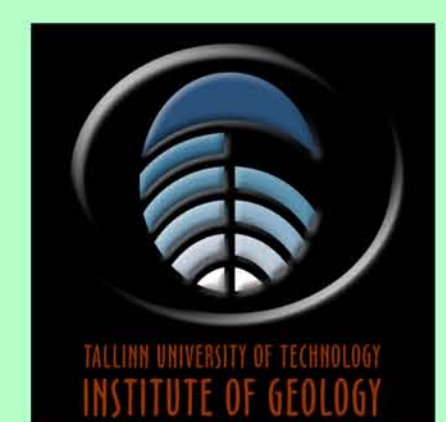


ECONOMIC MODELLING OF THE CAPTURE–TRANSPORT–SINK SCENARIO OF INDUSTRIAL CO₂ EMISSIONS:

THE ESTONIAN–LATVIAN CROSS-BORDER CASE STUDY

Alla Shogenova^a, Kazbulat Shogenov^a, Raisa Pomeranceva^b, Inara Nulle^b, Filip Neele^c and Chris Hendriks^d^aInstitute of Geology, Tallinn University of Technology, Ehitajate tee 5, 19086 Tallinn, Estonia
Tel.: +372-620-3024; fax: +372-620-3011. E-mail address: alla@gi.ee.^bLatvian Environment, Geology & Meteorology Centre, Maskavas iela 165, Riga 1019, Latvia^cTNO Built Environment and Geosciences, P.O. Box 80015, 3508 TA Utrecht, The Netherlands^dEcofys International Bv, P.O. Box 8408, 3503 RK Utrecht, The Netherlands

http://nts1.cgu.cz/geocapacity



http://www.gi.ee



http://co2neteast.energnet.com/

INTRODUCTION

Estonian–Latvian case study is the only one cross-border economic modelling of CO₂ capture–transport–sink scenario in the EU GeoCapacity project [1, 2]. This study was triggered by zero CO₂ storage capacity in Estonia and favourable for CO₂ storage geological conditions in Latvia [3, 4]. The possibility of such a scenario is proved by about 40–years–Estonia with natural gas when necessary. Estonia does not have CO₂ storage options on its own territory because of location in the shallow part of the Baltic sedimentary basin including valuable potable water. Among neighbours of Estonia only Latvia, EU GeoCapacity project country, as a possible partner could be considered for the CO₂ onshore storage with transport by pipelines.

Estonia is the largest CO₂ emitter in the Baltic Region. Nine large (emitting more than 0.1 million tonnes (Mt) of CO₂) industrial sources of CO₂, registered in 2005 in the EU Emission Trading Scheme, produced 11.5 Mt of CO₂ [3, 4]. In 2009 Estonia had already 13 large sources with the total CO₂ production of 22.7 Mt. The two largest Estonian power plants, Eesti and Balti produced respectively 7.7 and 2.25 Mt of CO₂ in 2005. Large emissions are explained by the use of local Estonian oil shale for energy supply. CO₂ emissions produced during combustion of oil shale are higher than those from other fossil fuels. The owner of the power plants, the national company Eesti Energia also exports energy to the Baltic region and Finland. Energy production grew notably in 2009 due to the closure of the Ignalina Nuclear Power Plant in Lithuania in 2009 and significant increase in the Estonian electricity export to Latvia and Lithuania. For these reasons Estonian CO₂ emissions per capita are among the highest in Europe and in the world. The power company Eesti Energia is searching for CO₂ storage options in the neighbouring regions. The construction of the new power plant units at the premises of the largest Eesti Power Plant is to be ready in 2016. According to EU directives, the new units have to be “capture ready”. This has forced Eesti Energia Company to find technological and geological solutions to the CCS (CO₂ capture and storage) problem. According to the EU CCS directive [5], the Ministry of Environment of Estonia has to create Estonian regulations for CO₂ storage in the nearest time.

CO₂ Sources and Capture System

The two largest producers of energy and CO₂ emissions in Estonia and in the Baltic region, Eesti and Balti Power Plants, were selected for this scenario (Fig. 1). The Eesti Energia Narva Power Plants Company (including Eesti and Balti Power Plants) is the largest producer of electrical energy in Estonia and one of the most important power producers in the Baltic Region. The company supplies electrical energy to Estonian consumers and heat to the city of Narva, and exports electricity to the Baltic States and also to the Nordic power market through the Estlink undersea cable. An average of 9–13 Mt of oil shale is delivered from two underground mines and one open pit to the Narva Power Plants by rail each year. A power plant produces electricity in energy production units. Each energy production unit consists of two boilers, a turbine and 7 km of pipes.

