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Options for geological storage of CO_2 in the Baltic Sea region

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Summary

The Baltic Basin is a large (~700 km wide) intracratonic depression filled with sedimentary strata ranging in age from Late Proterozoic to Quaternary. The Baltic Basin is centred in the southern Baltic Sea, which is surrounded by a number of countries, i.e. Denmark, Sweden, Finland, Estonia, Latvia, Lithuania, Russia, Poland, Germany. Sedimentary basins like the Baltic Basin are worldwide considered to constitute major sinks for geological storage of CO_2. Despite quite different storage potential in the countries surrounding the Baltic Basin there is a joint interest as to increase the understanding of the overall storage potential of the basin. Different scenarios are considered such as in- and off–basin transportation and storage of CO_2, enhanced oil recovery (EOR) and mineral immobilization of CO_2. The total practical storage capacity of the Baltic Basin deep aquifers is evaluated to reach 1 Gt of CO_2, while the potential in the oil and gas fields is evaluated as negligible. The storage potential is mainly concentrated in Latvia, therefore the cross-border strategy should be considered. The total storage capacity in the basin is largely unknown. Estimates of storage in closed traps are in the range of several hundred Mt while storage in the regionally extending sandstone aquifers such as the Middle Cambrian sandstone formations could amount to up to a few Gt. These estimates have to be improved by joint research and investigations of the aquifer properties and boundary conditions.

However, the total annual CO_2 emission from large (>100 kt of CO_2) sources in Sweden, Finland, Estonia, Latvia and Lithuania exceed the available storage capacity in the area. Even if the local storage potential is fully utilized there has to be an off-region cross-border scenario to solve the storage needs in the future. Ship or pipeline transportation to other adjacent sedimentary basins, such as the Danish or North Sea basins will be required to accommodate the future storage volumes from the larger emission sources in the Baltic Sea region.

Beside the potential of storing CO_2 in deep saline aquifers and HC-fields there is a potential of mineral carbonation in the Baltic Sea region. This has been estimated to be in the order of several Gt of CO_2 and is related to mineralisation of CO_2 in ultramafic rocks in the Early Precambrian crystalline basement in Finland and Lithuania. Mineralisation in alkaline ashes, which forms a by-product of oil shale utilization for energy production in Estonia are in addition included here.

Introduction

The emission of greenhouse gases in Sweden originates mainly from the transport sector, followed by the energy sector and the agriculture sector. From 1990 till 2009, emissions decreased with 17%. In 1996, there was a peak in CO_2 emissions, caused by burning of fuel, with 7 tons per capita, whereas in 2008 this had decreased to 5,5 tons per capita. The total CO_2 emission from the burning of fuel was in 2008 50 Mt.

Finland's greenhouse gas emissions were in year 2007 78.5 Mt CO_2-ekv, of which carbon dioxide amounted to 66.3 Mt (year 2008). This is 10% more than Finland's Kyoto target, and the emissions are expected to grow further during the next decades. The heat and power production accounted for 42 % of Finland's greenhouse gas emissions. About 40 large sources exceeding 100 kt of CO_2 annual emissions are registered. The emissions per capita are high (12.1 tonnes in 2007).

Nine large sources are located in Estonia. They are concentrated in the north and northeast of the country, producing altogether 14.5 Mt CO_2 (year 2007). The high GHG emission rate in Estonia results basically from the application of oil shale for power production. The largest stationary CO_2 sources produced respectively 9.3 and 2.9 Mt CO_2 in 2010. The emissions per capita is the highest in the region, one of the highest in Europe and at the 15th place in the world rate in 2007 (14.9 tonnes).

In Latvia, the large sources produce about only 2 Mt of CO_2. The main producers are located in the western part of the country. The emissions per capita are low (3.4 tonnes in 2007).

In Lithuania, ten big sources produce about 5.5 Mt/y of CO_2. Those are ammonia plant, two cement plants, oil refinery, the rest are power and heat producers. The emissions per capita are minor (4.6 tonnes in 2007).

