Economical, Geological and Geophysical Modelling of Estonian-Latvian Transboundary CO_2 storage

Alla Shogenova, Kazbulat Shogenov and Jüri Ivask
Institute of Geology at Tallinn University of Technology, Estonia
alla@gi.ee

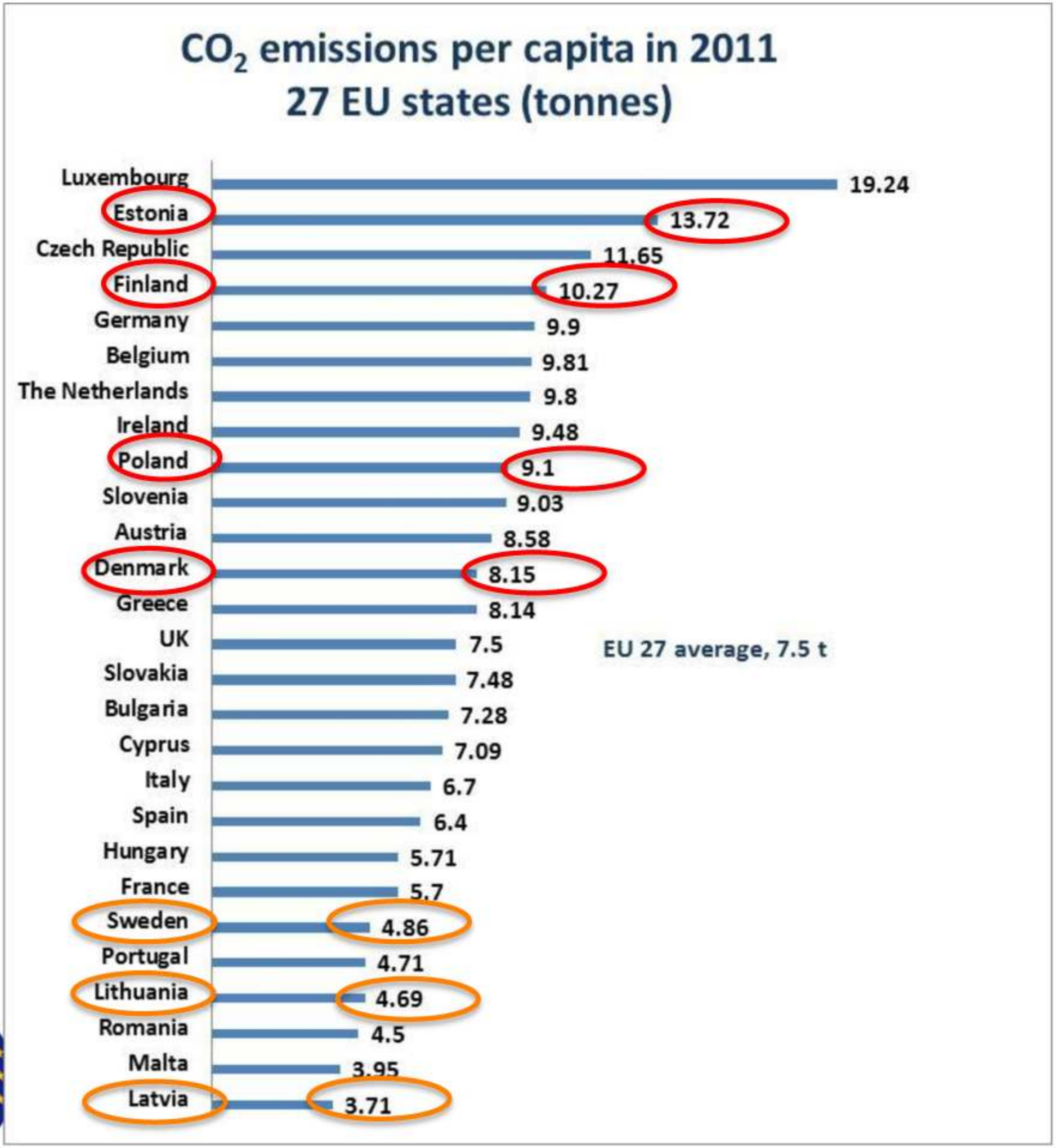
1. Why we need transboundary storage?

- Emissions versus storage capacity
- CCS Legislation Results versus emissions and storage capacity

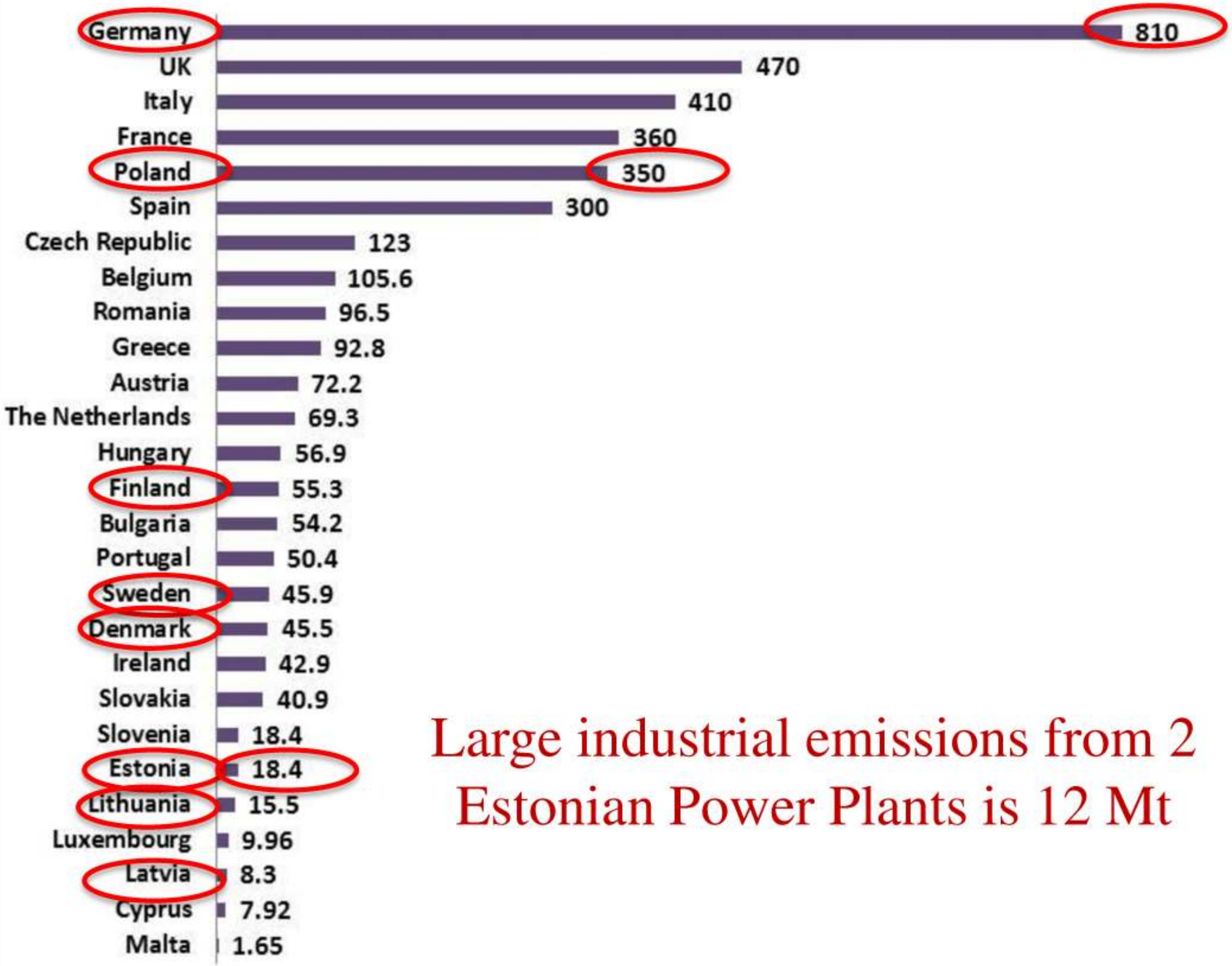
2. Modelling of transboundary storage and prospective structures in Latvia