The Eesti Power Plant is the largest energy enterprise in Estonia and in the Baltic Region. It has eight energy production units with a total electric capacity of 1610 MW. The Balti Power Plant has four energy production units with a total electric capacity of 765 MW and a gas-fuelled reserve and peak load boiler unit with three boilers with an installed heat capacity of 400 MW. Each power plant has one new energy production unit that uses the circulating fluidised bed technology, while the rest of the units are older and burn pulverised oil shale.

The Eesti and Balti Power Plants are the largest CO₂ emitters in Estonia and in the Baltic Region. In 2005 they produced, respectively, 7.7 and 2.25 Mt of CO₂, but these amounts increased up to 9.4 and 2.7 Mt of CO₂ in 2007 and up to 15.3 and 3.2 Mt of CO₂ in 2009. Large emissions are explained by composition of the oil shale commercial seams, which are interlayers in the Estonian Ordovician carbonate rocks. CO₂ emissions produced during combustion of oil shale are higher than those from other fossil fuels. The CO₂ content in the flue gas produced during combustion of Estonian oil shale can reach 15–25%. The CO₂ emissions produced by the Eesti and Balti Power Plants are higher than emissions of all large industrial sources in Latvia and Lithuania taken together [3, 4]. The oxyfuel technology was applied in the modelled CCS scenario. This involves the combustion of the fuel with pure oxygen, resulting in a gas flow with a high concentration of CO₂.



Table 3. Large industrial emissions in Estonia in 2005–2009

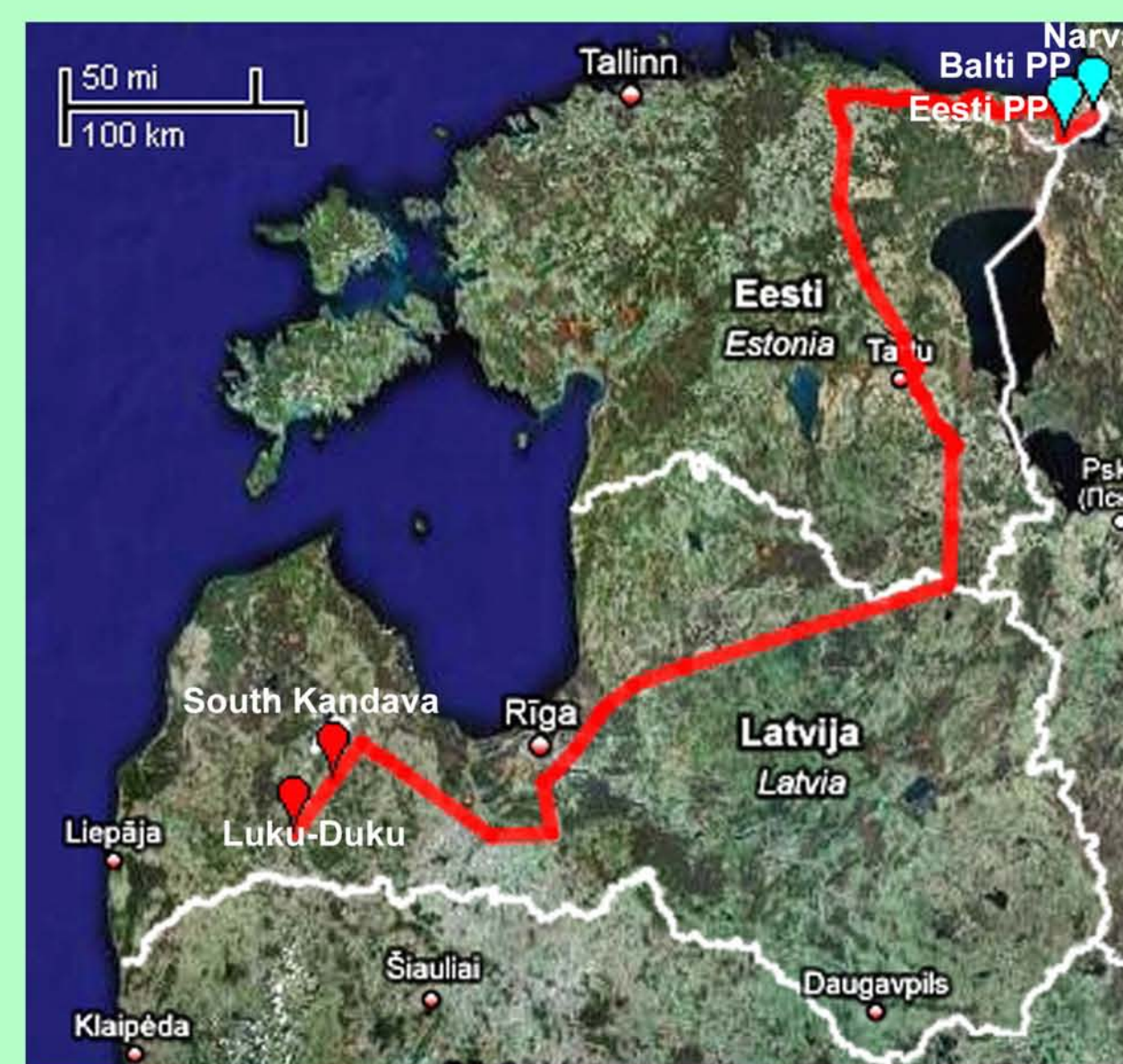
Year	Large CO ₂ sources (>100000 tonnes) registered in ETS		Eesti Power Plant (EPP)	Balti Power Plant (BPP)	Share of EPP and BPP in large CO ₂ emissions
	Number of sources	Million tonnes	Million tonnes	Million tonnes	%
2005	9	11.5	7.7	2.25	86.5
2007	9	14.5	9.4	2.7	83.4
2009	13	22.7	15.3	3.2	81.5

