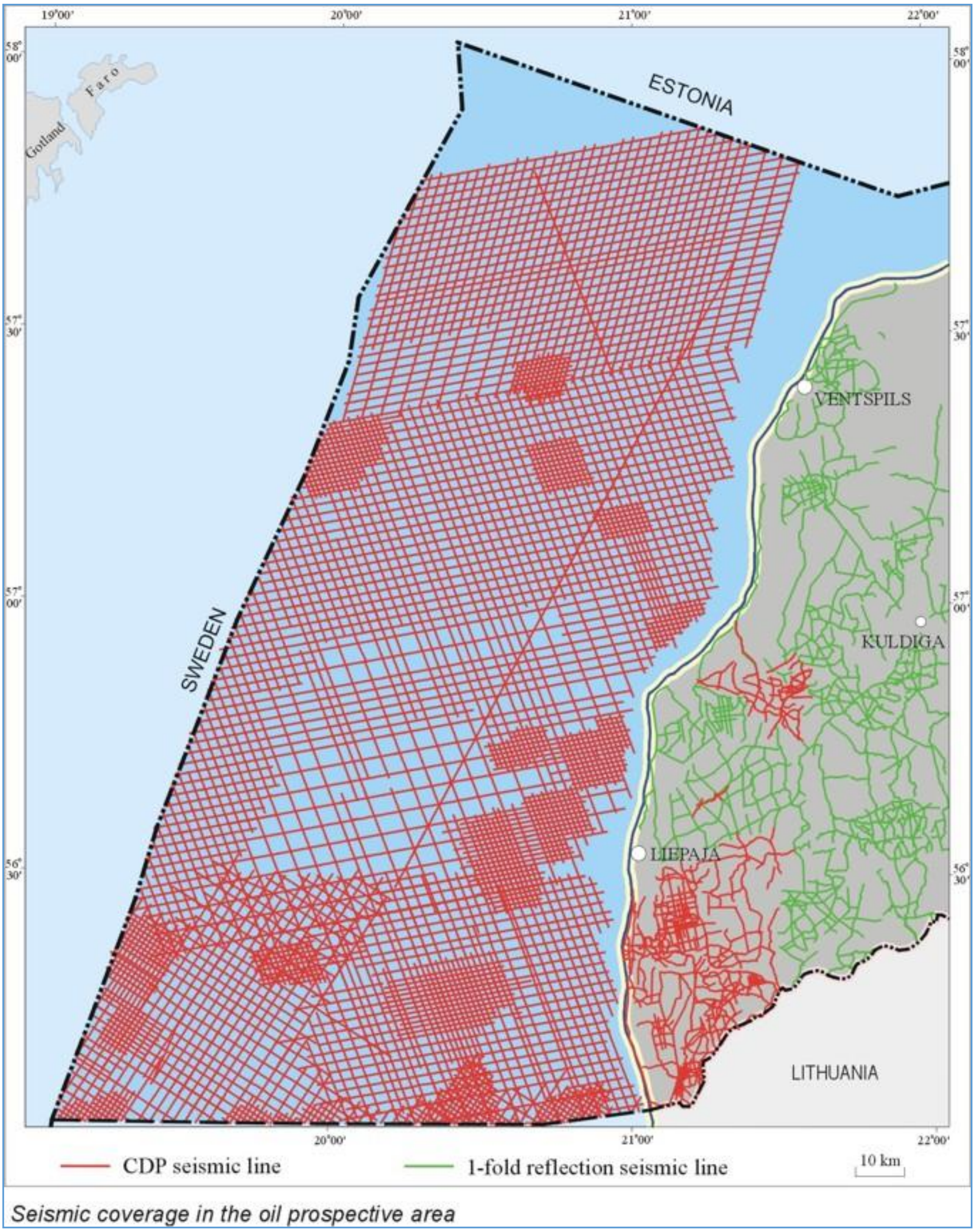


Fig. 8 New seismic data coverage for the offshore area of Latvia and old seismic data coverage in the adjacent onshore area (LEGMA/OPAB).

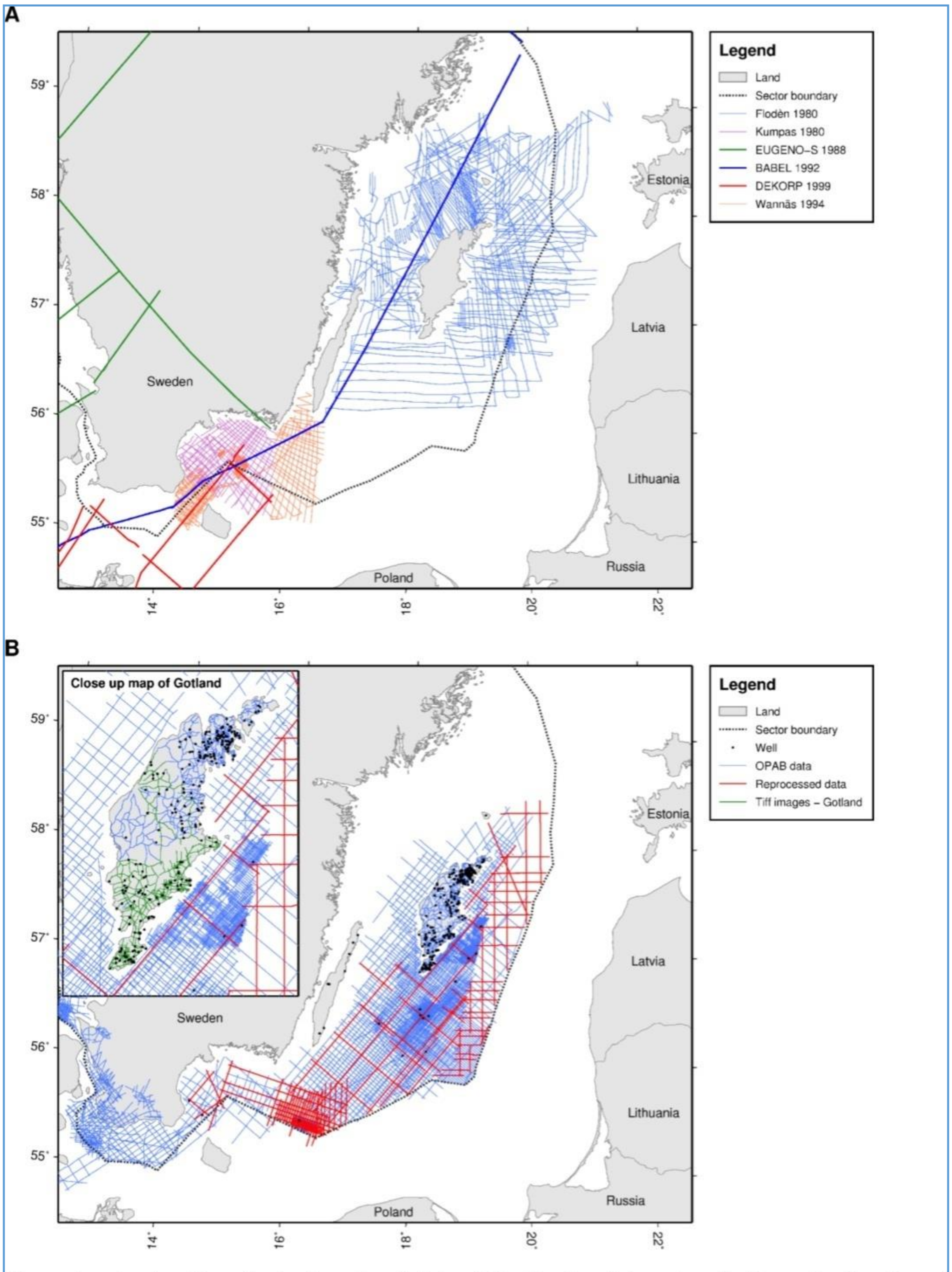


Figure showing location of seismic and well data within the Swedish sector. A). Shows the location of the single channel dataset referred to as “FLODEN” in the excel spreadsheet (this dataset includes lines labelled as Flodén 1980, Kumpas 1980 and Wannäs 1994 on the figure). Deep seismic data referred to as “BABEL” in the spreadsheet are labelled as BABEL 1992. B). All lines shown here are multi channel 2D seismic data which are part of the dataset referred to as “OPAB” in the spreadsheet. Well data are also shown as black dots.

Fig. 9 Data coverage in the selected offshore and onshore areas of Sweden (UU/SGU/OPAB).