- Economic Modelling of of Estonian-Latvian Transboundary CO_2 storage
- Detailed study and modelling of 4 prospective structures
- Modelling of the E6 structure in the Baltic Sea, offshore Latvia

3. Prospects for future regional cooperation


CO2 emissions per capita in 2011
27 EU states (tonnes)
Luxembourg 19.24
Estonia 13.72
Czech Republic 11.65
Finland 10.27
Germany 9.9
Belgium 9.81
The Netherlands 9.8
Ireland 9.48
Poland 9.1
Slovenia 9.03
Austria 8.58
Denmark 8.15
Greece 8.14
UK 7.5
Slovakia 7.48
Bulgaria 7.28
Cyprus 7.09
Italy 6.7
Spain 6.4
Hungary 5.71
France 5.7
Sweden 4.86
Portugal 4.71
Lithuania 4.69
Romania 4.5
Malta 3.95
Latvia 3.71
EU 27 average, 7.5 t

Total CO_2 emissions (Mt) in 2011
27 EU states

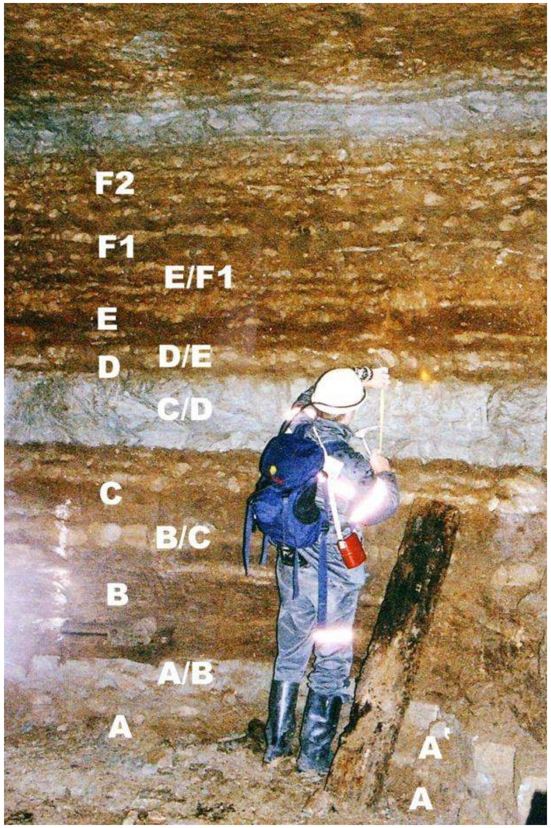


Large industrial emissions from 2 Estonian Power Plants is 12 Mt

Estonian oil shale (kukersite) is the main source of industrial CO_2 emissions

- Estonia is the largest commercially exploited oil shale deposit in the world with total reserves exceeding 7 Gt of oil shale.
- Kukersite oil shales forming the productive bed of the Estonia deposit occur in the Kukruse Stage of the Upper Ordovician (Llandeilo – early Caradocian).
- Average organic matter content in the Estonian oil shales is 36 %. The area of the Estonia deposit is about 3000 sq.km.
- At the present time extraction takes place in 2 underground mines and 3 open-cast pits
- The oil shale is used mainly for energy and shale oil production

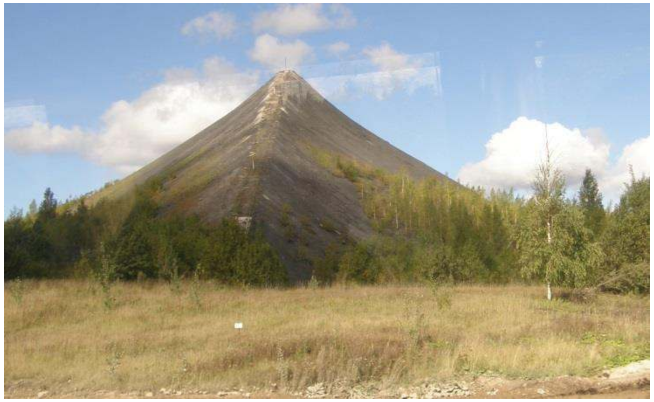
Oil shale open-cast pit



Underground mine

Environmental problems

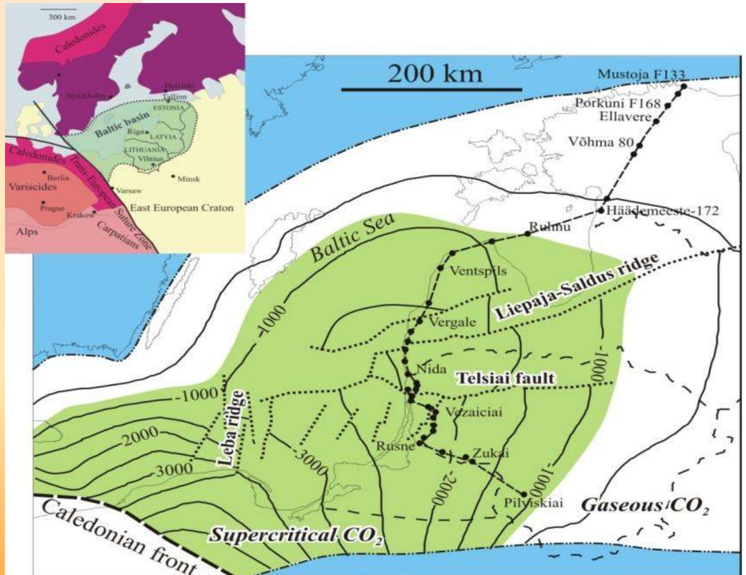
- During combustion of the oil-shale, local low-grade carbonaceous fuel, for energy production per every tonne of the oil shale about **860 kg of CO_2** and **450-500 kg** of oil shale **ash** are formed (in case of mineral coal only 100 kg of ash is produced)
- It has been shown that instead of emitting CO_2 and storage of ash in the waste heaps, it is possible to bind CO_2 with oil shale ash-waste water suspension and use the neutralized residue in construction and mining industries.
- Implementation of CO_2 mineral carbonation technology can help to mitigate environmental problems at the north-east of Estonia and to cut 10-12% of emitted by Estonian power plants CO_2 emissions



Artificial waste heap composed of semicoke and oil shale ash mixture in Kohtla-Järve region of Estonia

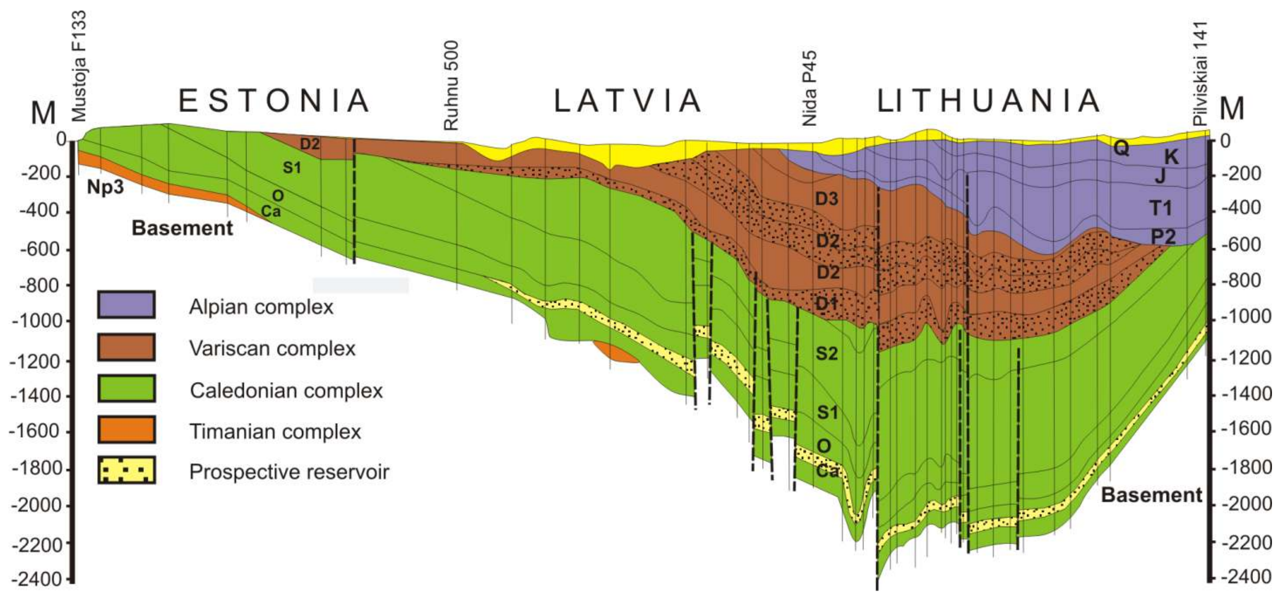
Waste water at the Estonian Power Plant, near Narva, pictured by Reet Pruul

Storage capacity in the Baltic Region



Depths of top of the Cambrian aquifer in the Baltic basin. The P-T fields of gaseous and supercritical state of CO_2 (P = 73.8 bars, T = 31°C) are shown. The line of the geological cross-section is indicated.

