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ScienceDirect
Energy Procedia 00 (2008) 000–000
Energy Procedia
www.elsevier.com/locate/XXX

GHGT-9

CO_2 storage capacity of deep aquifers and hydrocarbon fields in Poland – EU GeoCapacity Project results

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Abstract

It was showed results of CO_2 storage capacity estimation in aquifers and hydrocarbon deposits in Poland, which were achieved within realization of 6 FP project EU GeoCapacity. CO_2 storage capacity was calculated in Mesozoic aquifers at regional scale (Lower Cretaceous – 7,647 Mt, Lower Jurassic – 43,826 Mt, Lower Triassic – 26,494 Mt) and for selected 18 geological structures (3,522 Mt). Storage capacity calculated for Polish hydrocarbon fields, using an assumption of 1:1 volumetric replacement of hydrocarbons with supercritical CO_2, is 764.32 Mt and storage capacities of particular fields are diverse.

Keywords: CO_2, aquifer, storage capacity, tectonic structure, Poland, depleted hydrocarbon fields, CO2-EOR

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Introduction

The EU GeoCapacity Project (run within frames of the EU 6th FP in 2006 – 2008) aims to spot and list main CO_2 emission sources in European countries, especially in 13 countries not covered already within the frames of previous EU R&D projects (Bulgaria, Croatia, Czech Republic, Estonia, Hungary, Italy, Latvia, Lithuania, Poland, Romania, Slovakia, Slovenia, Spain) together with as well as to estimate regional and local CO_2 storage potential of the mentioned countries, the Project participants.

Within frames of the EU GeoCapacity Project authors estimated CO_2 storage volume within aquifers in Poland of regional magnitude (Lower Cretaceous, Lower Jurassic, Lower Triassic) and in tectonic structures placed in these aquifers (R. Tarkowski & B. Uliasz-Misiak) as well as in hydrocarbon deposits (A. Wójcicki). Capacity estimation was performed according to methodology proposed in the Project.

Estimation of CO_2 storage volume within deep brine aquifers and for tectonic structures localized there was limited to calculation of the volume resulting from structural trapping.

In case of hydrocarbon fields the selection of possible storage sites was based on ultimate reserves (production by now plus remaining proven reserves of oil and/or gas), reservoir depth – ensuring CO_2 will appear in supercritical conditions there and production history.

1. Deep aquifers and geological structures suitable for CO_2 storage

The best conditions for underground CO_2 storage occur within significant part of the Polish Lowlands (Northern and Central Poland). There are found sedimentary rocks of miscellaneous age (mainly Mesozoic and Cenozoic), geologically well defined. They do possess good reservoir properties while being characterized by large thickness, extent and porosity, less by fractures or fissures (Fig. 1). At the top they are sealed with thick impermeable rocks [9].

An analysis of deep aquifers in the Polish Lowlands involved data on the existence of thick reservoir rocks, lack of contact with potable water aquifers, position at large depth (below 1000 m), good geologic recognition level, existence of the overburden indicate 3 Mesozoic aquifers (Lower Triassic, Lower Jurassic and Lower Cretaceous) as the most adequate sites to quest for reservoirs and locations of geological structures for underground carbon dioxide storage [9]. It does not exclude any possibility of defining suitable locations within other areas or other deep aquifers (e.g. Upper Triassic).

Lower Cretaceous. The Lower Cretaceous reservoir horizons consist mainly of sandstones and sandy and carbonate-sandy deposits of Barremian-Albian age. They are separated by discontinuous series of low and non permeable sediments composed of siltstones and mudstones. Depth of the Lower Cretaceous succession top varies between 0 m (at outcrops) to over 2800 m below the surface level (Mogilno Trough).

Total thickness of the Lower Cretaceous succession ranges from several dozen metres at basin peripheral zones to several hundred metres (500 m) in the Mogilno Trough. Percentage of water bearing deposits within the Lower Cretaceous section is versatile and varies between 10% - 100% [1].

Within Lower Cretaceous section, the sandstones Lower and Middle Albian age make up a potential reservoir suitable for CO_2 storage. This deposits display the best reservoir properties within sections of the Mesozoic Polish Lowlands. The Lower Cretaceous formations are overlain over most of the area by Upper Cretaceous rocks (limestone, chalk) characterized by low permeability and being a very good seal for the Lower and Middle Albian sandstones [4].