Table 1. Availability and ownership of relevant seismic and deep bore hole data in the Baltic region - Metadatabase

Country/info	Offshore Seismic	Data ownership	Onshore seismic	Data ownership	Wells offshore	Data ownership	Wells onshore	Data ownership	regional studies	Remarks
DENMARK (Bornholm area)	2D seismic of various vintages (1970-1990s; semi-detailed and detailed; several thousand km); the most detailed south and west of Bornholm. 3 lines acquired in 2014 at WSW Bornholm coast.	Public, with exception of three lines of 2014 (Private - Rønne Varme A/S)	Two 2-D lines (continuation of 2014 offshore survey) in WSW Bornholm	Private (Rønne Varme A/S)	2 wells SW of Bornholm drilled into Silurian	Public (access through GEUS)	8 shallow (~250 m), scientific wells drilled into Lower Paleozoic formations (S-O-Cm).	GEUS	Covered by EU GeoCapacity and CO2STOP	information mostly after the website: data.geus.dk
ESTONIA	Deep seismic profile was made between Gotland and Saarema islands	Ostrovsky, A.A., Flueh, E.R.& Luosto U. 1994. Deep seismic structure of the Earth's crust along the Baltic Sea profile. Tectonophysics, 233, 279-292.	1) FENOLORA seismic refraction profile - 1979; 2) Sovetsk-Kohtla-Järve seismic refraction profile 1983-1986	Luosto, U. 1991. Moho Depth Map of the Fennoscandian Shield Based on Seismic Refraction Data - Inst.Seismology, Univ. Helsinki, Report S-25; 43-50	One well at the south-western small island Ruhnu could be approximated as drilled onshore. It is the deapest and the most southern Estonian well.	Data is published in: Põldvere, A. (ed.).2003. Estonian Geological Sections. Bulletin 5. Ruhnu (500) drill core. Geological Survey of Estonia, Tallinn.	400 wells penetrated Cambrian rocks, but only in several at the south-western Estonia Deimena stage Ruhnu Formation was found.	Geological Survey of Estonia, TTUGI	In EU GeoCapacity CCS storage potential of Estonia was estimated as zero.	Only at the south-western part of Estonia Cambrian Deimena Stage Ruhnu Formation is present and was studied only in several wells. Devonian rocks available at the southern Estonia are too shallow and covered only by quarternary sediments.
FINLAND	BABEL (2 268 km) and BALSET (1, 300 km) deep seismic profiles in northern parts of Baltic sea. http://www.seismo.helsinki.fi/english/research/lithosphere.html	Public	Not applicable, no potential sedimentary formations.	Not applicable, no potential sedimentary formations.	No deep offshore wells.	No deep offshore wells.	Not applicable, no potential sedimentary formations.	Not applicable, no potential sedimentary formations.	The Finnish sedimentary formations were assessed in Solismaa 2009. Based on current knowledge it is highly unlikely to find suitable sedimentary CO2 storage formations in Finland, but due to lack of data it can not be totally excluded either.	There are deep enough sedimentary formations in the Bothnian bay that have not been investigated in detail. Based on age, they are assumed to be of low porosity.
LATVIA	1) About 24,500 km of CDP seismic lines were acquired from 1976 to 1991, covering practically all the Latvian sector of the Baltic Sea by a 2x2 km seismic grid. Numerous structures have been identified. 2)The Latvian Geological Department continued offshore operations in 1991-92, carrying out detailed seismic investigations in the area close to the Swedish and Lithuanian border. 3) 2006 - 2D seismic data (about 200 km). 4) 300 sq kms of 3D seismic data was acquired in 2010, by Balin Energy, owner of the Offshore License 1 & North Block (2009).	LEGMC-Latvian Environment, Geology and Meteorology Centre	1) Seismic reflection method -SR (1958-1971): 12000 line km (mostly in western part); 2) Modern seismic investigation (CDP)-Common Depth Point (1986-1993): 2500 line km (western Latvia and Incukalns);	LEGMC-Latvian Environment, Geology and Meteorology Centre	1) 2 wells penetrated Cambrian deposits (E6-1 and P6-1). E6-1 is exploration wells drilled by "CO Petrobaltic" company. P6-1 was drilled for stratigraphic tests by Arctic offshore Oil & Gas Exploration Trust, Russia. 2) The E6 structure was licensed to the Odin oil company in 2008 for oil exploration and production. 3) In 2013 Balin Energy drilled a 1,460-meter exploration well with the semi-submersible rig 'Ocean Nomad', but failed to find hydrocarbons. The well was drilled in cooperation with the Latvian Ministry of Economy, Ministry of Foreign Affairs and Ministry of Environmental Protection and Regional Development. The drilling work was supervised by Senergy, a global energy supplier. Licence 1 & North Block - both licensed to Balin Energy Balin Energy, a JV co-owned by PKN ORLEN and Kuwait Energy has completed drilling its first vertical well in the Northern Block of Latvia's economic zone. The JV drilled a 1,460-meter exploration well with the semi-submersible rig 'Ocean Nomad', but failed to find hydrocarbons. The well was drilled in cooperation with the Latvian Ministry of Economy, Ministry of Foreign Affairs and Ministry of Environmental Protection and Regional Development. The drilling work was supervised by Senergy, a global energy supplier.http://www.energy-pedia.com/news/latvia/new-154896	1)LEGMC-Latvian Environment, Geology and Meteorology Centre, "CO Petrobaltic", Arctic offshore Oil & Gas Exploration Trust 2) Odin Energy 3) Balin Energy	447 wells penetrated Cambrian deposits, including 200 wells at the territory of Incukalns UGS (mostly in western Latvia).	LEGMC-Latvian Environment, Geology and Meteorology Centre	EU GeoCapacity (LEGMC) & CO2STOP (TTUGI). EU GeoCapacity - only onshore structures were assessed by LEGMC (LEGMA at that time). CO2Stop: Offshore structures were added - E6 and E7 (located at the Lithuanian area according to the modern EU borders). Onshore South-Kandava and Dobele structures were updated, according to PhD study of K. Shogenov. Other structures as in EU GeoCapacity.	The 3rd offshore well E7 is located now in Lithuania, according to the modern EU borders
LITHUANIA	regional, semi-detailed and detailed 2-D seismic, 1970-80s (entire Lithuanian sector, digital recording, reprocessed in 2004)	Lithuanian Geological Survey	regional, semi-detailed and detailed 2-D seismic, 1970-80s (west and central Lithuania, coverage varies, Cambrian and Silurian reservoirs); detailed 2-D and 3-D surveys, 1990-2010s (west and central Lithuania, Cambrian and Silurian reservoirs)	Lithuanian Geological survey; oil companies operating in Lithuania	well D5-1; oil show, tight Cambrian reservoir	Lithuanian Geological Survey	400 wells penetrated the Cambrian reservoir in a whole territory of Lithuania	Lithuanian Geological Survey	CO2 storage related national and internatonal studies	Cambrian reservoir is well studied in Lithuania; these data provide good basis for pilot experiments
POLAND	regional 2-D seismic, 1960s, ~3000 km (entire Polish sector - analog recording); regional, semi-detailed and detailed 2-D seismic, 1970-80s, ~9000 km (entire Polish sector, mostly western part - digital recording, reprocessed in 2000s); detailed 2-D and 3-D surveys, 2000s and 2010s (several structures in Cambrian in eastern and central part of the Polish sector)	public (until 1989); after 1989 - LOTOS	regional, semi-detailed and detailed 2-D seismic, 1970-80s (entire area, coverage varies); detailed 2-D and 3-D surveys, 1990 and 2000s (western and eastern part - conventional hydrocarbons' prospecting, in Permian and Cambrian respectively); detailed 2-D and 3-D surveys, 2000/2010s (a dozen areas in eastern part - shale gas and oil prospecting in Lower Paleozoic)	public (until 1989); after 1989 - Polish Oil and Gas Company and other operators - BNK, ENI, FX Energy, Marathon, Lane Energy, Visent	53 wells in entire Polish sector, including 50 within the Cambrian aquifer/reservoir area (29 cored) and 3 wells in the westernmost part of Polish sector - drilled in Permian-Mesozoic aquifers (all cored)	wells drilled until 1989 - public (10 in Cambrian, 3 in Permian-Mesozoic); wells drilled after 1989 - LOTOS (40 in Cambrian)	221 wells in the area of onshore Cambrian aquifer/reservoir (drilled into the aquifer reservoir or its Lower Paleozoic caprock; 174 cored); 367 wells in the area of onshore Permian-Mesozoic aquifers (347 cored)	wells drilled until 1989 - public (183 in Cambrian, 309 in Permian-Mesozoic); wells drilled after 1989 - Polish Oil and Gas Company and other operators - BNK, ENI, FX Energy, Marathon, Lane Energy, Visent, (38 in Cambrian or its Lower Paleozoic caprock, 56 in Permian-Mesozoic)	EU GeoCapacity & CO2STOP (Cambrian aquifer mentioned, no assessment; a couple of HC fields assessed; GIS/WebGIS); national programme "Assessment of formations and structures for safe CO2 storage including monitoring plans" (Cambrian aquifer assessed; a few HC fields mentioned and/or assessed; GIS/WebGIS)	The range of Cambrian aquifer suitable for CO2 storage has been assumed after BASTOR2 an well data, southern onshore boundary for Permian-Mesozoic aquifers - latitude of Szczecin (~53.44 N; the same with onshore Cambrian aquifer). Well inventory after CBDG database (http://www.pgi.gov.pl/en/data-bases.html) and Polish Ministry of Environment (www.mos.gov.pl).
RUSSIA (Kaliningrad)	Regional and semi-detailed 2-D seismic were carried out in the last decades of XX century. In 2006-2008 semi-detailed and detailed 2-D seismic surveys	The newest data (on the Cambrian reservoir and its caprock) are owned by Lukoil (?).	Regional and semi-detailed 2-D seismic were carried out in the last decades of XX century.	???	Within the area of D6 oil field alone 17 E&P wells were drilled. Since 2006 (?) new 11 exploration wells were drilled in NE part of Russian sector.	The newest data (on the Cambrian reservoir and its caprock) are owned	Dozens of hydrocarbon E&P wells were dilled in last decades of XX century.	???	???	

