CCS in the Skagerrak/Kattegat area

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Abstract

This paper presents an ongoing project with the aim to assess a CO_2 infrastructure in the Skagerrak/Kattegat region (the sea bordered by north of Denmark, south coast of Norway and the west coast of Sweden). The area comprises 10-12 CO_2 emission sources of more than 0.5 Mt/year. The geological and geophysical assessment of CO_2 storage potential in the described area as well as reservoir modelling and simulations are performed in work package (WP) 1. The results from WP1 are used in the other work packages. Candidate storage sites are matched with those point sources in the region that are technically and economically feasible for CO_2 capture, together with an assessment of the connecting infrastructure needs. WP 2 focuses on identifying optimal technological CO_2 infrastructure solutions. Sources-to-sink solutions are in the process of being developed based on input from WP1 and WP3. Assessment of the build-up of a complete CCS infrastructure from a system perspective is the overall focus of WP 3, covering economical, practical and judicial aspects. The project group explores the economic potential for capture at each individual site including looking at other CO_2 mitigation options and propose relevant capture technology with cost estimations. Dissemination of project results is organized in a separate work package, WP4.

Keywords: CCS infrastructure; industry; Scandinavia; Skagerrak

1. Project background and structure

In an unpublished pre study finished in 2008, Tel-Tek with project partners concluded that within an approximately 100 km radius circle centred in the Skagerrak (see fig. 1), more than 13 million tons of CO_2 annually were emitted from large mainly fossil fuel based point sources (> 500 kt/y) like for instance refineries, petrochemical, cement as well as power plants. About 10-12 CO_2 sources of this size are found within this relatively limited geographical area. Of this amount, about 10 million tons could technically be captured by applying MEA based post combustion technology. The potential for CO_2 storage within this area has so far not been known, but there are well known storage possibilities on the Norwegian continental shelf in the North Sea.

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Regional assessments including both capture, transport as well as storage potential in an integrated manner are so far few. One example is the Rotterdam Climate Initiative [1]. This paper describes: 1) Results from a completed study on large CO_2 point sources in the Skagerrak-Kattegat area and 2) preliminary results from an ongoing interdisciplinary project with the overall goal to establish a basis for large scale handling of CO_2 in this area and adjacent parts of the Southeastern North Sea. Work is focused on CO_2 sources and capture possibilities, transportation and infrastructure, possible storage sites as well as legal aspects relating to the whole CCS chain. The work is partly financed through Interreg/KASK (EU) and other public funding from Sweden and Norway, and partly by industry and the Climit Programme [2], which is administered in cooperation between the Norwegian Research Council and Gassnova – the Norwegian state enterprise for carbon capture and storage. Current industry partners are listed in paragraph 6. In addition to Interreg/KASK and Gassnova, public funding is from Swedish Energy Agency, Telemark County, Vestfold County, Gothenburg Region and Innovation Norway. Research partners are Chalmers Technical University in Gothenburg, University of Gothenburg, University of Oslo, Telemark University College, Sintef Petroleum Research and Tel-Tek (project coordinator). The project is in-line with continued efforts to improve mapping of CO_2 storage opportunities of near-coastal areas of Europe, in this case the near-coastal areas of Northern Denmark, Western Sweden and Southern Norway. Recently GEUS joined the project and will supply the consortium with data from Denmark, including onshore. The project further develops and disseminates knowledge to create a CCS infrastructure in the Scandinavian region. Moreover, the project further develops cooperation between industries emitting CO_2, and investigates their common possibilities for CCS.

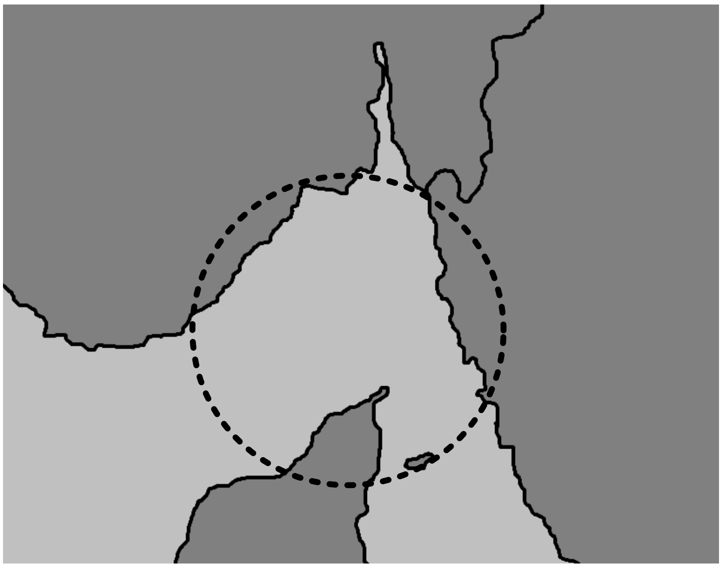

Figure 1: The study area

The ongoing study is arranged in four work packages that run in parallel: Three scientific/technical work packages and one work package for dissemination of results. The four work packages are described in more detail below.