RESULTS

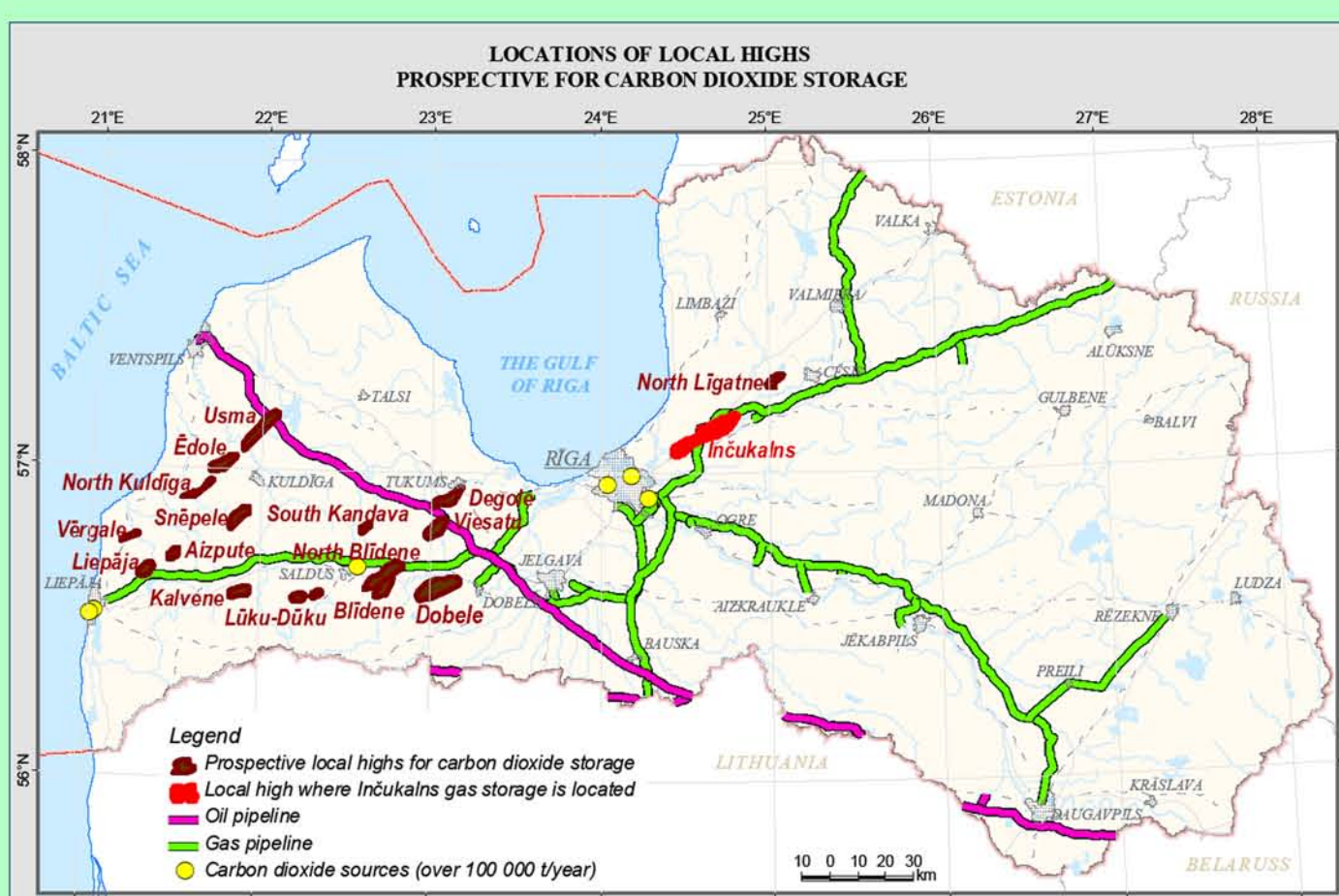
The summary of the input parameters of the Estonian–Latvian scenario is given in Table 1. The output economic parameters of the calculated by the DSS scenario are given in Table 2. Preparatory works for this scenario could be started in 2012–2013 together with the construction of new power plant units. Estonian and Latvian CCS regulations could be ready by that time. Development/construction period of the site in Latvia could take up to three years, including geophysical exploration and drilling of boreholes at two sites. Taking into account the well injection rate of about 1.5 Mt/yr and total injected emissions of about 10.5 Mt/yr, at least seven boreholes with a minimum depth of 1070 m should be drilled. The total estimated cost of storage works including maintenance costs (€0.2 million per year per site) is €250 million. The possibility of reconstructing the conserved boreholes can reduce drilling costs. The estimated pipeline length required for CO₂ transportation is about 800 km. The storage sites could be ready to 2016 year, when new blocks will be built. With a conservative storage capacity for 8 years of emissions in two storage sites the total cost of the project is €2.8 billion for 30 years of pay out time. The most expensive in the scenario are capture (€1.9 billion) and transport costs (€0.45 billion). Capture cost makes 68% and transport cost is 16% of the total cost of the scenario. The total cost for one tonne of CO₂ avoided (75.8 Mt) is €37.4, including €25.5 for capture, €3 for compression, and €5.3 for transport and €3 for storage of one tonne of CO₂ injected (84.2 Mt).

Table 2 Economic parameters of the Estonian–Latvian case study (NPV is a net present value, SRC NPV is a net present value for capture costs).

NPV	2835	€ million	NPV storage normalised	3.0	€/tCO ₂ injected
NPV capture	1928	€ million	Unit technical cost	37.4	€/tCO ₂ avoided
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 ₂ avoided	SRC NPV capture 1	825	€ million
NPV capture normalised	25.5	€/tCO ₂ avoided	SRC NPV compression 1	48	€ million
NPV compression normalised	2.8	€/tCO ₂ avoided	SINK NPV storage 0	129	€ million
NPV transport normalised	5.3	€/tCO ₂ injected	SINK NPV storage 1	121	€ million

Figure 1 Estonian–Latvian case study. Eesti and Balti Power Plants are shown by green–blue symbols, storage sites by red symbols. The proposed CO₂ pipelines (along with natural gas pipelines) are shown by a red line.

Storage Sites

Figure 2 Major Cambrian aquifer structures (CO₂ storage potential exceeding 2 Mt) of Latvia and Inčukalns underground gas storage [8, 9].

Two geological structures of Latvia have been proposed for CO₂ storage – Luku-Duku and South Kandava. These structures were determined by seismic investigations and studied by four (Luku-Duku) and five (South Kandava) boreholes. However these are not among the most prospective structures studied in Latvia, and they are not the closest to Estonia. Three most prospective in Latvia structures (best studied, with the largest capacity) have already been planned for natural gas storage and for storage of Latvian CO₂ emissions.