	were acquired in NE part of Russian sector. In that area also 3-D seismic (?) surveys covering D6 oil field (2006-2008) and D2, D33 and D44 structures (2009-2011) were acquired.					by Lukoil (?).				
SWEDEN	OPAB: Over 33000km of 2D marine seismic data aquired between 1970 and 1990. These data cover the majority of the Swedish sector of the Baltic basin. These data are available as a mixture of digital pre-stack, post stack and analogue post stack data. FLODEN: Over 25000km of 2D single channel seismic data, mostly aquired during the 70s could possibly be made available from Stockholm university. This data gives a good image of the near surface but does not penetrate beyond approximately 400m depth. BABEL: Several deep crustal seismic reflection profiles (BABEL) may also be available.	OPAB - owned by Geological survey of Sweden. FLODEN - owned by Stockholm university. BABEL - Uppsala university has permission to use this data for research.	OPAB: Over 2000km of 2D stacked seismic data are available from the island of Gotland. These data are available as a mixture of analogue and digital data. Data from the OPAB dataset are also available onshore in Skåne.	OPAB - owned by Geological survey of Sweden.	OPAB - approximately 14 wells have been drilled offshore between 1970 and 1990 in the Baltic Basin and Hanö Bay basin. Very limited core data is available for some wells. Log data, however is available for a number of these wells.	OPAB - owned by Geological survey of Sweden.	OPAB - Over 300 wells have been drilled on shore Gotland and in Skåne. Very limited core data is available for some wells. Some well log data is available.	OPAB - owned by Geological survey of Sweden.	Regional studies assessing the CO_2 storage potential in the Swedish sector of the Baltic basin have been performed by the Swedish Geological Survey (SGU) in 2011, SLR in the BASTOR phase I and II reports, by Uppsala university in 2014 and NORDICCS.	The Cambrian Faludden, När and Viklau reservoirs have been highlighted as potential CO_2 storage reservoirs. Of these the Faludden reservoir appears to be the most prospective for CO_2 storage. The most propsective CO_2 storage scenario in this reservoir, is within a large stratigraphic trap.
Country/info	Offshore Seismic	Data ownership	Onshore seismic	Data ownership	Wells offshore	Data ownership	Wells onshore	Data ownership	regional studies	Remarks
DENMARK (Bornholm area)	2D seismic of various vintages (1970-1990s; semi-detailed and detailed; several thousand km); the most detailed south and west of Bornholm. 3 lines acquired in 2014 at WSW Bornholm coast.	Public, with exception of three lines of 2014 (Private - Rønne Varme A/S)	Two 2-D lines (continuation of 2014 offshore survey) in WSW Bornholm	Private (Rønne Varme A/S)	2 wells SW of Bornholm drilled into Silurian	Public (access through GEUS)	8 shallow (~250 m), scientific wells drilled into Lower Paleozoic formations (S-O-Cm).	GEUS	Covered by EU GeoCapacity and CO2STOP	information mostly after the website: data.geus.dk
ESTONIA	Deep seismic profile was made between Gotland and Saarema islands	Ostrovsky, A.A., Flueh, E.R.& Luosto U. 1994. Deep seismic structure of the Earth's crust along the Baltic Sea profile. Tectonophysics, 233, 279-292.	1) FENOLORA seismic refraction profile - 1979; 2) Sovetsk-Kohtla-Järve seismic refraction profile 1983-1986	Luosto, U. 1991. Moho Depth Map of the Fennoscandian Shield Based on Seismic Refraction Data - Inst.Seismology, Univ. Helsinki, Report S-25; 43-50	One well at the south-western small island Ruhnu could be approximated as drilled onshore. It is the deapest and the most southern Estonian well.	Data is published in: Põldvere, A. (ed.).2003. Estonian Geological Sections. Bulletin 5. Ruhnu (500) drill core. Geological Survey of Estonia, Tallinn.	400 wells penetrated Cambrian rocks, but only in several at the south-western Estonia Deimena stage Ruhnu Formation was found.	Geological Survey of Estonia, TTUGI	In EU GeoCapacity CCS storage potential of Estonia was estimated as zero.	Only at the south-western part of Estonia Cambrian Deimena Stage Ruhnu Formation is present and was studied only in several wells. Devonian rocks available at the southern Estonia are too shallow and covered only by quarternary sediments.
FINLAND	BABEL (2 268 km) and BALSET (1, 300 km) deep seismic profiles in northern parts of Baltic sea. http://www.seismo.helsinki.fi/english/research/lithosphere.html	Public	Not applicable, no potential sedimentary formations.	Not applicable, no potential sedimentary formations.	No deep offshore wells.	No deep offshore wells.	Not applicable, no potential sedimentary formations.	Not applicable, no potential sedimentary formations.	The Finnish sedimentary formations were assessed in Solismaa 2009. Based on current knowledge it is highly unlikely to find suitable sedimentary CO_2 storage formations in Finland, but due to lack of data it can not be totally excluded either.	There are deep enough sedimentary formations in the Bothnian bay that have not been investigated in detail. Based on age, they are assumed to be of low porosity.

Annex 6 Planning of a pilot test CO2 injection site

Introduction

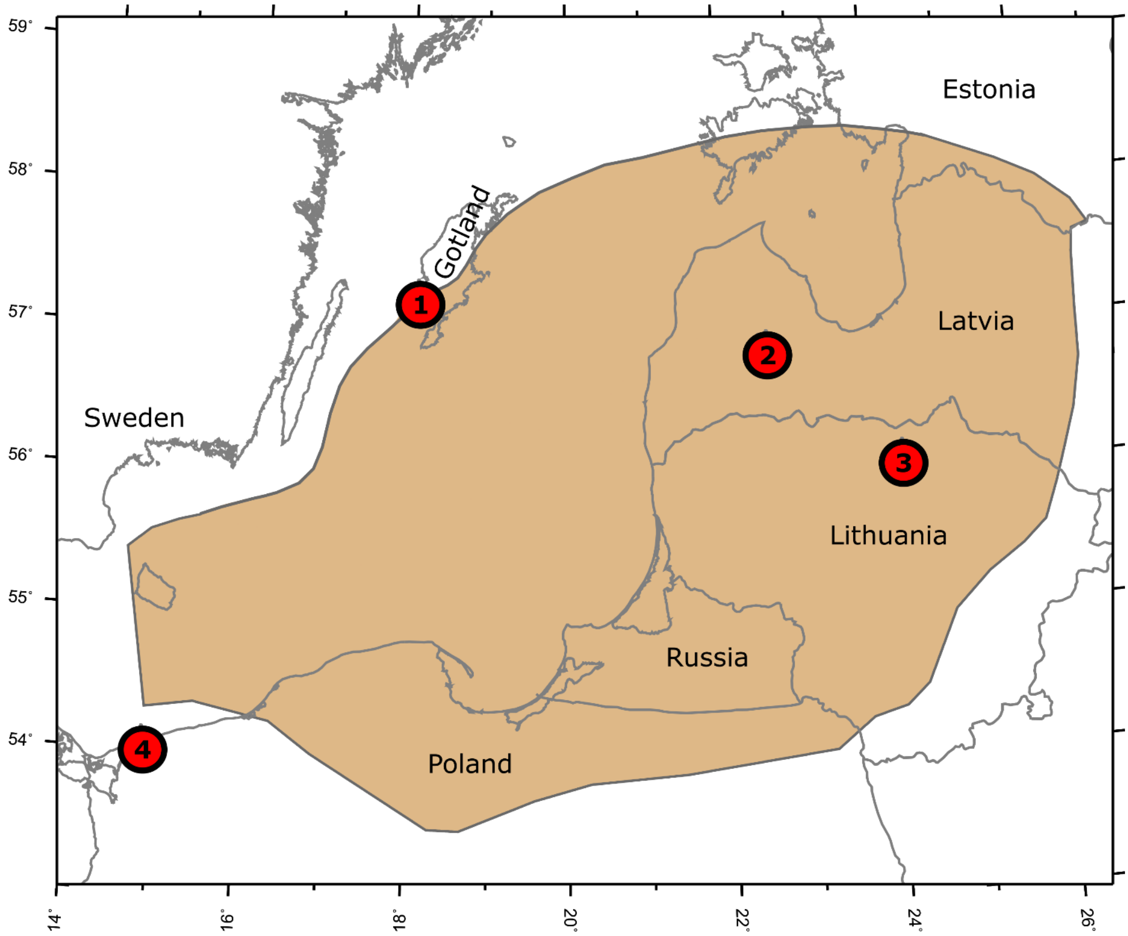
The establishment and operation of CO_2 storage pilot sites is a crucial step on the road to the implementation of industrial scale Carbon Geological Storage. Pilot sites provide a means to collect valuable geological information about potential CO_2 storage reservoirs and their associated cap rocks, necessary to adequately characterize the CO_2 storage opportunity. They also provide an opportunity to develop and operate the surface and down-hole infrastructure and to test monitoring technology. Most importantly, pilot sites provides a real life test of the viability of the proposed CO_2 storage system and help to build public confidence and acceptance of the technology. However, despite this, the number of CO_2 pilot sites in Europe is very limited (e.g. The Ketzin project in Germany is one of the few examples (Juhlin et al., 2007)).