The permeability coefficient varies from $5.5 \cdot 10^{-4}$ to $1 \cdot 10^{-9}$ m/s. It has been assumed that the permeability coefficient is approximately $2 \cdot 10^{-5}$ m/s. Open porosity of Lower Cretaceous rocks, determined by laboratory analyses, ranges between 3 and 45%, most frequently it falls within the interval of 15 - 25% [7].

Lower Jurrasic. Lower Jurassic aquifers are composed of sandstone complexes of Hettangian, Sinemurian, Domerian and Upper Toarsian age. They are separated by discontinuous series of low permeable sediments (claystones, mudstones, fine-grained sandstones). Depth to the top of the Lower Jurassic sequence varies between 0 m (at outcrop zones) to over 3900 m below the surface level (Mogilno Trough). Total thickness of Lower Jurassic succession ranges from several - 100 metres at basin peripheral zones to 800 - 1200 m in the Pomerania and Kujawy Swell area. Percentage of water bearing deposits within the Lower Jurassic section is versatile and varies between 25% - 100% [1].

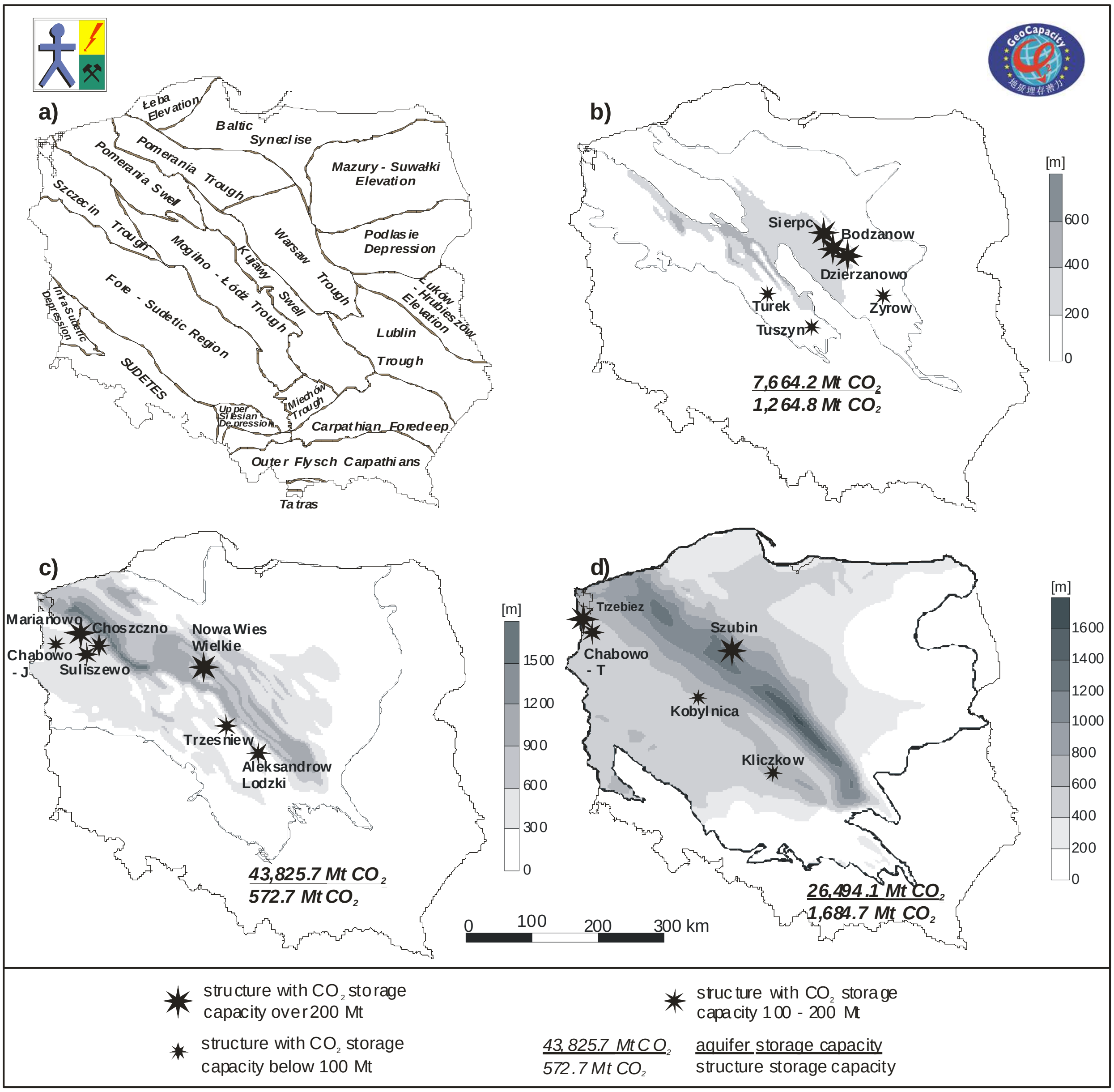

Fig. 1. Tectonical sketch of geological units in Poland (after Pożaryski [5]) (a) and thickness maps of the Lower Cretaceous (b), Lower Jurassic (c) and Lower Trissic aquifers (d) with geological structures selected to CO_2 storage

The best conditions for CO_2 underground storage are displayed by the Upper Toarsian age, Lower Aalenian sandstones, as well as by the sandstones of Upper Pliensbachian age. Clay series overlying Lower Jurassic deposits (Upper Aalenian) of diverse thickness 100 - 160 m are a good sealing horizon [4].

The permeability coefficient varies from $1{\cdot}10^{-4}$ to $2{\cdot}10^{-7}$ m/s. The average value is $5{\cdot}10^{-6}$ m/s. Open porosity of Lower Jurassic water-bearing rocks, determined from laboratory measurements, is up to 33% [7].