The Luku-Duku structure (Fig. 3) is situated within the tectonically dislocated zone of the Salduze–Sloka–Inčukalns high. The Luku-Duku local high is a near-fault brachyanticlinal fold about 50 km² in area. The thickness of reservoir rocks is 45 m, their top lies at a depth of 1024 m. Reservoir rocks are represented by sandstones of the Middle Cambrian Deimena Formation (Cm₁dm), underlain by sandstones with inter-layers of siltstones and claystones of the Lower Cambrian Ventana and Lower-Middle Cambrian Tetre Formations (Cm₁vn–Cm₁zb). Middle Cambrian reservoir sandstones are covered by argillaceous rocks of the Lower Ordovician Tremadocian Zebre Formation (O₂zb). The Zebre Formation consists of the Lutini (O₂zb₁), Kumbri (O₂zb₂), Zirni (O₂zb₃), Kalvene (O₂zb₄) and Zante members (O₂zb₅). The Ordovician, Silurian and Devonian carbonate and siliclastic rocks represented with total thickness of about 1 km overlie the cap rocks of the Zebre Formation. Reservoir sandstones of the Middle Cambrian Deimena Formation in the Luku-Duku structure have an average porosity of 22%, permeability more than 200–300 mD, reservoir water temperature 19° C and reservoir water salinity 103–105 g/l.