Geologically, the Baltic Sea region lies within the Baltic Basin, which can be described as a broad synclinal depression which underwent its primary stage of development during the Late Silurian – Early Devonian, as a flexural fore-land basin in association with the Caledonian orogeny (Poprawa et al., 1999). To the north, the Basin is primarily filled with a sequence of Palaeozoic strata. For these Palaeozoic sediments, deposition began in the Cambrian with a sequence of shallow marine sandstones, siltstones and shales. These are overlain by finer grained sequences of limestone, marl and shale deposited in the Ordovician and Silurian (Fig. 2) (Ūsaitytė 2000; Sopher et al., 2016). To the South of the Baltic Basin, these Palaeozoic strata are overlain by younger sediments ranging from Carboniferous to Mesozoic in age (Fig. 1).

A number of studies have identified and assessed the storage capacity of reservoirs within the Baltic Basin, which are potentially suitable for CO_2 storage (Shogenova et al., 2009; Erlström et al., 2011; Vernon et al., 2013; Sopher et al., 2014; SLR and Uppsala University, 2014; Lothe et al., 2015; Yang et al., 2015). In several of these the CO_2 storage opportunities are thought to be significant enough to be important for the Baltic Region and Northern Europe. However, to date no pilot sites have been established in the Baltic Sea region.

In this report we begin by discussing several potential pilot sites within the Baltic Sea region. Based on a range of criteria, we then select a preferred pilot site which we discuss in more detail. For the preferred pilot site we also present a proposed project plan and budget. The four pilot sites discussed in this report are: Site 1 (Southern Gotland) located on the island of Gotland, Sweden. Site 2 (South Kandava) located in Latvia. Site 3 (Vaškai structure) located in Lithuania and Site 4 (Kamień Pomorski) located in Poland. Fig. 1 shows the locations of the four pilot sites as well as showing schematically where the potential storage reservoirs for the four sites sit within the overall stratigraphy of the Basin. It is clear that Site 1, Site 2 and Site 3 are all located in the same stratigraphic interval, targeting a Middle Cambrian sandstone reservoir, while Site 4 targets a younger Zechstein Hauptdolomite reservoir. A brief description of each of the four pilot sites will now follow.

A).



B).

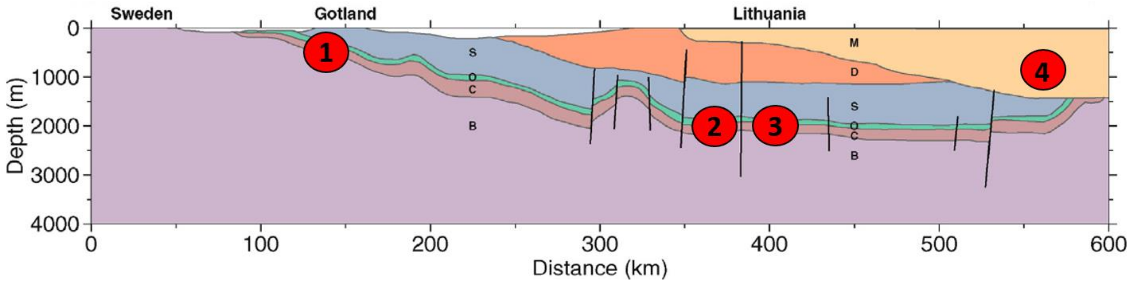


Fig 1: A). Map of the Baltic Sea region. The brown area indicates the approximate area where Cambrian sandstones are present below 500m depth. This can be used to approximate the area over which potential CO_2 storage reservoirs can exist in the Cambrian across the Baltic Sea. The locations of the four potential storage sites discussed in this report are shown on the map. B). Schematic cross section extending from Gotland to Lithuania. The general placement of the four pilot sites within the Basin are shown on the section. B, C, O, S, D denote Basement, Cambrian, Ordovician, Silurian and Devonian, respectively. M denotes strata which is younger than Devonian. Site 1, 2, 3 and 4 refer to the Southern Gotland, South Kandava, Vaškai structure and Kamień Pomorski pilot sites, respectively. Please note that on the schematic section only the stratigraphic placement of the sites is accurate, for the actual depths please refer to the following text (i.e. in reality Site 4 is the deepest of the sites considered).

2.0 Site 1: Southern Gotland

The Gotland site is located on the NW flank of the Baltic Basin, which can be characterized as a relatively large, unfaulted monocline. The Pilot site targets the Middle Cambrian Faludden reservoir (equivalent to the Deimena sandstones in the Baltic States). In the area of Gotland the Faludden reservoir can be described as a well sorted, medium-grained quartz sandstone deposited in a shallow marine environment. It reaches thicknesses in excess of 50m across large parts of the basin and has favourable reservoir properties, with porosity and permeability values ranging from 10-16% and 200-400mD, respectively (Sopher et al., 2014). Within the Swedish sector of the Baltic Sea, the Faludden reservoir is thickest in the deepest part of the basin to the SE and thins towards the NW. The reservoir does not outcrop at the seabed and instead pinches out stratigraphically. This allows for a CO_2 storage scenario where CO_2 is injected and allowed to migrate updip towards the reservoir pinch-out where it will be trapped by the updip termination of the reservoir. The Cambrian Viklau and När sandstone reservoirs which underlie the Faludden reservoir represent lower quality reservoirs and can be considered to provide secondary potential storage reservoirs for the project. A series of impermeable layers overlie the Faludden reservoir on Gotland, which are capable of acting as cap rocks for the proposed project. The most important of these are the regionally extensive Bentonitic Limestone unit and the lowermost part of the Silurian interval (Sopher et al., 2014). The Bentonitic Limestone unit is typically 45-60m thick across the area of the proposed injection site and consists of micro-crystalline limestone with interbeds of bentonite clay. Permeability measurements in Latvia indicate values of less than 1mD in both the Bentonitic limestone and Lowermost Silurian (SLR & Uppsala University, 2014). In places small accumulations of natural gas are observed within the Faludden reservoir across the Swedish sector which demonstrates the viability of this reservoir-cap rock system for CO_2 storage.

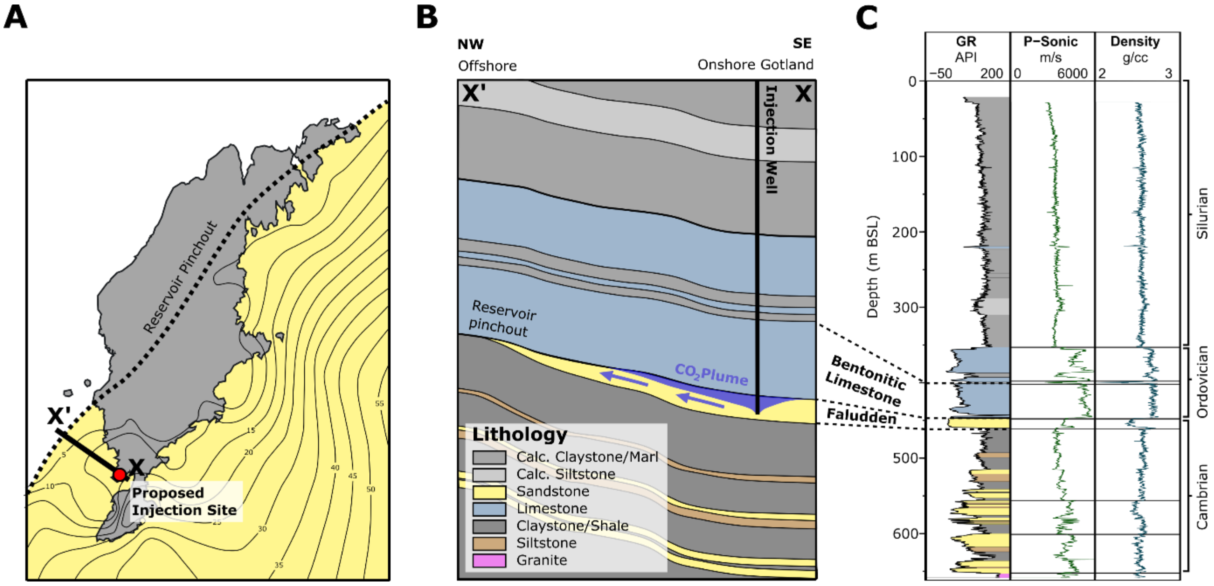


Fig. 2: A). Map of Gotland with contours denoting the Faludden reservoir thickness in meters. The dashed line denotes the reservoir pinch-out. The location of the schematic profile in B) is shown as well as the location of the proposed injection site. B). Shows a schematic NW-SE profile through the proposed injection site. After injection CO_2 would most likely migrate updip towards the reservoir pinch-out, located off shore. C). Shows natural gamma ray, P-wave sonic and density well logs. Basic stratigraphy and lithology are annotated.