Storage potential of deep saline aquifers of Baltic sedimentary basin

Worldwide, deep saline aquifers are considered the most potential candidates for large scale storage of CO_2.The sedimentary succession in the Baltic Basin is characterised by more or less undeformed strata. In hydrogeological terms, it is considered as an artesian basin comprising a number of aquifers of different age and composition, separated by impermeable layers. The capability of an aquifer to transmit and store CO_2 is controlled by the depositional environment, structure, and P-T conditions. Critical factors are:

- the regional hydrogeological conditions
- the thickness, lateral extent and continuity of the aquifer;
- the reservoir properties (porosity, permeability, mineralogy heterogeneity etc)
- seal properties (mineralogy, induration, fractures, capillary entry pressure etc) Faults, stress field
- P = 73.8 bars, T = 31^{o}C are considered as the lower limit of supercritical conditions to store CO_2 in an aquifer.
- Boundary conditions, leakage points, open or closed aquifer

Based on analysis of those parameters, only the Cambrian sandstone aquifer is assessed as a potential aquifer for CO_2 storage in the Baltic Basin. The other large sandy aquifers (*e.g.* Lower Devonian, Middle-Upper Devonian) are considered as non-prospective for near-future utilisation for CO_2 storage due to absence of structural traps. Their storage potential might be reconsidered in a future after the CO_2 geological storage becomes a mature technology and non-structural trapping concept is proved in other regions.

The Cambrian sandstone aquifer represents the basal part of the Baltic sedimentary succession. The depth varies from outcrops in Estonia to more than 2 km in west Lithuania and >3 km in the Polish part of the basin. The aquifer is composed of fine-grained quartz arenite with interbeds of siltstone and shale. The thickness of the aquifer is in the range of 10–80 m (average 40–60 m). The Cambrian sandstones are sealed by a 200–1150m thick Ordovician–Silurian shales and limestones which are considered as a reliable sealing of the reservoir. The tight seal is also verified by the HC traps found in the upper sandstone layers. The porosity of sandstones within the P-T prospective area is in the range of 6–22% (averaged values for different structures). The permeability varies from 10 to 1000 mD (averaged values). The sandstone becomes more indurate below c.1200 m depth due to an increasing amount of silica cement filling the pores. The most porous and permeable and homogeneous sandstone beds are found in the upper most part of the sequence, corresponding to the Faludden and Deimena formations (Erlström et al., 2011). Favourable temperature (>31^{o}C) and pressure (>7.8 MPa) conditions for storage of supercritical CO_2 occur in the central and western parts of Lithuania and Latvia, north Poland, and offshore Sweden, Latvia, Lithuania, Russia, Poland, Denmark and Germany. Estonia is located in the shallow margin of the basin where the P–T parameters are unfavourable.

Only two large structures have been identified in Lithuania. The total storage capacity is estimated to amount to only about 30 Mt of CO_2 (Sliaupa et al., 2008). Furthermore, the largest structure has a priority for development of UGS (underground gas storage). A somewhat larger storage capacity of c. 100 Mt CO_2 is plausible in a higher-risk geological scenario in the western parts of Lithuania.

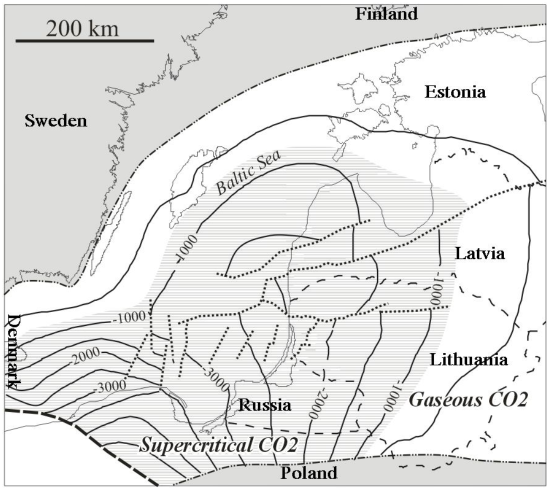

Fig. 1 *Depths of Cambrian aquifer. Shaded area shows where P-T conditions suitable for CO_2 geological storage, i.e. c. >800 m depth.*

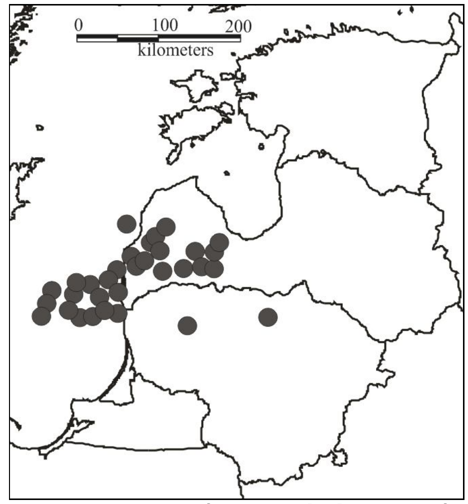

Fig.2 *Location of potential deep aquifer structures for CO_2 geological storage in the eastern Baltic region.*

Sixteen large onshore Cambrian structures, with estimated storage capacity exceeding 2-74 Mt CO_2, have been identified in west Latvia (Fig.2). The total capacity of onshore large structures is estimated as high as 404 Mt of CO_2, with the potential of the largest uplifts reach 40-74 Mt of CO_2. (Sliaupa et al, 2008, Shogenova et al, 2009b).