LUKU-DUKU

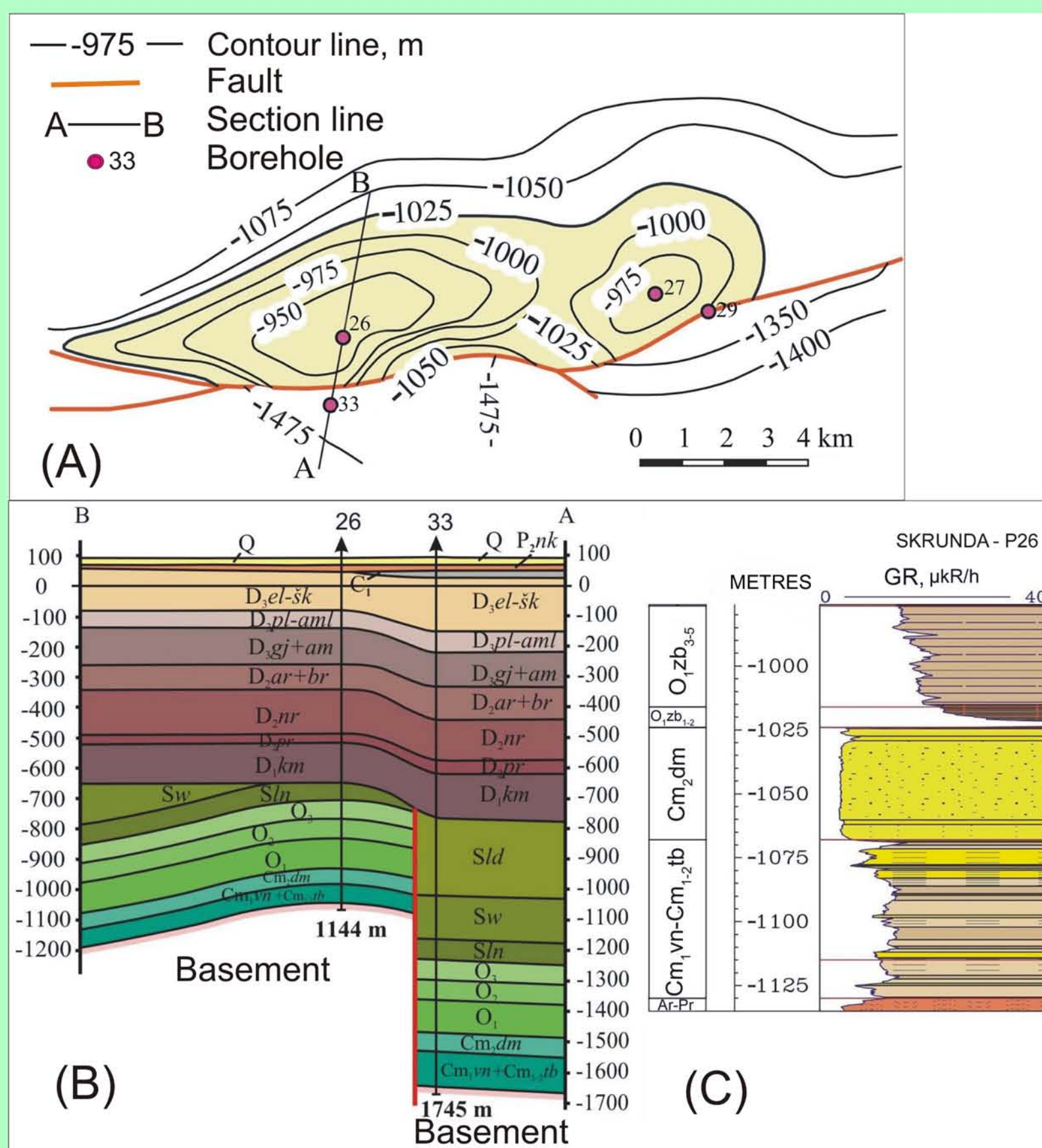


Figure 3 (A) Structural map of the top of the Cambrian reservoir sandstones in the Luku-Duku structural trap. (B) Geological section along the line A–B. (C) Geological section of the Cambrian reservoir and Ordovician cap rocks in the Skruna-P26 borehole (26 in parts A, B).

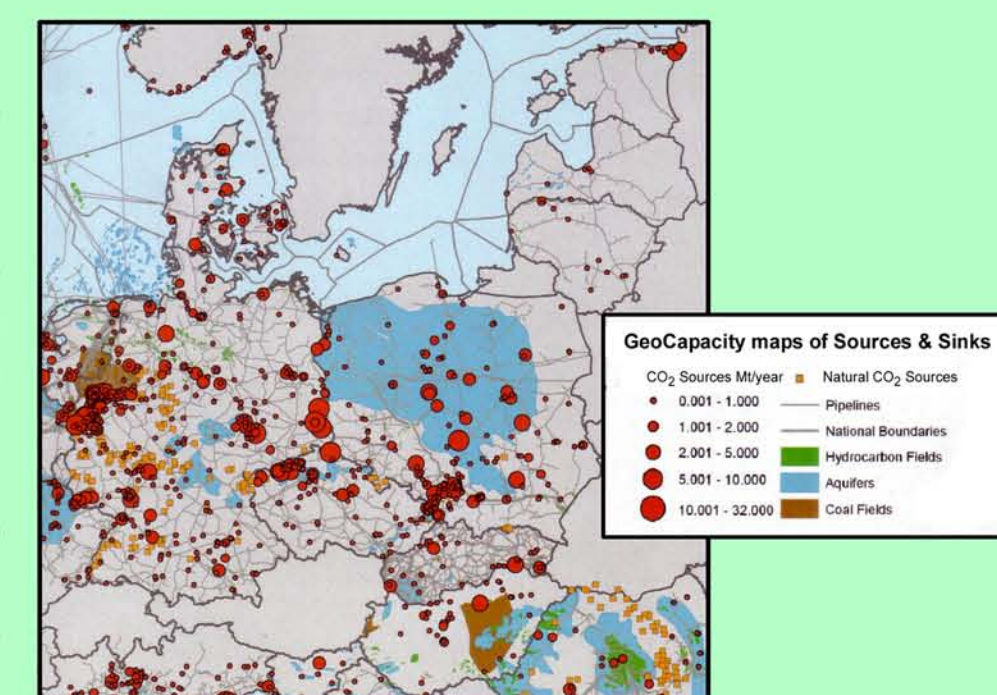
Table 1 Summary of the input parameters for storage in the GeoCapacity Model.

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	11
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

The GeoCapacity GIS and DSS

Data for the economic modelling were collected into the Geographic Information System (GIS) in the frame of the EU GeoCapacity project [1, 2, 6]. The GIS database includes locations of large CO₂ sources, potential aquifer storage sites and injection points, hydrocarbon fields and injection points, coal fields and potential injection points, the existing pipelines and pipeline terminals and natural sources of CO₂. All data were mapped by the project partners from 26 countries and integrated into the GIS in the same format to ensure data consistency. The objective of the GeoCapacity GIS was data visualization and access and input for the economic Decision Support System (DSS).