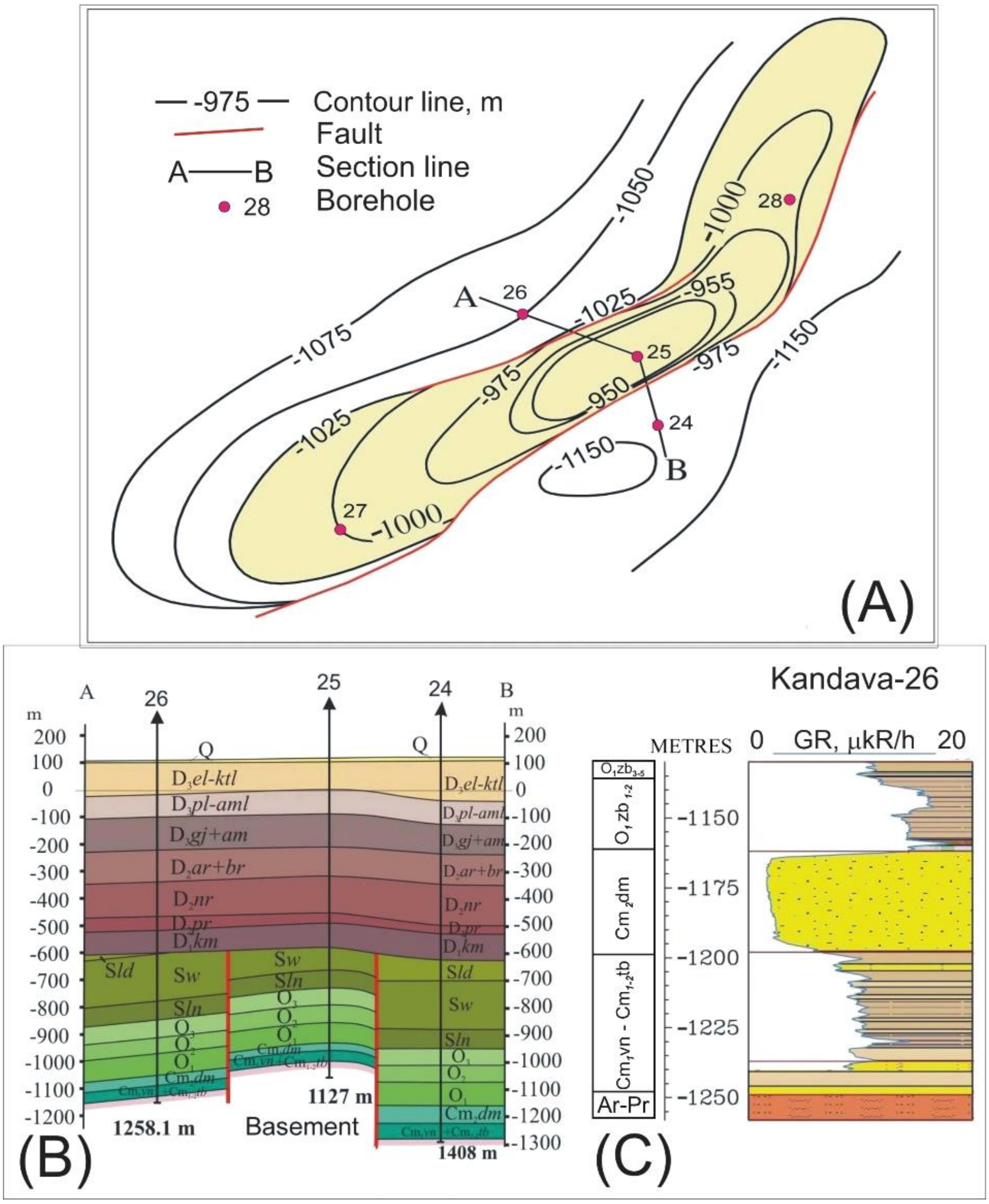
The Skåls-1 well which is located 500m from the proposed drill site can be used to approximate the geological section which would be encountered at the pilot injection site. At the proposed pilot site the Faludden reservoir would be located at a depth of approximately 450m Below Mean Sea level (BSL) and would have a thickness of approximately 13m. The Bentonitic limestone (primary cap rock) would have a thickness of approximately 45m. The Faludden reservoir dips gently towards the SE, hence it is anticipated that the injected CO_2 plume would migrate to the NW towards the stratigraphic pinch-out of the reservoir, which is located approximately 20km away (Fig. 2).

2.1 Site 2: South Kandava

The South Kandava Site is located on the NE flank of the Baltic Basin. This part of the Basin is more effected by faulting, which has given rise to a number of structural traps which provide potential CO_2 storage sites across Latvia and Lithuania. South Kandava is one of these structures. The South Kandava structure is a fault bounded anticlinal fold, striking SW-NE, which was formed prior to the Devonian. The target reservoir within this structure is the Middle Cambrian Deimena sandstone. Within the structure the reservoir has thicknesses of between 23-67m and favourable reservoir properties, with average porosity and permeability values of 21% and 300 mD, respectively. The reservoir sandstones within the structure are described as massive, fine-grained, well sorted, porous and loosely cemented. The area of the structure is approximately 97km^2 and the top of the reservoir is at a depth of between 933m and 1224m (Fig. 3).

Lower Ordovician strata which unconformably overly the Cambrian sequence provide the caprock for the proposed pilot site. The lower part of the cap rock consists of 5-10 cm of calcite cemented basal breccia consisting of marlstones. The Breccia is covered by 20-50 cm thick dark-green, glauconitic, weakly cemented siltstones. These siltstones are overlain by dark-green, violet-brownish, carbonate clays which occasionally contain limestone beds. The lower Ordovician cap rock is 30-36 m thick and is thought to have very low permeability <1mD. Above the structure the total thickness of Ordovician and Silurian strata is 224m and 225m, respectively (Shogenov et al., 2013). Devonian silicilastic and mixed carbonate-siliciclastic rocks overlie the Silurian section at the site.

Five wells are drilled in and around the structure. Kn25, Kn27 and Kn28 are located within the structural closure, while Kn24 and Kn26 are located outside (Fig. 3).



Fig, 3: (A) Structural map of the top of the Cambrian reservoir sandstones in the South Kandava structural trap. Location of Line A-B is annotated on the map. Locations of the 5 wells are shown as pink dots. (B) Geological section along the line A–B. (C) Geological section of the Cambrian reservoir and Ordovician cap rocks in the Kandava–26 borehole (26 in parts A and B) (Shogenova et al., 2011).

2.2 Site 3: Vaškai structure

The third potential CO_2 pilot site is within a structural closure, called the Vaškai structure, which is located 10 km from the city of Pasvalys in Northern Lithuania. Between 1992 and 1999 this site was investigated for Underground Gas Storage, which led to the acquisition of 168km of seismic around the structure and the drilling of five wells. Based on these data it was clear that two large faults control the northern and southern edges of the structure, which appears to be a pop up-structure. However it was not possible to adequately constrain the sealing nature of the northern and southern edges of the structure. For example the deformation on these edges could be sharp folding of the sequence or brittle faulting, leading to very different inferred sealing properties. As a result the site was abandoned due to uncertainty of the sealing nature of the bounding faults. The structure is elongated in a west-east direction, parallel to the bounding faults and has a closure area of approximately 35.2km^2 (Fig. 4). The proposed reservoir for the site is a sequence of sandstones which are Lower–Middle Cambrian in age and are located at a depth of between 900 and 950m. The reservoir consists of medium- to fine-grained quartz sandstones with interbeds of shales and siltstone. The porosity and permeability of the reservoir is believed to be in the range of 19.5–24.5% and 90–1628 mD, respectively.

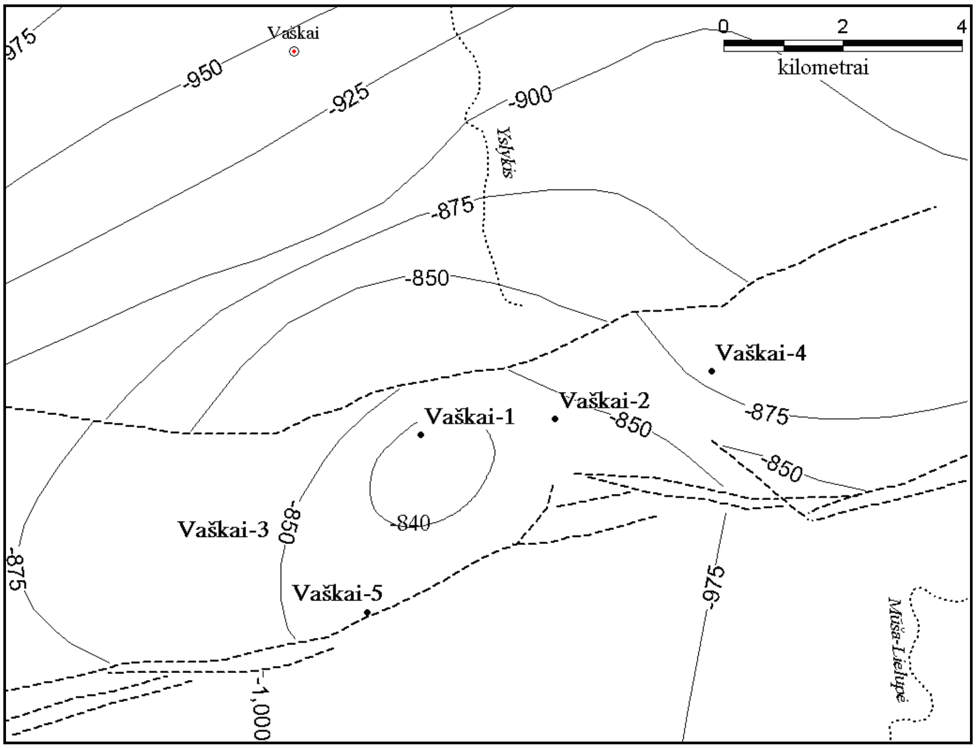


Fig.4. Structural map of top of Cambrian reservoir. Site evaluation deep wells are indicated.