Offshore, the main potential is also related to Latvian economic zone. 15 large structural traps were defined based on drilling and seismic data. The total potential is of order of 300-400 Mt of CO_2. The storage potential in the Swedish offshore sector of the Baltic Basin is uncertain. Localized closed structures and traps area largely missing. Therefore, the future potential of storage in this area lies within the prospect of storing in regionally extending aquifers. If this is proven to be possible there is a potential which may amount to several hundred Mt to a few Gt of CO_2,

Safe and controlled storing of CO_2 in regional aquifers, such as the Cambrian aquifer in the Baltic Basin, are more and more considered to be realistic alternatives which puts the storing capacity of the Baltic Basin in to a new perspective. (Erlström, Sivhed, 2012).

CO_2 storage potential related to EHR and depleted oil fields

There are a number of oil fields discovered in Cambrian, Ordovician, and Silurian reservoirs in Lithuania, Kaliningrad district, Sweden, and Poland, both onshore and offshore. Several gas fields are in operation in the Polish offshore sector. The extractable volumes range from 17 kt to 9.1 Mt of oil. So far, there are no abandoned HC fields in the region. Most of fields are in the tail stage, therefore EOR option utilising CO_2 injection is considered as a prospective option in the near future. EOR prospects are related to oil fields in the Cambrian sandstone reservoir. The CO_2 net (gross) volumes of Lithuania are evaluated 4.3 (9) Mt, Kaliningrad onshore 29.1 (58) Mt and offshore 7.7 (15) Mt, Polish offshore 7.4 (15) and 16 Mt in gas fields. These are relatively small amounts, which makes this option of minor importance in the overall storage scenario, except for some EOR economic benefits.

CO2 mineral trapping

Mineral trapping can be considered as an industrial process, which does not necessarily include geological storage. The ultramafic rocks are considered as most prospective media for mineral carbonation and immobilization of CO_2 (Oelkers et al., 2008) A number of serpentinite bodies were discovered in the crystalline basement in Finland and Lithuania. Serpentinties are exposed on the surface in Finland, while covered by rather thin (300–400 m) cover of sediments in Lithuania.

Moreover, they often associate with some valuable mineral resources, *e.g.* iron ore. The estimated capacity of east Finland, according to Finish studies, is of order of 2 to 3 Gt CO_2. In Lithuania it is as high as 0.5–1 Gt CO_2. Despite of the large capacity and associating benefits, the mineral trapping is considered to be at the research, developing and early pilot stages and needs feasibility studies to reduce the energy consumption and improve the economic parameters. In Sweden there occur several rock bodies composed of ultramafic rocks but many of these are also considered valuable mineral and ore deposits, which disqualifies them as suitable for CO_2 storage.

An alternative approach is under development in Estonia. The energy generation is based on oil shales in the country. The alkaline ashes are produced as a by-product in the technological chain. This material is reactive to CO_2 and can be employed for CO_2 immobilisation (Shogenova et al., 2009a). It can bind 10-12% of CO_2 emissions using fresh oil-shale ash and waste water produced by the two largest Estonian power plants emitting more than 12 Mt CO_2 per year. Up to 90% of CO_2 is possible to avoid using near deposited old alkaline ash as sorbent. The availability of the raw material is more than sufficient, as in addition to the annual production of waste ash (6Mt), the waste heaps contain more than 250 Mt of hydrated ash. An additional advantage of this approach is the neutralisation of the alkalinity of ash offering a possibility for environmentally sound land-filling of waste residue.

Cross-border scenarios

The joint interest of finding solutions for geological storage of CO_2 in the Baltic Sea region requires establishment of collaboration research and industrial projects where different alternatives are evaluated. One of these is the assessment of the total regional storage capacity in the deep saline aquifers in the Baltic Basin, thus the Cambrian Sandstone and if it is possible to implement storage not only in closed structures. Another important issue is to create a common evaluation of other alternatives, including storage options such as the Danish and North Sea basins.

Acknowledgments

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