The DSS was developed in the EU GeoCapacity project to evaluate the technical and economic feasibility of CO₂ storage in the subsurface [2, 7]. The economic tool developed in the EU GESTCO project was updated and improved to extend its functionality. The new economic tool can be used to define CO₂ capture, transport and storage systems, consisting of a selection of CO₂ sources and sinks and the connecting pipeline network. The DSS uses the database of CO₂ emission points and storage locations in Europe (GeoCapacity GIS) [4, 5]. The system is a combination of an internet application, which visualises the data and allows the user to select sources and sinks and create a pipeline network, and an application to be run on a local computer, which performs a stochastic analysis of the costs of a CO₂ capture, transport and storage system.



Storage Sites

Only local structures in the Cambrian reservoir sandstone are prospective for CO₂ storage in the Baltic Region [3]. Faults and folds are widespread within the Caledonian complex in western and central Latvia. The depth of the Cambrian reservoir varies from 700 m in central Latvia to 1700 m in SW Latvia. All anticline structures prospective for CO₂ storage are situated in these regions (Fig. 2). Sandstone of the Cambrian aquifer prospective for CO₂ storage, the thickest reservoir in the Cambrian section in the western and central Latvia, belongs to the Deimena Regional Stage. (Deimena Formation and Cirma strata). The section is represented by sandstone, siltstone and claystone with sandstone, comprising up to 75–90%. Siltstone and claystone make up 10–30% of the section; their thickness varies from 0.2 to 3–4 m, somewhere reaching 10 m. The sandstone is light grey and white, quartzose, fine-grained. The siliclastic part of the sandstone is well sorted and comprises more than 90% of the deposits. Among clastic material, quartz prevails (95–99%); the rest of the minerals is represented by pelitised potassium feldspar, muscovite and biotite. Cement of the sandstone is clayey and quartzose. In its top part, the cement is frequently kaolinite, secondary carbonate, locally gypsum-bearing. The Cambrian sandstone is loosely or medium cemented characterised by good filtering and volume properties. On most of the Latvian territory, the average effective porosity of sandstone is 20–25%, permeability reaches hundreds and thousands of mD, mineralization of groundwater 85–123 g/l and water temperature is 11–25° C. Thickness of the reservoir sandstones is 20–70 m.

The Inčukalns underground natural gas storage was established in the largest Cambrian structure in 1968. The main criteria used for identification of the prospective structures are: a local high determined by seismic data, the size and depth of the trap, reservoir properties and reliable cap rock. On the basis of these criteria, 16 prospective structures were revealed: Dobele, North Bilde, Bilde, Snepele, South Kandava, Degole, Luku-Duku, Kalvene, Vergale, Edole, North Kuldiga, Viesatu, Aizpute, Usma, Liepāja and North Ligate (Fig. 2).