The proposed caprock for the site is the Ordovician sequence overlying the reservoir. The permeability of the caprock is not known, but it is thought to be very low. The sealing nature of Ordovician caprock was proved by drill stem test conducted in the structure and is believed to be good based on logs in the wells and threshold pressures measurements on cores. The thickness of the sequence of relatively impermeable shales, which are Ordovician and Silurian in age is approximately 360m. The storage capacity of the Vaškai structure is assessed 8.7 Mt of CO_2.

A major advantage of the Vaškai structure is that two of the wells, Vaškai-4 and 5 have not been abandoned and could be made accessible for potential use in a CO_2 pilot site, hence significantly reducing costs. Another advantage is that an industrial supplier of CO_2 is located relatively nearby which could provide CO_2 for an injection experiment (Jonava chemical plant).

2.3 Site 4: Kamień Pomorski

The fourth potential pilot site is located in the NW corner of Poland within the medium size oil field Kamień Pomorski, which is almost completely depleted. This oil field is located within an anticlinal structural trap and is operated by the Polish Oil and Gas Company. This pilot site provides the opportunity to investigate combining CO_2 storage with hydrocarbon production i.e. Enhanced Oil Recovery (EOR). The potential reservoir for this proposed pilot site is the Zechstein Hauptdolomite, which is predominantly a fracture reservoir. The reservoir top is located at a depth of 2232m and the water-oil contact at a depth of 2315m. The Hauptdolomite reservoir, which belongs to the Zechstein Stassfurt sequence, lies on top of Werra anhydrites. This reservoir consists of crystalline, crushed and fractured grey dolomites, which grade into anhydrites at the base of the reservoir. The average matrix porosity and permeability values of the reservoir are 5-7% and approximately 0.24 mD. The average net reservoir thickness is 14.5-22.5m. The Hauptdolomite is the sole oil reservoir formation in the Polish Permian basin (NW Poland).

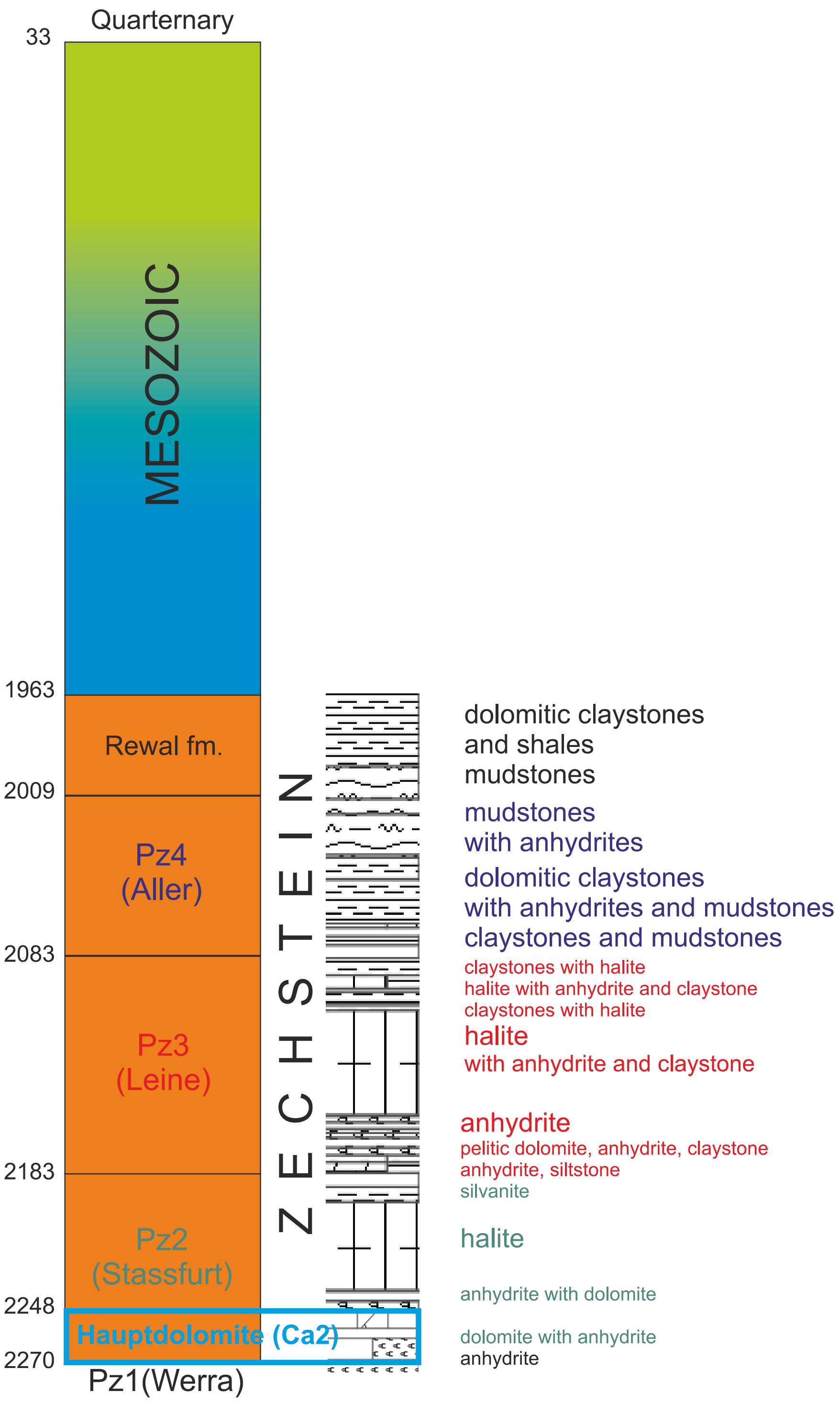


Fig. 5: Geological column describing the sequence at the Kamień Pomorski site.

The primary seal for this pilot site is the 50-80m thick salt complex of Stassfurt sequence, consisting of impermeable halite and silvanite beds, interbedded with anhydrite. The secondary seal (The Leine sequence) is 70-90 m thick and consists of halite, anhydrite and, to a lesser extent, claystone. Above the Leina sequence there a sequence of claystones and anhydrite which is over 100m thick. It is clear that the sealing nature of the caprock is to a large extent already validated by the presence of hydrocarbons within the anticlinal structure, hence, it is likely that the seal would be suitable for CO_2 storage (Fig. 5).

The estimated CO_2 storage capacity from static modelling is 2.60-3.93 Mt. Dynamic modelling of a CO_2 based EOR scheme estimates that between 0.9-2.2Mt of CO_2 could be stored in the structure, which would at the same time provide an additional recovery from the oil field of between of 0.4-1.7 Mt of oil. There are 16 wells in the area around the structure. The reservoir was discovered in 1971 and developed in 1972. Until the year 1976 the reservoir pressure and production decreased, so water flood was applied in order to provide pressure support to stabilise production. The water flood was applied first continuously and later in cycles. However, in 1981 this measure was abandoned because water appeared in all of the production wells. From 1994 until now the operators have been re-injecting sour gas, a waste product of oil production from the reservoir. The complicated history of extraction and injection of a range of different fluids and gases in this reservoir will make the process of monitoring the injected CO_2 at this potential pilot site more challenging.

2.4 SWOT analysis

At this stage we have presented four different pilot CO_2 storage site, with different strengths and weaknesses. In order to compare the different pilot sites and select a preferred alternative to focus on in more detail for the remainder of the report a SWOT analysis was performed (Strengths, Weaknesses, Opportunities and Threats). The results of the SWOT analysis are shown in the Table 1.0 below.

Based on this comparison, it appears that the pilot site with the most positive result from the SWOT analysis was Site-1, Southern Gotland. Some of the significant advantages of this site are:

- This site provides a test of Middle Cambrian sandstone reservoirs, which are a large scale and important storage opportunity for the Baltic region.
- It investigates a stratigraphic trap type scenario which is arguably the highest capacity storage concept known in the Baltic Basin (Faludden stratigraphic trap).
- The injection site has been identified and an agreement has already been made with the land owners.
- The project has a high degree of economic and technical maturity and is ready to include in a proposal.
- A member of the CGS Baltic group is willing to be the lead applicant on a proposal and to lead the project (Uppsala University).