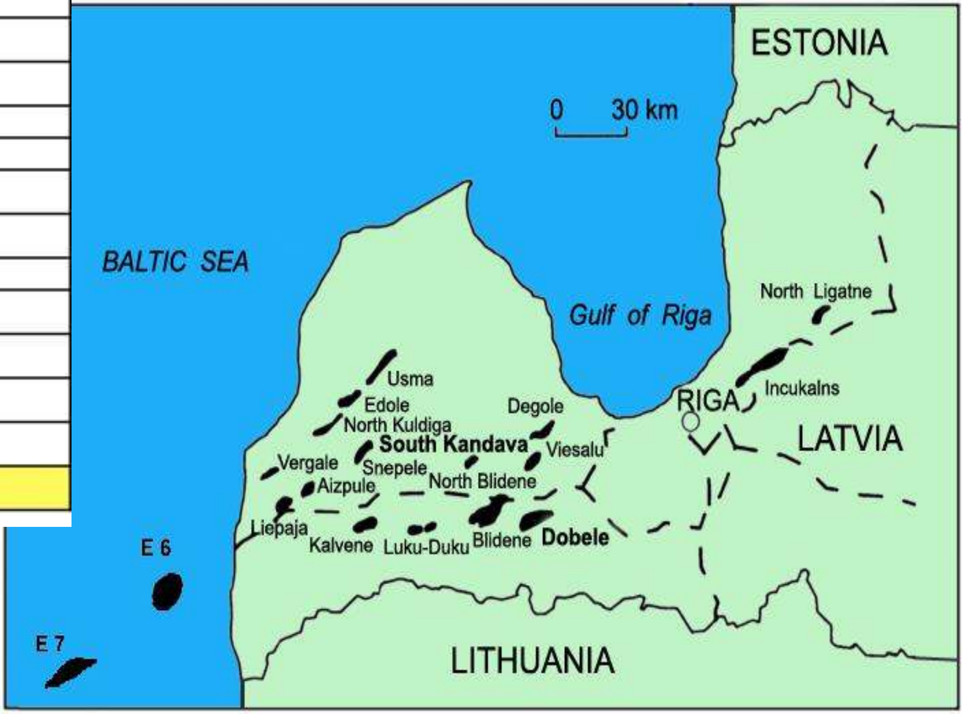
Sliaupa et al 2008



Shogenova et al 2009

Onshore Storage Capacity in Latvia (EU GeoCapacity Project results)

Structure	Depth, m	Thickness, m	Area, km²	CO_2 storage capacity, Mt
Aizpute	1096	65	51	14
Blidene	1050	66	43	58
Degole	1015	52	41	21
Dobele	950	52	67	56
Edole	945	71	19	7
Kalvene	1063	45	19	14
Liepaja	1072	62	40	6
Luku-Duku	937	45	50	40
N. Kuldiga	925	69	18	13
N. Ligatne	750	50	30	23
N.Blidene	920	40	95	74
S.Kandava	983	25-30	69	44
Snepele	970	30	26	17
Usma	975	50	20	2
Vergale	981	65	10	5
Viesatu	1020	50	19	10
Total				**404**



Shogenova, A., Sliaupa, S., Vaher, R., Shogenov, K., Pomeranceva, R. 2009a. The Baltic Basin: structure, properties of reservoir rocks and capacity for geological storage of CO2. Estonian Academy Publishers, Tallinn . Estonian Journal of Earth Sciences **58**(4), 259-267.

Storage capacity in the Baltic Region

Šliaupa et al 2013. CO2 storage potential of sedimentary basins of Slovakia, the Czech Republic, Poland and the Baltic States Geological Quarterly, **57**, **2**

- Last reported capacity in the Baltic Countries (Šliaupa et al, 2013):
- Latvia onshore: 400 Mt
- Latvia offshore: 300 Mt
- Lithuania onshore: 29 Mt

Potential for EHR in the Baltic onshore and offshore:

- Lithuania: 5.7 Mt
- Kaliningrad: 26 Mt onshore and 7Mt offshore
- Poland : 7Mt offshore oil and 16 Mt for gas fields

CCS Legislation Results versus emissions and storage capacity

Estonia

- The **highest CO_2 emissions per capita** in the Baltic Sea Region and Europe
- Two largest in the Baltic Region power plants (12 Mt/y CO_2
- **No** CO_2 storage **capacity**
- CO2 storage is **not permitted** except for research, but requirements for new power plants (300 MW) to be capture ready (not yet accepted by EC)

Latvia

- The **lowest CO_2 emissions** and emissions per capita in the Baltic Sea Region and mostly in Europe
- **Significant** (compared to emissions) onshore and offshore CO_2 storage **capacity**
- CO2 storage is **temporaly not permitted** (not yet accepted by EC)

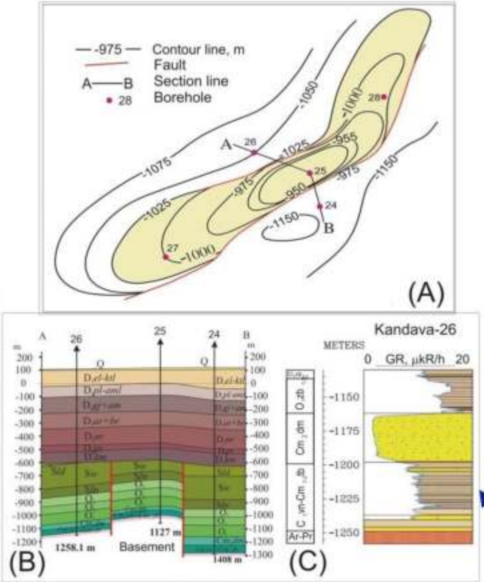
Economic Modelling of of Estonian-Latvian Transboundary CO_2 storage

Methods

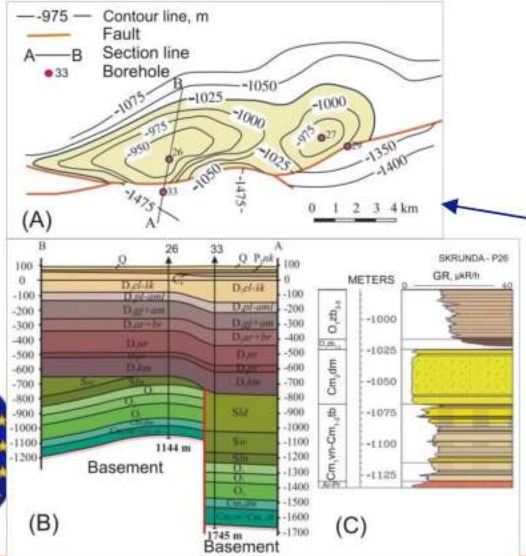
- Data for the economic modelling were collected into the Geographic Information System (GIS) in the frame of the EU GeoCapacity project
- The GIS database includes locations of large CO_2 sources, potential storage sites and injection points, existing pipelines and pipeline terminals and natural sources of CO_2
- The DSS was developed in the EU GeoCapacity project to evaluate the technical and economic feasibility of CO_2 storage in the subsurface
- The DSS uses the database of CO_2 emission points and storage locations in Europe (GeoCapacity GIS)
- The system is a combination of an internet application, which visualizes the data and allows the user to select sources and sinks and create a pipeline network, and a tool which performs a stochastic analysis of the costs of a CO_2 capture, transport and storage system.