SOUTH KANDAVA

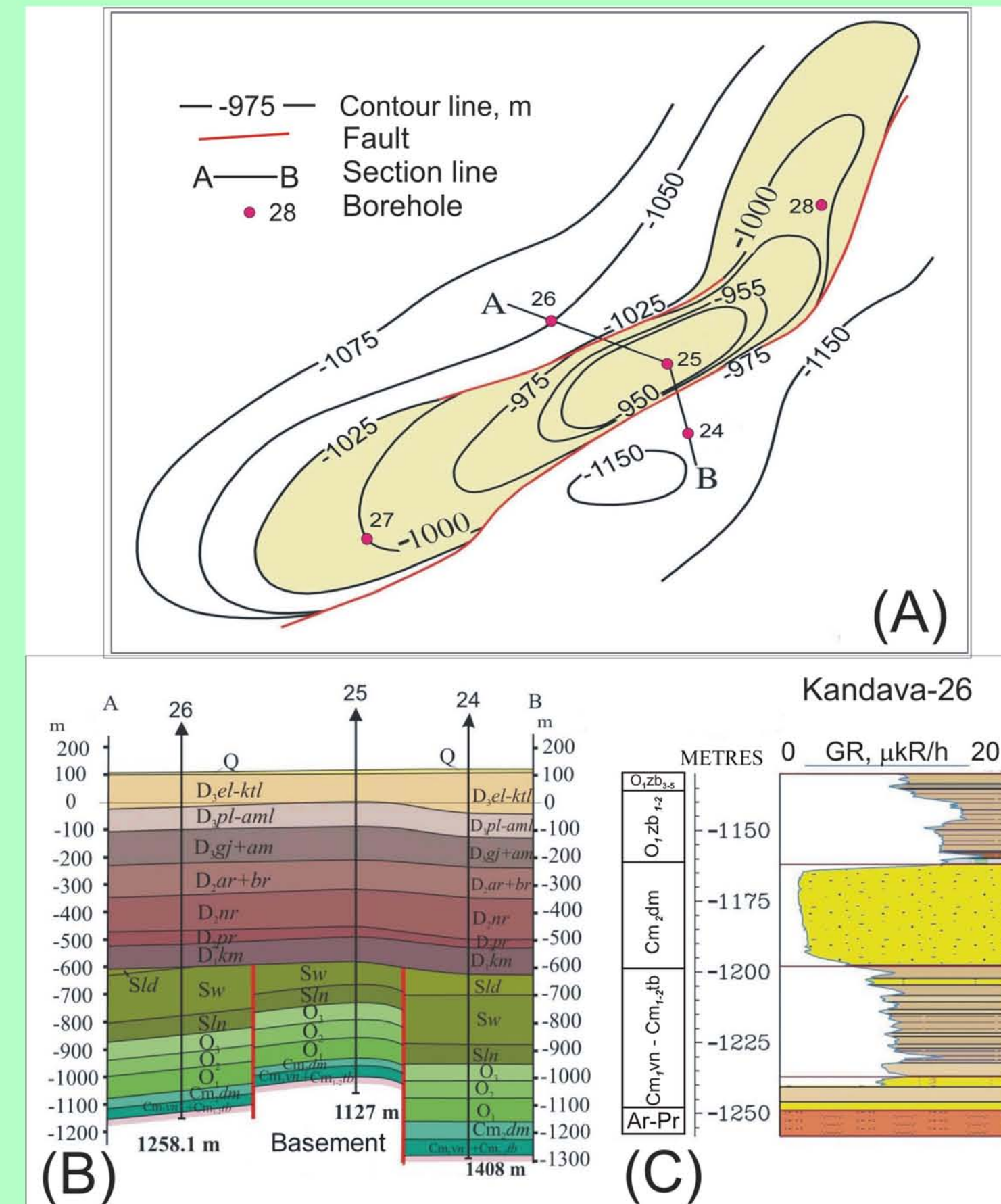


Figure 4 (A) Structural map of the top of the Cambrian reservoir sandstones in the South Kandava structural trap. (B) Geological section along the line A–B. (C) Geological section of the Cambrian reservoir and Ordovician cap rocks in the Kandava-26 borehole (26 in parts A and B).

The South Kandava structure (Fig. 4) is a brachyanticlinal fold stretching from NE to SW located in the centre of Latvia. The south-eastern and north-western flanks of the fold are bounded by faults. Its area is about 69 km², the thickness of the reservoir is 25–36 m. The top of the reservoir rocks is represented by sandstones of the Middle Cambrian Deimena Formation located at a depth of 1053 m. Cambrian Deimena Formation in South Kandava structure has an average porosity of 20%, average permeability 300 mD, reservoir water temperature 11° C and reservoir water salinity 109–115 g/l.

CONCLUSIONS

- Two planned new blocks of power plants with the expected capacity of 400 and 300 MW and annual CO₂ emissions 8 and 2.7 Mt were selected for economic modelling by DSS.
- Two anticline structures of Latvia, Luku-Duku and South Kandava with the area of 50–70 km², the depth of the top of the Cambrian reservoir of 1020–1050 m, the thickness of the Cambrian sandstones of 28–45 m, average porosity 20–22%, permeability of about 300 mD and conservative CO₂ storage capacity of 40 and 44 Mt of CO₂, which will be enough for 8 years, were selected for the scenario.
- Total costs of the project estimated by DSS as 2836 € million for 30 years of payment period.
- The cost of one tonne CO₂ avoided is 37.4 €, of which 68% is oxyfuel capture cost (€25.5).
- The total cost of transport (800 km) is €447 million.
- The transport cost of one tonne CO₂ transported is € 5.3.
- The storage cost for two sites together is €250 million, of one tonne CO₂ injected is €3.

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