The main disadvantage of this site compared to the other sites reviewed here is that no accessible wells are located at the potential test site which could be utilized for the project.

Major reasons for selecting this site as the preferred alternative in this report is the fact that the project is technically mature enough to proceed with a funding proposal and that a member of the CGS Baltic group is willing to lead the application. Of the remaining 3 sites, which are not selected as the preferred alternative in this report, the Vaškai structure (Site 3), appears to be the most attractive option. This site has some major advantages such as the availability of open wells in the structure, a deep enough reservoir to store CO_2 in a supercritical state and the proximity of a CO_2 source for the experiment. Therefore although we do not discuss this alternative further here, we recommend that efforts are made to advance the technical and economic maturity of this potential pilot site.

	Site 1: Southern Gotland	**Site 2: South Kandava**	**Site 3: Vaškai structure**	**Site 4: Kamień Pomorski**
Initial Costs (not including running costs or cost for CO_2) Cost for injection borehole only	2.5M euros	2.5M euros	*2.5M euros* No info provided Assumed here to cost the same as the pilot site in Latvia	4.5M euros
Relevance	Provides a test of the Middle Cambrian Faludden / Deimena Sanstone. A widely distributed and important reservoir for the Baltic Region.	Provides a test of the Middle Cambrian Faludden / Deimena Sanstone. A widely distributed and important reservoir for the Baltic Region.	Provides a test of the Middle Cambrian Faludden / Deimena Sanstone. A widely distributed and important reservoir for the Baltic Region.	Provides a test of the Zechstein Hauptdolomite. Results mainly of relevance for Poland CO_2 storage understanding.
Theoretical Potential CO_2 storage capacity	Storage capacity of Faludden stratigraphic trap is very large >1000Mt	44 Mt (Shogenova et al., 2009).	8.7 Mt	2.6-3.93 Mt (0.9-2.2 Mt from dynamic reservoir modelling).
Industry Involvement	No industry partner clearly identified	No industry partner clearly identified	No industry partner clearly identified	Polish oil and gas company would be involved if it was to be an EOR project.
Data availability	Data from over 300 wells is available from the island of Gotland, as well as over 2000km of 2D seismic data. However, there are no seismic lines directly over the proposed storage location.	Data is available from 5 wells located in and around the structure. (3 inside and 2 outside the structural closure).	Data is available from 5 wells have been drilled into the structure. The area is characterized by 168km of seismic lines.	Data from 16 wells can be used to characterize the reservoir.
Cap rock/reservoir rock	13m thick 10-16% porosity 200-400 mD	23-67m thick 21% porosity 300 mD	57m thick 19.5-24.5% porosity 90-1628 mD	14.5-22.5m thick Fracture porosity and permeability
Faulting	Relatively undisturbed by faulting	Fault bound structural closure	Fault bound structural closure	Relatively undisturbed by faulting
Potential leakage through old wells	Some old wells are in the area. They are thought to be cemented	Some old wells are located in the structure	Some old wells are located in the structure	Some old wells are located in the structure

Accessibility to a site/landowners	Land owner contacted and has given permission to use the site	Unknown if land owners would agree to a site.	Unknown if land owners would agree to a site.	Polish oil and Gas company owns the land – Unknown if they would agree to a site.
Super-critical conditions	No	Yes	Yes	Yes
Oil (risk of hitting unwanted oil during drilling)	Risk of encountering unwanted oil in Ordovician carbonate mounds above the reservoir	No	No	No
Public interest	Unknown	Unknown	Unknown	Unknown
Monitoring and experiments	The relatively shallow reservoir depth and gaseous CO2 will make it easy to see an anomaly using seismic methods. It will be easy to drill monitoring wells.	Greater depth and supercritical CO2 will make seismic monitoring more challenging. More time and difficulty to drill monitoring wells	Greater depth and supercritical CO2 will make seismic monitoring more challenging. More time and difficulty to drill monitoring wells	Sub salt environment challenging for seismic monitoring. Deep reservoir, making monitor wells more challenging. Monitoring will be challenging because of the previous extraction of oil and injection of water and sour gas.
CO2 sources/transport	Bio gas plant nearby can provide small amounts of CO_2 for injection. Industrial producers on Swedish mainland.	Most likely need to purchase CO_2 from a nearby industrial supplier.	Industrial source of pure CO_2 nearby (Jonava chemical plant).	Most likely need to purchase CO_2 from a nearby industrial supplier.
Renewables relevance	Energy storage	Underground gas storage / energy storage	Underground gas storage / energy storage	EOR
Logistics	Located on an island, can be restrictive to transport of materials.	Located on mainland	Located on mainland	Located on mainland
Accessible wells at the site?	No	No	Yes	Yes
Maturity of technical /	High	Low	Low	Low

economic understanding of pilot site. (High = ready to submit application).				
Is there a member of the CGS Baltic group who would be willing to be the head applicant on a proposal and lead the project?	Yes	No	No	No

Table 1: SWOT analysis comparing the four different potential pilot sites in the Baltic Sea area.

3.0 Detailed description of preferred alternative

In this section we present a more detailed characterization of the southern Gotland site (Site 1).

3.1 Detailed description of the site

A description of the Southern Gotland site is given in section 2.0. In the following section we provide some more detail about the potential pilot site. A proposal was submitted in January 2017 to the EU Horizon 2020 call for pilot sites, which included the southern Gotland site. However, this proposal was put together outside of the CGS Baltic SEED project. Therefore, in this report, we provide a more general description of a potential test site on Gotland and focus largely on the results from the SwedSTORECO2 project, which was completed in 2013 (SwedSTORECO2, 2013). This project focused on investigating the possibilities for CO_2 storage within Swedish bedrock and also the possibility of establishing a CO_2 storage test site in Sweden.

A location on southern Gotland, where a pilot CO_2 site could be located is on the Näsudden peninsular on southern Gotland, within the Näsudden wind park (Fig. 6). Ideally a single injection well would be drilled as well as several monitoring wells. The monitoring wells would provide valuable information about the reservoir and caprock around the injection well. The monitor wells could also be instrumented to collect valuable dynamic reservoir data during the operation of the pilot site.

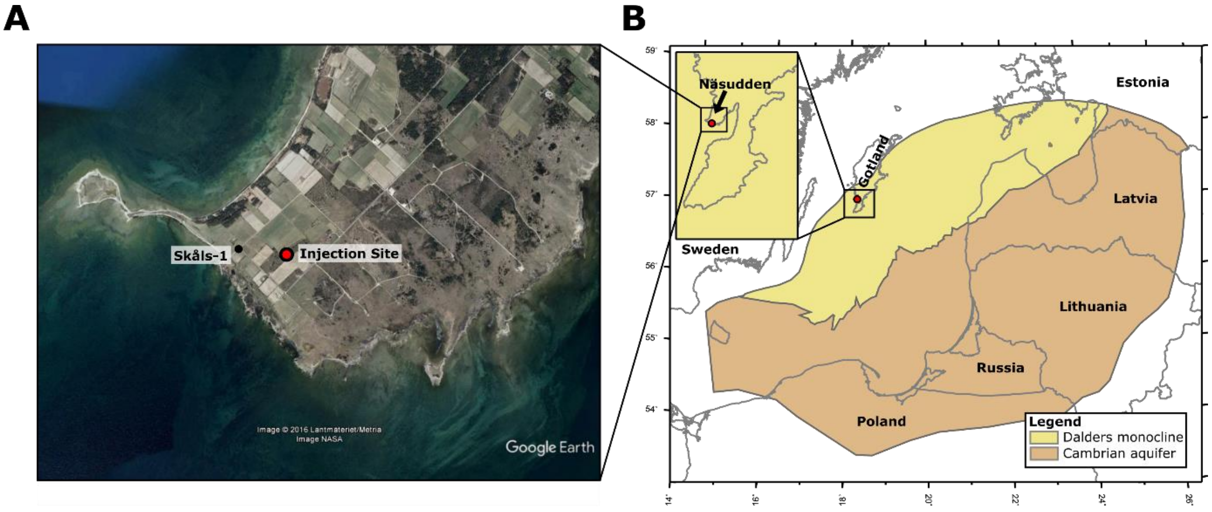


Fig. 6: A). Satellite image of the Näsudden peninsular and the proposed injection site (after Google Earth, 2016). The location of the Skåls-1 well is also shown. B). Map showing the Location of Gotland within Northern Europe. The brown polygon approximates the areal extent of Cambrian sandstone reservoirs (i.e. Faludden / Deimena /

När / Viklau sandstones) across the Baltic Basin. The yellow polygon denotes an area where the Middle Cambrian Faludden sandstone is thought to be relatively continuous and un-faulted, referred to as the Dalders monocline (Vernon et al., 2013; Yang et al., 2015). This highlights how a pilot injection site on Gotland provides insight into a set of reservoirs, which present a significant regional CO_2 storage opportunity, relevant for the whole Baltic region. The inset map shows the location of the Näsudden peninsular on southern Gotland. Red dot denotes the location of the proposed pilot site.