Results of the economic modelling of the possible Estonian-Latvian transboundary capture-transport-storage scenario showed, that cost of one tonne of CO_2 avoidance (37.4 €, Shogenova et al. 2011b) is corresponding to the cost calculated for European coal industry by ZEP (37 €, ZEP, 2011).

South-Kandava - 40 Mt CO_2



Luku-Duku – 44 Mt CO_2



Narva plant -2.7 Mt CO2 (2005)
3.7 Mt in 2011

http://www.estonica.org/en/Balti_power_plant_near_Narva/

Photo: Postimees/Scanpix

Eesti plant -8 Mt CO2 (2005)
8.4 Mt (2011)

Source: 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.

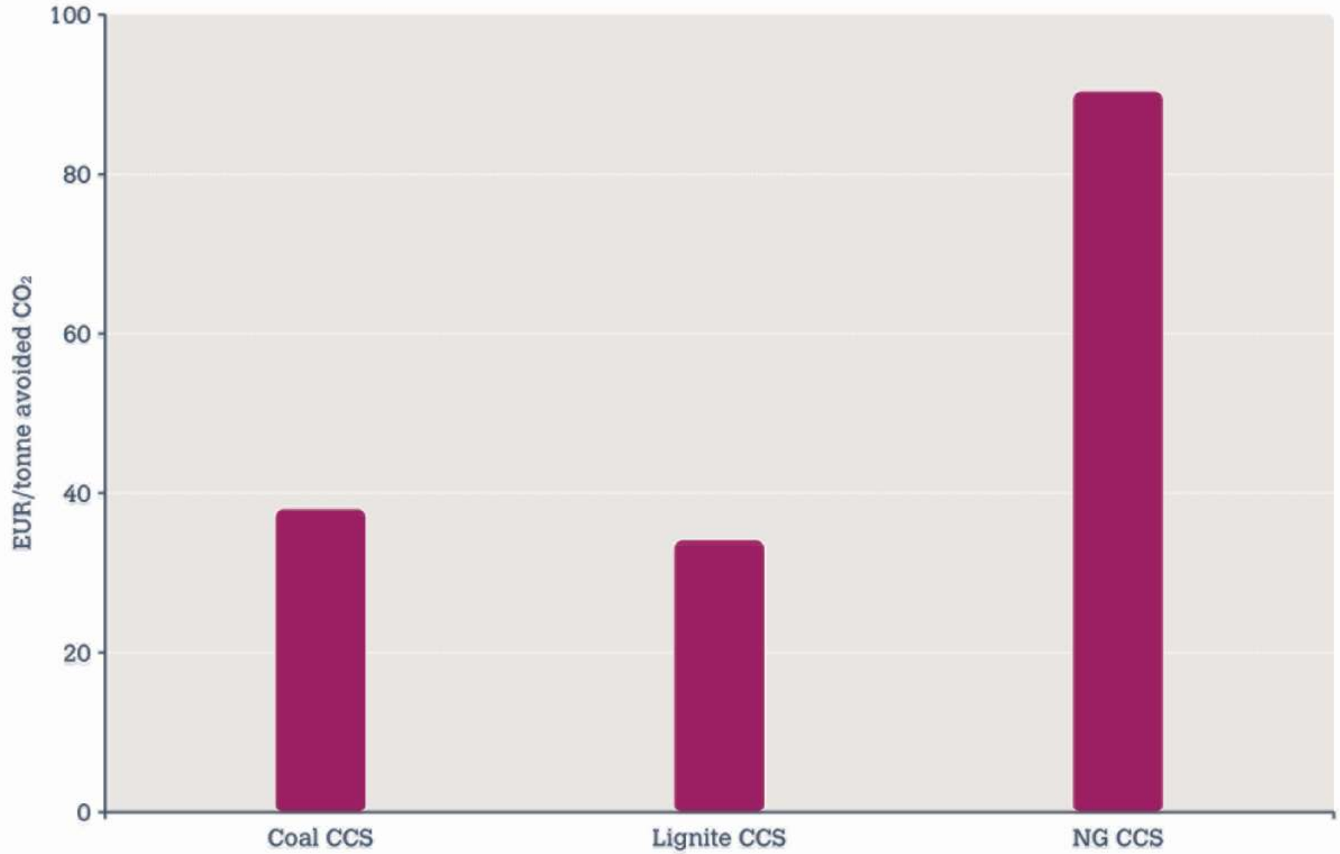
Summary of the input parameters for storage in the GeoCapacity Model

Sink Name	Luku-Duku	South Kandava
Sink type	aquifer	aquifer
Depth (m) (from the earth surface)	1024	1053
Current reservoir pressure (bar)	93.7	98.3
Maximum reservoir pressure (bar)	107.8	113
Reservoir radius (km)	8	5
Trap radius (km)	8	5
Reservoir thickness (m)	45	28
Porosity (%)	22	20
Connate water fraction	0.25	0.25
Net to gross ratio	0.8	0.8
Reservoir temperature (°C)	19	24.5
Permeability (mD)	300	300
Well radius (m)	0.15	0.15
Storage capacity (MtCO_2)	40.2	44
Well injection rate (Mt/yr)	2	2
Storage efficiency factor in trap (%)	40	40
Number of wells	3	4
CO_2 concentration	20	20

Economic parameters of the Estonian – Latvian case study (NPV is net present value, SRC NPV is net present value for the capture costs)

NPV	**2835**	**€ million**	**NPV storage normalised**	**3.0**	**€/tCO_2avoided**
NPV capture	**1928**	**€ million**	**Unit technical cost**	**37.4**	**€/tCO_2avoided**
NPV compression	**210**	**€ million**	**Pay out time**	**30**	**Yr**
NPV transport	**447**	**€ million**	**SRC NPV capture 0**	**1103**	**€ million**
NPV storage	**250**	**€ million**	**SRC NPV compression 0**	**162**	**€ million**
NPV normalised	**37.4**	**€/tCO_2avoided**	**SRC NPV capture 1**	**825**	**€ million**
NPV capture normalised	**25.5**	**€/tCO_2avoided**	**SRC NPV compression 1**	**48**	**€ million**
NPV compression normalised	**2.8**	**€/tCO_2avoided**	**SINK NPV storage 0**	**129**	**€ million**
NPV transport normalised	**5.3**	**€/tCO_2avoided**	**SINK NPV storage 1**	**121**	**€ million**

Figure 2: CO_2 avoidance costs for possible plants commissioned in the mid 2020s – the price of EUAs required to justify building CCS projects vs. a plant without CCS from a purely economic point of view (calculated on the same basis as Figure 1)



37 €/tonne CO_2 34 €/tonne CO_2 90 €/tonne CO_2

(Source: The Costs of CO2 Capture, Transport and Storage,
European Technology Platform for Zero Emission Fossil Fuel Power Plants, 2011