Lower Triassic. The top of the aquifer (Lower and Middle Bunter Sandstone) in the central part of the Pomerania and Kujawy Swell, Warsaw Trough and Szczecin-Mogilno-Łódź Trough, lies at a depth of about 1500 - 5300 m below the surface level. Total thickness of the Lower Triassic succession in this part of the basin varies from 200 to

1600 m. At the basin peripheries, the Lower Triassic sequence occurs at a depth of several hundred metres below the surface level, and its thickness is reduced to several dozen metres.

The sandstones of Lower and Middle Bunter Sandstone deposits are regarded as the rocks suitable for CO_2 underground storage. This sandstones are sealed at the top by Roethian silty and clastic-carbonate-evaporic sediments (Upper Bunter Sandstone). Thickness of the Roethian and its equivalents ranges between about 200 m to about 100 m [4].

Effective porosity is 15% - 30%. Permeability of these deposits is highly variable ranging from approximately 70 to 140 mD, and locally even up to 2410 mD [9].

Within the Polish Lowlands area numerous tectonic structures were defined (anticlinal structures and grabens). They are a manifestation of salt tectonism. Some of them, having been minutely examined, may make up adequate geological structures suitable for carbon dioxide underground storage [9, 10].

Within the Mesozoic aquifers of the Polish Lowlands, within frames of the EU GeoCapacity Project, there were chosen 18 tectonic structures (anticline – 15, tectonic grabens - 3). These structures occur in Lower Cretaceous (6) – Bodzanow, Dzierzanowo, Sierpc, Turek, Tuszyn, Zyrow, in Lower Jurassic (7) – Aleksandrow Lodzki, Chabowo-J, Choszczno, Marianowo, Nowa Wies Wielkie, Suliszewo, Trzesniew and in Triassic (5) – Chabowo-T, Kliczkow, Kobylnica, Szubin, Trzebiez.

CO_2 regional storage capacity in the Lower Cretaceous, Lower Jurassic and Lower Triassic aquifers of the Polish Lowlands were estimated. The following data were used for calculation of CO_2: average porosity, average contribution of permeable layers, average density of CO_2 in-reservoir condition, structural and thickness maps of relevant horizons (Tab. 1).