3.2 Local acceptance and logistics

The local acceptance of such a project is unknown. Although the site is located within the largest wind farm on Gotland, which indicates that the local population are somewhat open to the idea of industrial activity in the area. Public consultation would be an important component of the project, especially in the early stages.

Gotland is an island which lies some 80 km from the Swedish mainland. There is no large scale producer of CO_2 on the island. The most viable solution for transportation of CO_2 to the site would be transport of CO_2 using trucks from main land suppliers. These trucks would need to be transported by Ferry from the mainland to Gotland. Depending on the budget of the project, it would also be possible to transport CO_2 to the site using boats. A small biogas plant is located on Gotland which could provide small amounts of CO_2 for an injection experiment.

3.3 Monitoring plans

A comprehensive monitoring plan would be employed in such a project. Depending on the budget available for the project this could include:

- Downhole pressure and reservoir property measurements, made using equipment permanently installed in the monitoring wells and injection well.
- Surface CO_2 flux measurements.
- Baseline and repeat 3D seismic surveys, to characterize the site and monitor the movement and size of the injected CO_2 plume.
- A series of Vertical seismic profiles (VSP) could be acquired to image the CO_2 close to the monitor wells.
- Electrical resistivity tomography (ERT) could be applied using a permanently installed array.

3.4 Project consortium and potential partners/roles

In this report we do not identify a project consortium and potential partners/roles. However, it would be important to include partners who have experience and expertise in some of the following areas:

- Drilling operations.
- Other CO_2 pilot injection sites.
- Monitoring (e.g. seismic data acquisition, well based pressure measurements, etc.)
- Public consultation.
- Local geological knowledge.
- Hydrogeology.
- Rock physics.
- Geophysics.
- Geology.
- Reservoir modelling.

3.5 Project plan and schedule

The timeline for a pilot CO_2 storage project on southern Gotland would somewhat depend on the scope of the project, which would be dependent on the project budget. An example of a reasonable timeline with some key steps annotated is shown below (assuming that the project begins in Jan 2017):

2017-2019

- Baseline characterization of Southern Gotland site (data collection).
- Drilling of injection and monitoring wells.
- Complete instrumentation of wells.
- Instillation of storage tanks and evaporators at the site.
- Public consultation.

2019-2021

- Injection of CO_2.
- Collection of monitoring data.

2022

- Decommissioning of site.
- Removal of injection and gas storage equipment.

3.6 Preliminary Budget

The cost estimate presented in this report is scoping and gives an idea of only part of the cost of the project. The cost estimate is modified from one generated as part of the SwedSTORECO2 project completed in 2013 (SwedSTORECO2, 2013) (Table 2). This cost estimate assumes that two investigation boreholes have been drilled and that a seismic survey has already been performed at the test site. i.e. these are not included in this cost estimate. This cost estimate also assumes that 5000 tons of CO_2 will be injected over a 1 year period. The cost of the CO_2 for injection has not been included. The costs below are given in Swedish Kronor.

Fixed costs: Injection system		
Item	**Comment**	**Cost (kSEK)**
Power station installation	500 kW	300
Add-ons: controllers, data acquisition system, etc.		1000
Site establishment: Roads, water treatment, sewage, parking, internet, etc.		1000
Drilling of the injection borehole		13000
Distributed Temperature Sensors (DTS) plus pressure sensor in injection well (Weatherford)	Not required to inject, but important for monitoring	2500
U-tubes for fluid sampling	can be removed for downhole measurements	500
ERT (Electrical Resistivity Tomography) system		500
Borehole seismic system		2000
Off-site science		2000
Total		**22800**

Running costs and monitoring		
Item	**Comment**	**kSEK/yr**
Electricity for heating CO_2	50 SEK/t to 30ºC	250
Transport of CO_2 to the site (500 SEK/t)	5000 t per year and transported by truck	2500
Maintenance injection system	80 kSEK/month including installation	1000
Maintenance contracts	Includes safety and building inspections, cleaning, etc.	300
Sub-contractors: Reservoir and surface engineering	These are not necessarily required, but they provide a 3rd party assessment of the project	1200
Geophysical monitoring surveys (seismic)		1500
ERT (Electrical Resistivity Tomography) monitor		500
Hydrogeological monitoring		500
Total		**7750**

Personnel		
People	**Comments**	**kSEK/yr**
On-site personnel	2 people on a rotating schedule	2000
Off-site Management	50 % position	500
Off-site Operations	80 % position	800
Off-site Scientific coordination	50 % position	500
Off-site Administration	25 % position	150
Off-site Public outreach	50 % position	400
Total		**4350**

Total cost for a shallow site (1 year duration of the injection experiment, 5000 tons injected)		
Item	**Comment**	**kSEK**
Fixed costs		22800
Running costs (1 year)		7750
Personnel (1 year)		4350
Total		**34900**

Table 2: Cost estimate for the establishment of an injection facility on southern Gotland and for the drilling of an injection well (SwedSTORECO2, 2013).

This cost estimate shows that it could cost approximately 3.5M Euros to drill the injection borehole on Gotland and inject 5000 tons of CO_2 over the course of a year. The total cost for the project would however, be greater as one would need to include the cost of purchasing the CO_2 etc.

4.0 Conclusions

In this report four potential CO_2 storage pilot sites have been described. Based on a SWOT (Strengths, Weaknesses, Opportunities and Threats) analysis, site 1 located on southern Gotland was selected as the preferred alternative.

The southern Gotland site would provide a test of the most prospective storage concept which has been identified in the Baltic Basin, i.e. a stratigraphic trap within the Middle Cambrian Faludden sandstone reservoir. The maturity of the technical and economic aspects of southern Gotland site is also higher than that of the other potential sites.

A proposal has been submitted to the Horizon 2020 call for pilot sites which includes the southern Gotland test site, albeit outside the framework of the CGS Baltic SEED project.

References

Erlström, M., Fredriksson, D., Juhojuntti, N., Sivhed, U., Wickström, L., 2011. Lagring av koldioxid i berggrunden - krav, förutsättningar och möjligheter. Sveriges Geologiska Undersökning Rapporter och meddelanden 131, 7–94.

Juhlin, C., Giese, R., Zinck-Jrgensen, K., Cosma, C., Kazemeini, H., Juhojuntti, N., 2007. 3D baseline seismics at Ketzin, Germany: the CO2SINK project. Geophysics 72, B121–B132.

Lothe, A., Emmel, B., Bergmo, P., Mortensen, G. M., Frykman, P., 2015. Updated estimate of storage capacity and evaluation of Seal for selected Aquifers (D26). NORDICCS Technical Report D 6.3.1401 (D26). 80 pp.

Poprawa, P., Sliaupa, S., Stephenson, R., Lazauskiene, J., 1999. Late Vendian–Early Palaeozoic tectonic evolution of the Baltic Basin: regional tectonic implications from subsidence analysis. Tectonophysics 314, 219–239.

Shogenov, K., Shogenova, A., Vizika-Kavvadias, O. 2013. Petrophysical properties and capacity of prospective structures for geological storage of CO2 onshore and offshore Baltic. Elsevier, Energy Procedia, 37, DOI: 10.1016/j.egypro.2013.06.417, 5036-5045.

Shogenova, A., Sliaupa, S., Vaher, R., Shogenov, K., Pomeranceva, R., 2009. The Baltic Basin: structure, properties of reservoir rocks, and capacity for geological storage of CO2. Estonian Journal of Earth Sciences. 58, 259–267.

Shogenova, A., Shogenov, K., Pomeranceva, R., Nulle, I., Neele, F. and Hendriks, C. 2011. Economic modelling of the capture–transport–sink scenario of industrial CO2 emissions: the Estonian–Latvian cross-border case study. Elsevier, The Netherlands. *Energy Procedia* **4**, 2385-2392.

SLR and Uppsala University., 2014. Final report on prospective sites for the geological storage of CO2 in the southern Baltic Sea. Elforsk report 14:53. 99pp.

Sopher, D., Juhlin, C., Erlström, M., 2014. A probabilistic assessment of the effective CO2 storage capacity within the Swedish sector of the Baltic Basin. International Journal of Greenhouse Gas Control 20, 148–170.

Sopher, D., Erlström, M., Bell, N., Juhlin, C., 2016. The structure and stratigraphy of the sedimentary succession in the Swedish sector of the Baltic Basin: New insights from vintage 2D marine seismic data. Tectonophysics 676, 90-111.

SwedSTORECO2., 2013. Potential for CO2 storage in Swedish bedrock: SwedSTORECO2 - Phase 1. Final project report. http://www.swedstoreco2.se/index.php?id=2

Ūsaitytė, D., 2000. The geology of the southeastern Baltic Sea: a review. Earth-Science Reviews 50, 137–225.

Vernon, R., O'Neil, N., Pasquali, R., Nieminen, M., 2013. Screening of prospective sites for geological storage of CO2 in the Southern Baltic Sea. Espoo 2013. VTT Technology 101. 58 pp.

Yang Z, Tian L , Jung B, Joodaki S, Fagerlund F, Pasquali R, et al. Assessing CO_2 storage capacity in the Dalders Monocline of the Baltic Sea Basin using dynamic models of varying complexity. International Journal of Greenhouse Gas Control. 2015; 43:149-60.