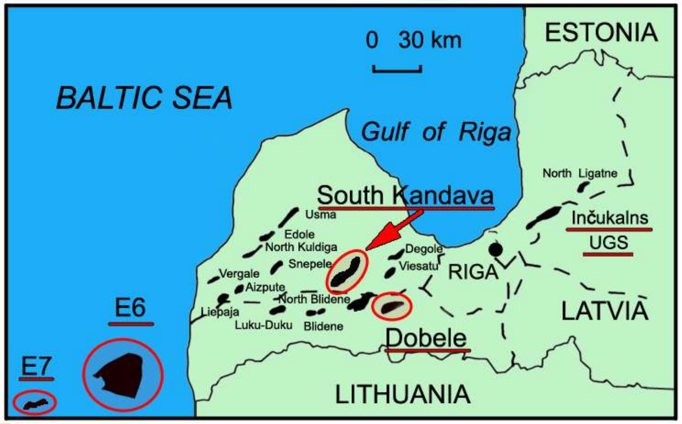
Results of economic modelling

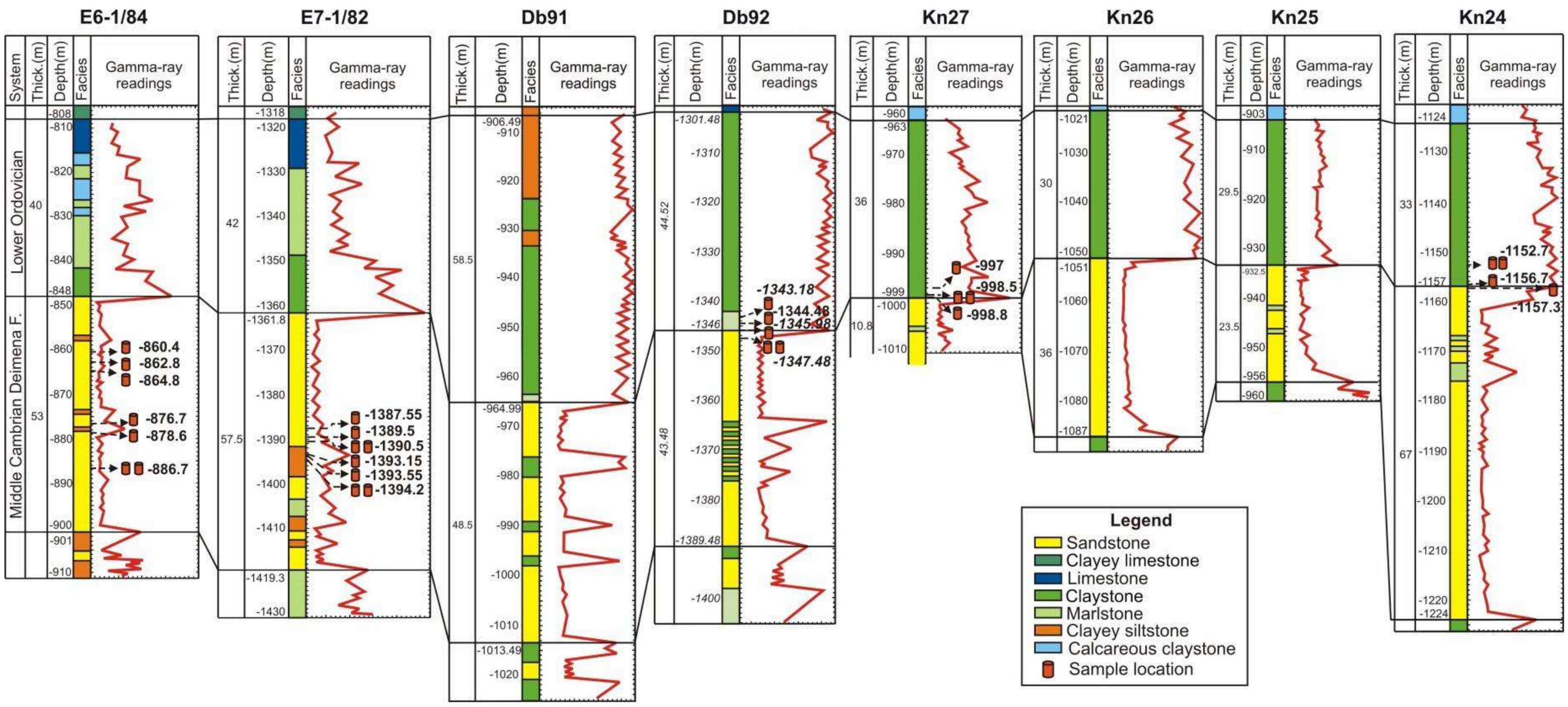
- Two largest Estonian power plants were chosen for the economic modelling of the capture–transport–sink scenario using the GeoCapacity Decision Support System (DSS) based on the GeoCapacity GIS database.
- Two anticlinal structures of Latvia, Luku-Duku and South Kandava with 40 and 44 Mt of CO_2 storage capacity were selected for the CO_2 storage.
- The estimated pipeline length required for CO_2 transportation is about 800 km.
- The oxyfuel capture technology is applied in this scenario. With a conservative storage capacity for 8 years of emissions, avoidance costs are rated at €37.4 per tonne of CO_2
- The total cost of the project estimated by the Decision Support System using the GeoCapacity GIS is about €2.8 billion for 30 years of payment period
- Results of the economic modelling of the possible Estonian-Latvian transboundary capture-transport-storage scenario showed, that cost of one tonne of CO_2 avoidance (37.4 €, Shogenova et al. 2011b) is corresponding to the cost calculated for European coal industry by ZEP (37 €, ZEP, 2011).

Source: 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.

Detailed Study, Geological and Geophysical Modelling of Prospective Latvian structures

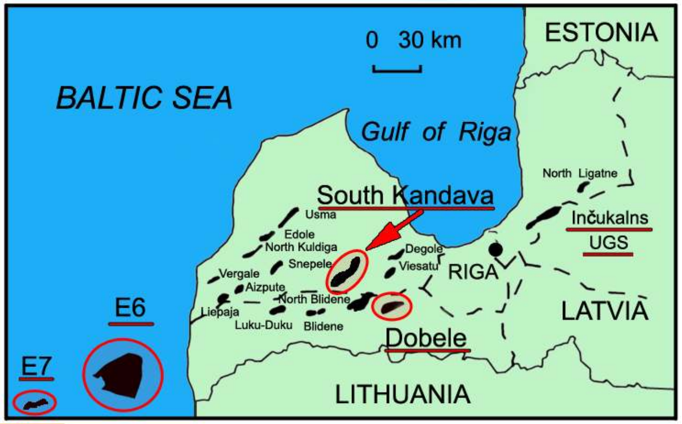
Detailed study in Latvian onshore and offshore structures





Shogenov, K., Shogenova, A., Vizika-Kavvadias O. 2013. Petrophysical properties and capacity of prospective for CO2 geological storage Baltic offshore and onshore structures. Energy Procedia, in press, 1-11.

Onshore Structures in Latvia ongoing research and modelling



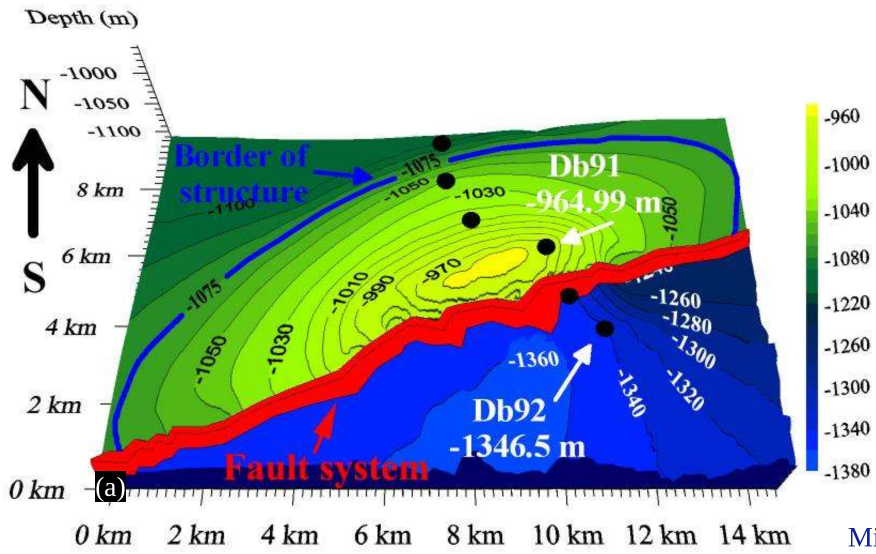
Dobele Structure: 70 km^2

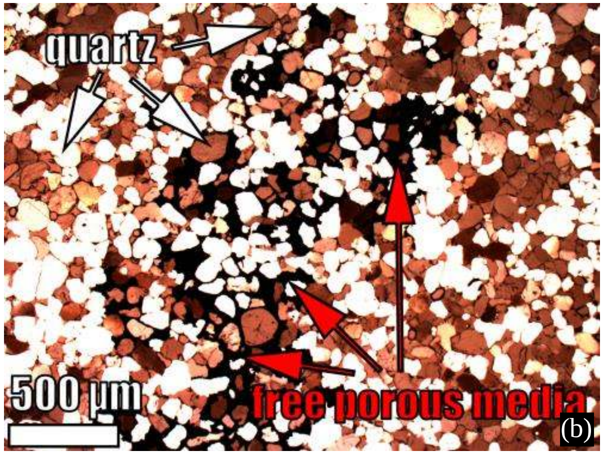
CO_2 Storage Capacity:

Optimistic 106 Mt

Conservative 20 Mt

(EU Geocapacity Project 56 Mt)