Table 1. CO_2 storage capacity in the Lower Cretaceous, Lower Jurassic and Lower Triassic aquifers and parameters used for calculation

Formation	Area [km^2]	Porosity [%]	Net gross ratio [%]	ρ_{CO2} [kg/m^3]	Storage capacity [Mt]
Lower Cretaceous	24,562.0	20.5	40	800	7,646.9
Lower Jurassic	70,106.0	17.3	60	700	43,825.7
Lower Triassic	112,036.0	9.7	70	600	26,494.1

It was assumed that the storage will be done in an area where the aquifer is at a depth interval of -1000 m – -3000 m. Average porosity, net gross ratio and CO_2 density was calculated for each aquifer. It was also assumed that the sandstone pore water will not be totally removed by sequestrated CO_2. Assumed sweep efficiency is 2%.

The largest CO_2 storage volume occurs in Lower Jurassic formations, less in Lower Triassic formations, the least in Lower Cretaceous formations.

Total storage volume (77,966.7 Mt) covers Poland`s 248 year emission, allowing emission level of 314.2 Mt in 2004 [11].

Storage volume of the defined 18 tectonic structures was calculated as product of the structure area, effective thickness, porosity, CO_2 density in deposit conditions and sweep efficiency 20%. Storage capacity of the structures in the Mesozoic of the Polish Lowlands varies from 64 Mt (Chabowo-J anticline) to 575 Mt of CO_2 (Bodzanow anticline) (Fig. 2).

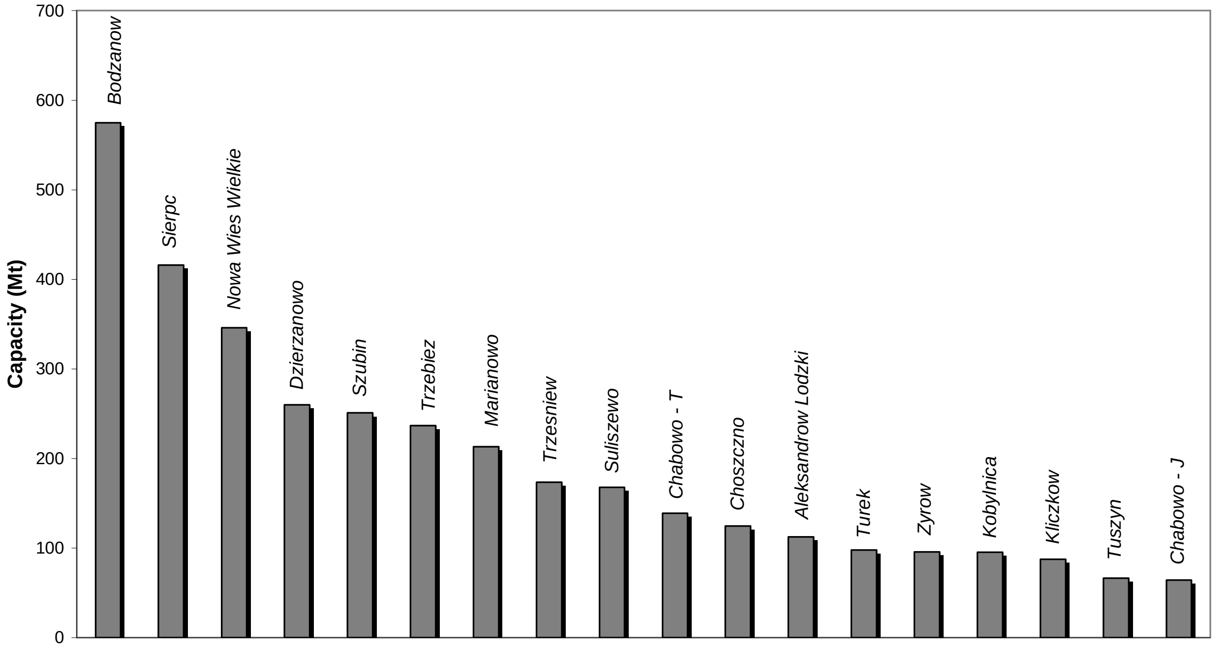

Fig. 2. CO_2 storage capacity of tectonic structures in Lower Cretaceous, Lower Jurassic and Triassic aquifers in the Polish Lowlands

Total storage capacity within the defined tectonic structures equals 3,522.2 Mt of carbon dioxide. It allows to store Poland`s 11 year emission in 2004 year. The largest CO_2 storage capacity occurs in structures seated in Lower Cretaceous aquifers – 1,264.8 Mt, less in Lower Jurassic – 572.7 Mt and least in Triassic – 1,684.7 Mt.