Microphotograph in polarized light of the Deimena sandstone from the well Db92 (1347.5 m). The fine-grained sandstone had 91% of SiO_2, 1,5% of CaO, 3% of Fe_2O_3, 1% of Al_2O_3 content and had good intergranual 20% open porosity

Shogenov, K., Shogenova, A., Vizika-Kavvadias O. 2013. Petrophysical properties and capacity of prospective for CO2 geological storage Baltic offshore and onshore structures. Energy Procedia, in press, 1-11

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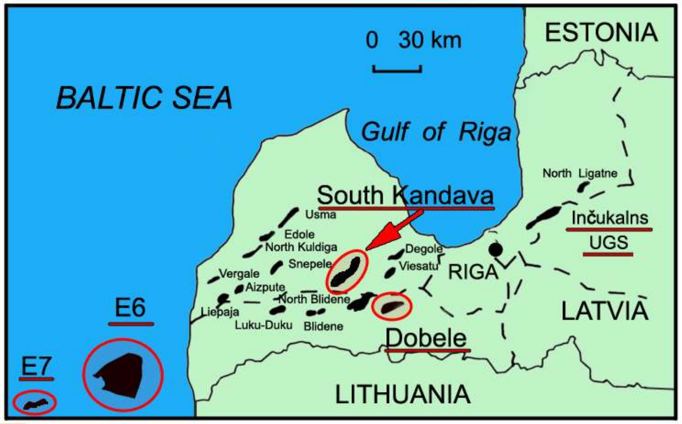
Onshore Structures in Latvia ongoing research and modelling



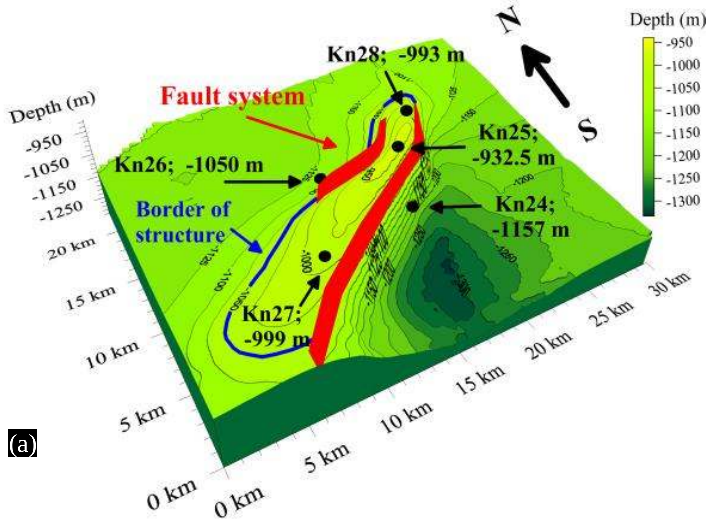
South Kandava Structure: 97 km^2

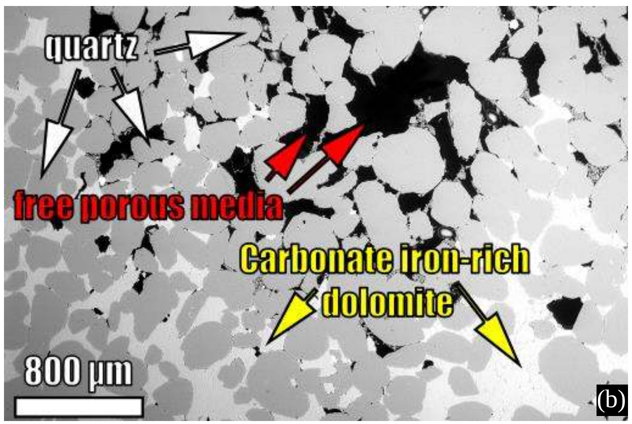
CO_2 Storage Capacity:

Optimistic 95 Mt

Conservative 25 Mt

(EU Geocapacity Project 44 Mt)





Shogenov, K., Shogenova, A., Vizika-Kavvadias O. 2013. Petrophysical properties and capacity of prospective for CO2 geological storage Baltic offshore and onshore structures. Energy Procedia, in press, 1-11

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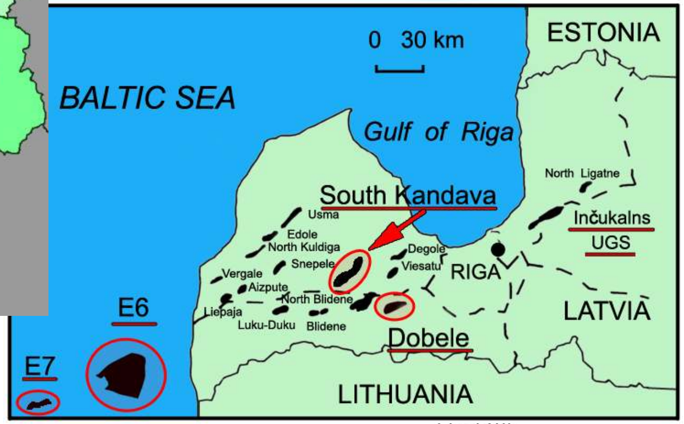
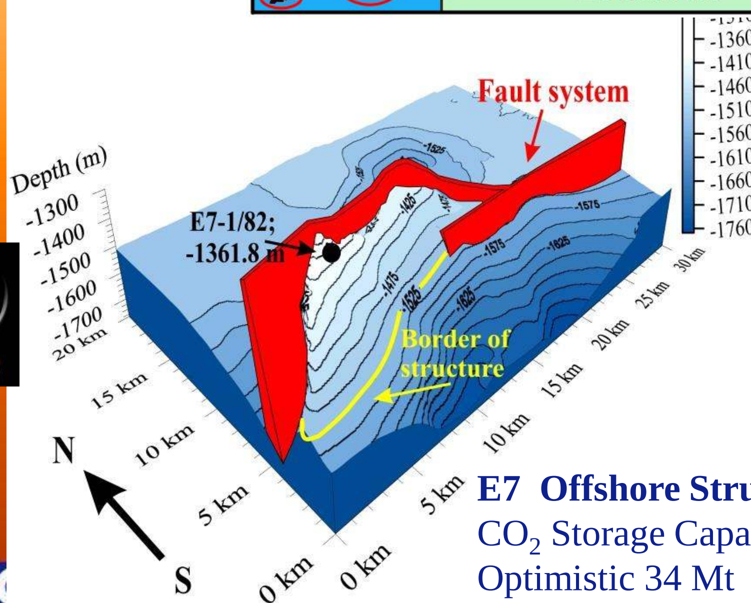
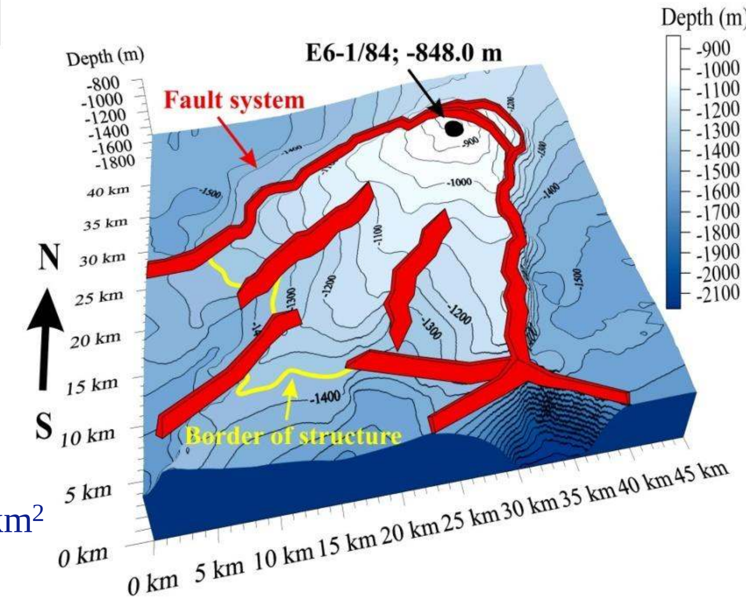
(b) SEM microphotograph of the Deimena quartz sandstone from the well Kn24 (1157.3 m). Quartz grains were almost completely cemented by carbonate iron-rich dolomite cement. It had low porosity (7%), close to 0 mD permeability and 81% of SiO_2, 6% of CaO, 2% of MgO and 2% of Fe_2O_3 content. XRD analyzes showed ankerite as minor element in the sample

Offshore Storage Capacity in Latvia (ongoing research) and modelling



E6 Offshore Structure: 600 km^2
CO_2 Storage Capacity
Optimistic 400 Mt
Conservative 160 Mt

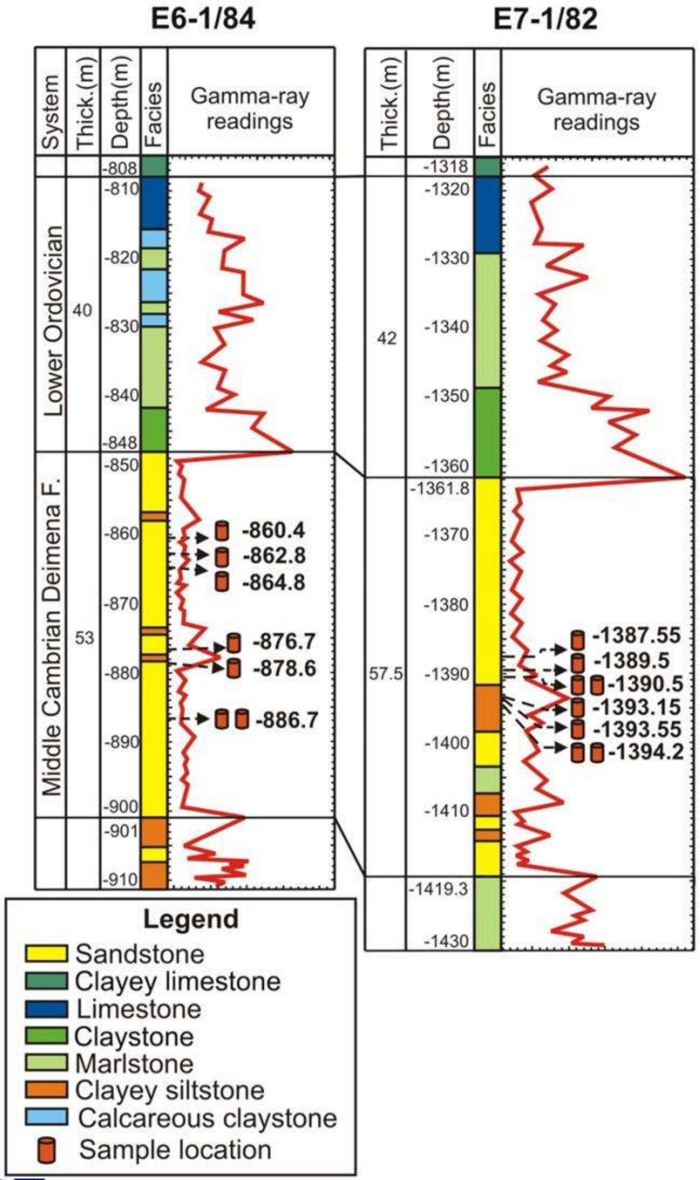


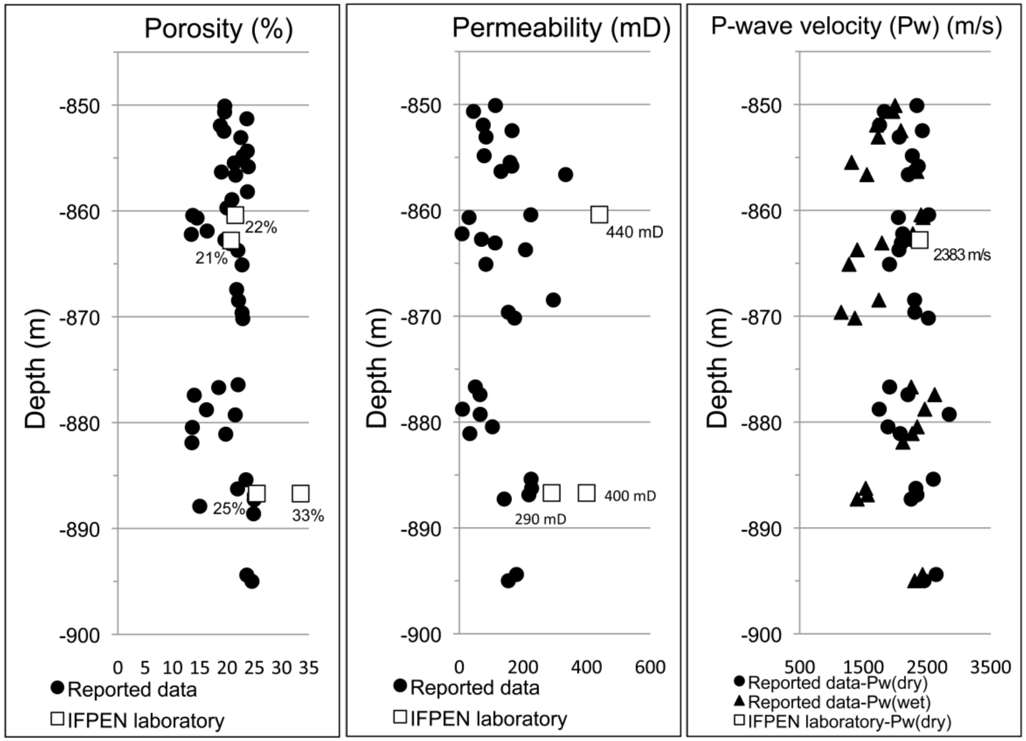


E7 Offshore Structure: 43 km^2
CO_2 Storage Capacity
Optimistic 34 Mt
Conservative 7 Mt

Shogenov, K., Shogenova, A., Vizika-Kavvadias O. 2013. Petrophysical properties and capacity of prospective for CO2 geological storage Baltic offshore and onshore structures. Energy Procedia, in press, 1-11

Detailed study of two offshore Latvian structures





Shogenov, K., Shogenova, A., Vizika-Kavvadias O. Properties and capacity of prospective structures for CO2 geological storage in the Baltic Sea: case study offshore Latvia. Submitted to Bulletin of The Geological Society of Finland.

Reservoir parameters in 4 studied structures

- Depth of the top: 850-1360 m
- Thickness 42-58 m
- Trap area 43-600 km2
- Salinity: 99-125 g/l
- Temperature 18-46 °C
- CO_2 density 660-900 kg/m3
- Sef optimistic: 10-20%, conservative: 4%
- Storage capacity: 34-396 Mt (optimistic), 7-160 Mt (conservative)