2. Hydrocarbon fields suitable for CO_2 storage

Possibilities of CO_2 storage within depleted/depleting hydrocarbon fields in Poland have been analysed from the viewpoint of availability of such sinks in not too distant future, i.e. taking into consideration their production history. Storage capacity figures were calculated using approach of FP5 GESTCO project [6] based on assumption of 1:1 volumetric replacement of extracted hydrocarbons with supercritical CO_2 within reservoirs.

Hydrocarbon fields in Poland [2, 3] are generally located in two areas, which differ in geology and production history (Fig. 3).

The first area is located in SE part of the country where oil production started in 1850/70s (in Carpathian flysch) and is still ongoing though for a very small extent; later also in the Carpathian Foredeep/Carpathian front area where gas production was developed after WWII (mostly of Miocene, rarely of its Mezo-Paleozoic basement). The whole area is dotted and particular fields are represented as polygons and triangles (indicating storage capacities).

These are twelve relatively big gas fields (storage capacities from 4.17 Mt of Uszkowce to 244.57 Mt of Przemysl; both fields can be found in easternmost part), located in the Carpathian Foredeep or at the front of Carpathians. They are usually depleted in 80% - 90% of original proven reserves.

Three small oil fields are denoted there (roughly in the centre), of storage capacities from 0.42 Mt (Jastrzabka) to 1.87 Mt (Weglowka). The field Jastrzabka is denoted because Polish government and petroleum industry plans small-scale CO_2 injection experiment there [8]. Weglowka and Osobnica fields are practically depleted and, despite of their small size, some (though minor) EOR potential exists for them.

Total storage capacity for this (SE) area is 421.25 Mt, where one big gas field – Przemysl makes over half.

The second area encompasses western part of Poland, Polish Lowlands, where Rotliegend and Zechstein gas fields occur, which have been developed after WWII, and in northern part of this area also two oil fields of Zechstein Hauptdolomite are exploited (one of them is the biggest oil field in the country, but developed a quite recently, another is practically depleted). In this area – in western Poland there are 13 gas fields mostly of Rotliegend (the dotted area determines the range of Permian basin where Zechstein formations are also enclosed) and Zechstein (one of Carboniferous) of various sizes. Their storage capacities vary from 2.41 Mt (Gorzyslaw – in north) to 91.88 Mt (Zuchlow – in south). They are usually depleted (in over 90%), especially in case of the bigger ones.

In northernmost part of this petroleum province, close to the shoreline and not far from German border, already depleted (40% of OOiP produced) Kamien Pomorski oil field of storage capacity 3.93 Mt occurs – likely an CO2-EOR candidate. South of Kamien Pomorski (~150 km) the biggest oil and gas field developed recently in Poland is located, of storage capacity 34.18 Mt. Though it is rather in an early stage of production (~20% of proven reserves extracted), the field might be useful as a sink (including secondary oil production) in a not very close (but in a not very distant either) future.

Total storage capacity for this (western) area is 240.26 Mt.