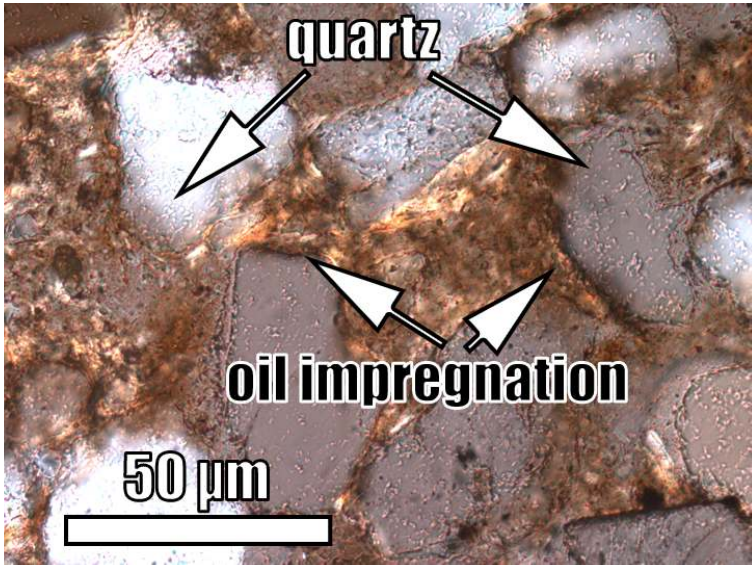
Summary

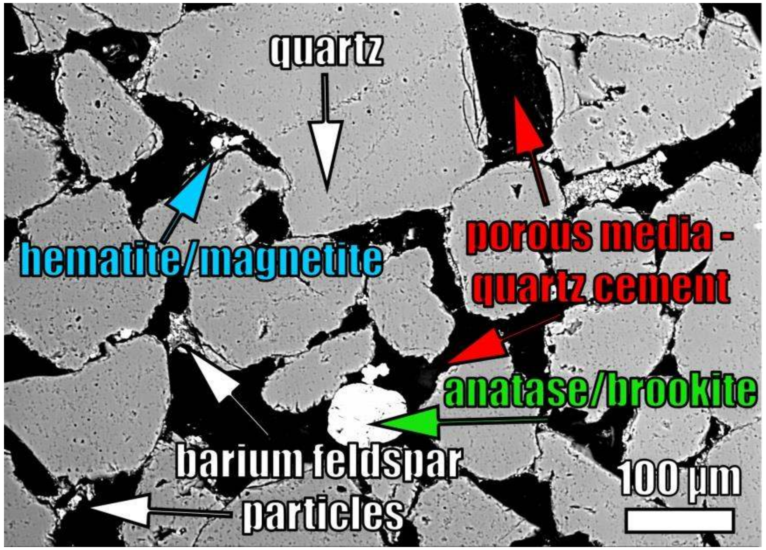
- The study was focused on the investigation of four prospective structures for geological storage of CO_2 in the Baltic region, specifically in the **onshore** structures **South Kandava and Dobele**, and **offshore structures (E6 and E7)** in Latvia.
- Using detailed petrophysical, mineralogical and geochemical analyses of the **Middle Cambrian Deimena Formation sandstones** in these structures, their CO_2 storage capacity was estimated with different levels of reliability (using min-max porosity and different storage efficiency factors).
- Different storage efficiency factors and minimum to maximum porosities of the reservoir rocks were applied for conservative and optimistic estimates.
- **Offshore structure E6 was estimated as the most prospective for CO_2** geological storage in the Baltic Region. Its optimistic CO_2 storage capacity was 265-630 Mt, and its average conservative capacity (**160 Mt**) is the largest among all the studied until now in Latvia onshore and offshore structures.
- Total capacity of four studied structures estimated using an optimistic approach was on average **630 Mt** and using a conservative approach **210 Mt**.
- Earlier capacity estimates made during the EU Geocapacity project of the Dobele and South Kandava onshore structures are in the range of our optimistic capacities.

Detailed study and modelling of the prospective structures in the Baltic Sea, offshore Latvia (E6)

TALLINN UNIVERSITY OF TECHNOLOGY
INSTITUTE OF GEOLOGY

Example of thin-sections study from E6 offshore structure



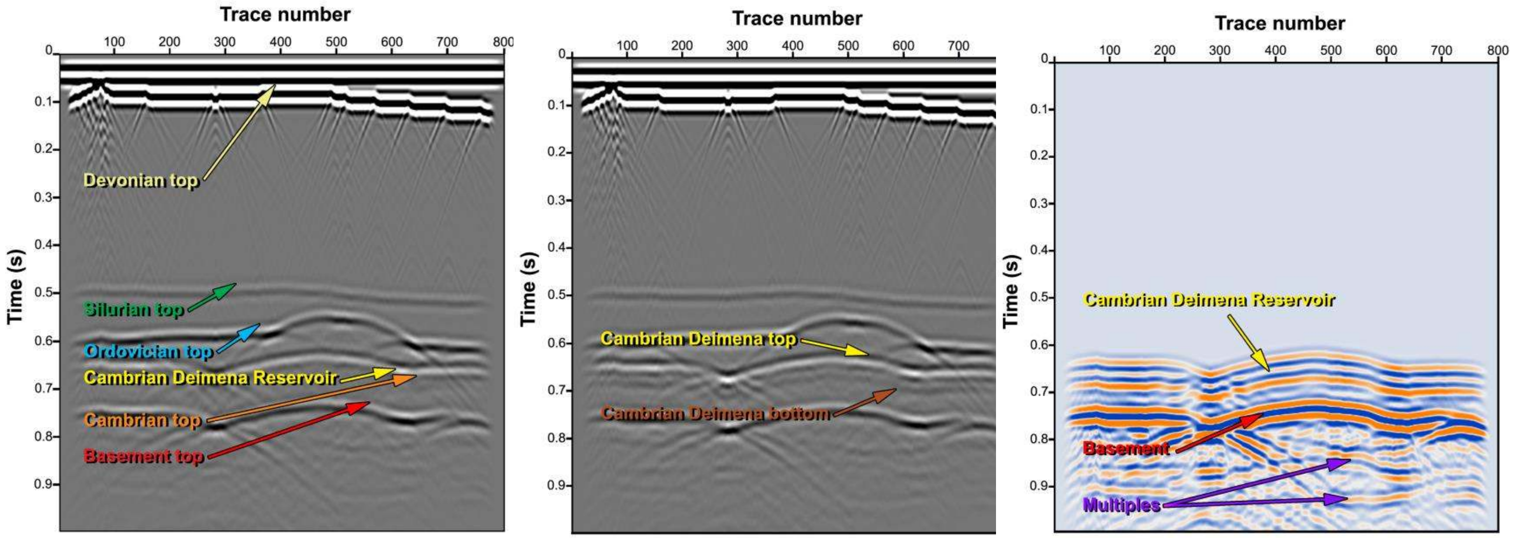


Microphotograph of thin section in cross-polarized light (a) and SEM microphotograph (b) of the Deimena sandstones from the well E6-1/84

- (a) Fine-grained quartz, carbonate and clayey cements presented in porous media were partially oil impregnated (876.7 m);
- (b) Minor amount of feldspar (sometimes barium feldspar) was found in all samples from the E6-1/84 borehole (886.7 m). Due to weak cementation this sample was broken into two parts, which had 26 and 33.5% of porosity, and 290 and 400 mD of permeability

Shogenov, K., Shogenova, A., Vizika-Kavvadias O. 2013. Petrophysical properties and capacity of prospective for CO2 geological storage Baltic offshore and onshore structures. Energy Procedia, in press, 1-11.

Seimic numerical modelling of CO2 storage in E6 offshore structure (to predict monitoring results and fate of CO2 flow)



- *Examples of synthetic plane-wave **(a and b)** and difference sections **(c)**. Plane-wave sections present 0% **(a)** and 5% **(b)** of CO_2 saturation. The seismograms are random noise-free. Approximate locations of the top of all geological formations **(a)** and the top and bottom of the Cambrian Deimena Sandstone Reservoir, saturated with CO_2 **(b)** are indicated. On the **(c)** introduced difference section of synthetic baseline (0% of CO_2) and the synthetic seismic line with 5 % of CO_2 in the saturating fluid*

Shogenov K, Gei D., OGS-Italy. 2013. Seismic numerical modelling to monitor CO2 storage in the Baltic Sea offshore structure, 2013, EAGE, London.

3D Geological, Lithological and Petrophysical Numerical Models of E6 Offshore Oil-Bearing Structure

K. Shogenov and E. Forlin/ OGS, Italy

- Main goal is coupled modelling of CO_2 plume migration within the geological storage site, estimation of geochemical, mineralogical and petrophysical changes in the host rocks and transitional cap rock-reservoir zone.
- One of the important objectives is integration of the fluid flow modelling and alteration experiment results into the 4D time-laps rock physics and seismic numerical model. The last one provides seismic monitoring tools of the CO_2 plume (Picotti et al., 2012).
- For 3D static structural reservoir modelling geological and reservoir engineering software JewelSuiteTM (JOA Oil & Gas B.V.) was applied.
- 2 scale models were made with 500x500 m and 30x30 m gridding
- The next step to be done: flow fluid modelling using COORES software.

Prospects for future regional cooperation

- We hope for including more countries in the Baltic transboundary scenarios
- Emission cluster would include the largest industrial Power Stations from Estonia, Finland, etc
- Storage cluster could include offshore structures in the Baltic Sea (Latvia, Lithuania, Sweden, Poland, etc) and North Sea sites as well
- Cooperation of the all Baltic Sea Region countries including Russia would be needed to create common infrastructure for CCS scenarios
- Political and public support from all Baltic Sea Region countries are needed
- Researches have to be more active in rising of public awareness, education and knowledge dissemination

THANK YOU FOR ATTENTION !