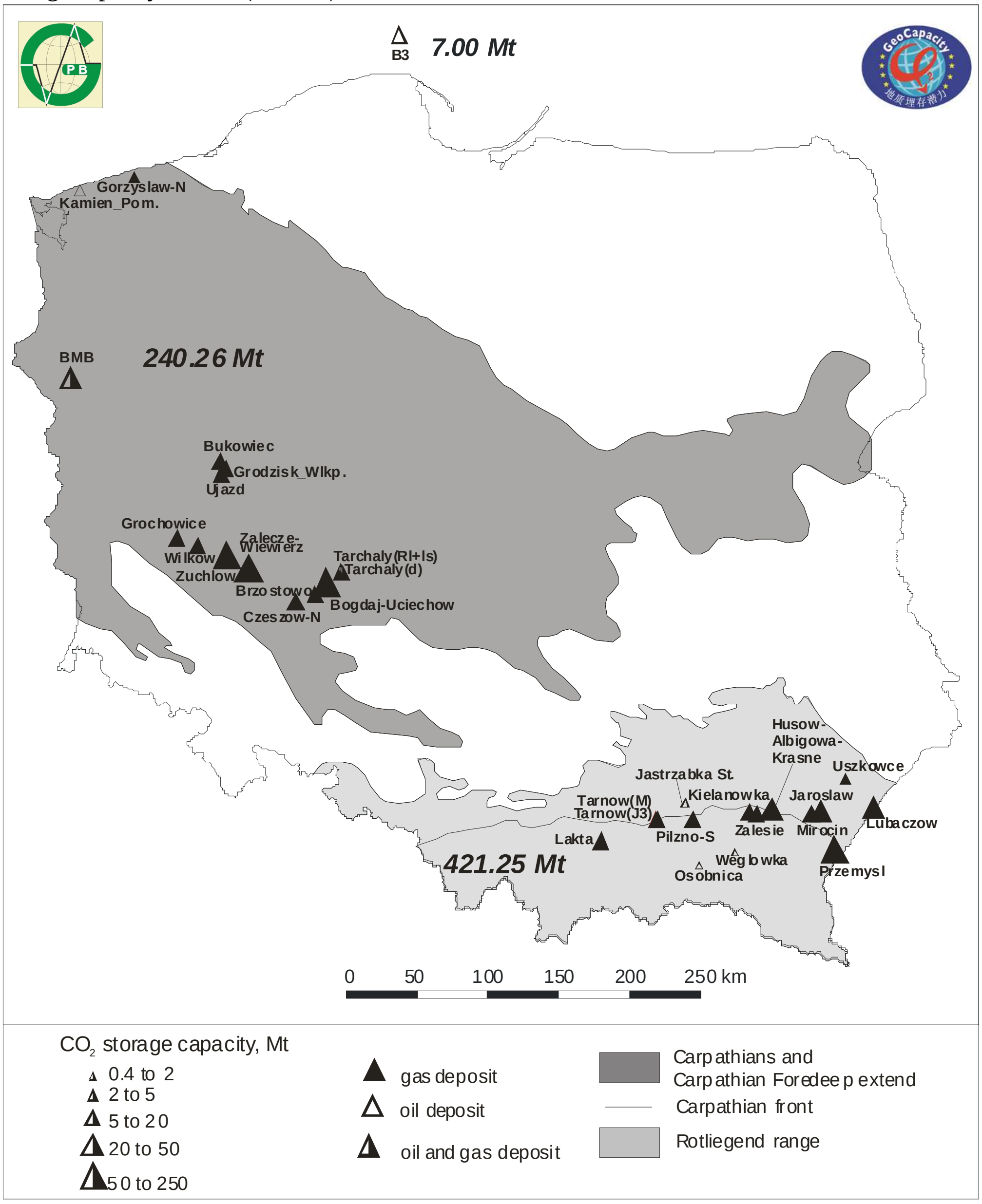

Fig. 3. CO_2 Storage potential of hydrocarbon fields in Poland (geological unit extend after Karnkowski [2])

The only offshore oil field exploited at this moment (B3) is of middle Cambrian, located about 70 km north of northernmost part of Polish coast, and does not belong to both these above mentioned hydrocarbon provinces. Its storage capacity is estimated as 7.0 Mt. By present, cumulative oil production gave over 50% of original proven reserves (it was developed in 1990s). So, it is expected the field will be depleted by 2016 and the use of CO2-EOR cannot be excluded then.

Total storage capacity in these (selected) hydrocarbon fields of Poland is over 764 Mt. Four fields have storage capacities over 50 Mt (one gas field in SE Poland, three gas fields in western part).

3. Conclusions

Carbon dioxide storage capacity estimation accomplished within frames of the EU GeoCapacity Project confirmed that CO_2 storage within aquifers is the best option for Poland. Due to large capacity the aquifers allow to store carbon dioxide coming from large emission sources for many years. CO_2 storage in hydrocarbon deposits may be of local importance due to much less storage volume available in hydrocarbon reservoirs, especially in oil ones, comparing to tectonic structures (aquifers). In case of depleted or depleting oil reservoirs it could be combined with secondary oil production (CO2-EOR), but such cases are rare in Poland.

Acknowledgments

EU GeoCapacity project is co-funded by 6th Framework Programme of European Union – contract no. FP6-518318. The project is coordinated by GEUS – Geological Survey of Denmark and Greenland.

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