2. Geology and Geophysics in Skagerrak/Kattegat/Eastern North Sea and on-shore Denmark

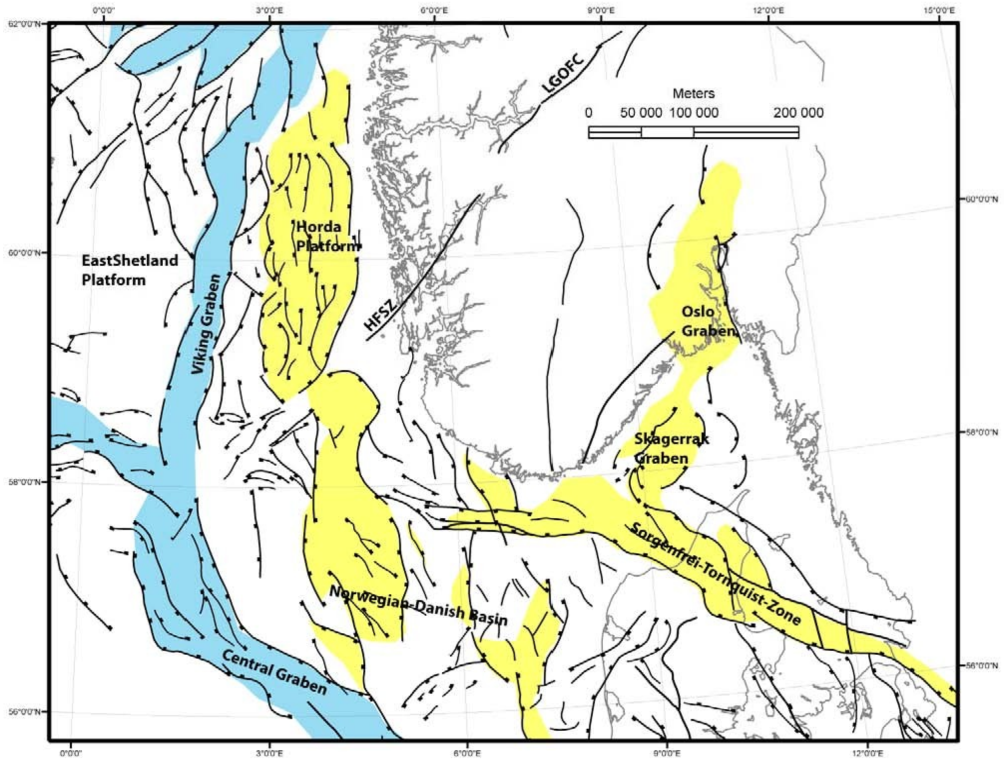

Figure 2: Overview map of the main study area with the main structural elements. The principal structural elements of southern Scandinavian including the Danish Basin (i.e. eastern part of the Norwegian-Dansih Basin), the Sorgenfrei-Tornquist Zone, Skagerrak-Kattegat Platform, Skagen Graben and the Ringkøbing-Fyn High. Main tectonic elements of the study area and its surroundings, East Shetland Platform, Horda Platform, Oslo Graben, Skagerak Graben, Sorgenfrei-Thornquist Zone, HFSZ = Hardangerfjorden Shear zone, LGOFC = Lærdal-Gjende-Olestøl Fault Complex.

Work package 1 focuses on screening of possible geologic storage sites in the Skagerrak area. Available data sets (seismic lines and well bore data) from the area both offshore and also onshore in Denmark is being assessed. The WP is divided into three parts:

1) Screening of the whole area based on seismic data and correlation to wells. This work forms the basis for defining the geographical focus of the next two stages.

2) The most promising geographical/geological areas are studied in detail with regard to sequence stratigraphy, thickness and lithofacies distribution as well as physical properties of potential reservoir units, and faults affecting potential reservoirs and their caprocks.

3) Reservoir modelling and simulations: Based on regional geological models several formations and locations are in the process of being identified as possible targets for permanent CO_2 storage Reservoir models of selected locations will then be constructed and simulation of CO_2 injection will give pressure development and distribution of free and dissolved CO_2 for the injection period and the following 5000 years. Possible long term risk factors resulting in migration of CO_2 through the overburden will be identified and simulated. Variation of input parameters such as topography and reservoir properties will be performed to identify critical parameters important for permanent CO_2 storage.

Phase 1 of this Work Package has resulted in a brief screening of potential reservoirs for geological storage of CO_2 in the eastern part of the North Sea, Skagerrak and Kattegat area. Relevant data and literature have been reviewed and compiled. Selected regional profiles of Paleozoic, Mesozoic and Cenozoic sedimentary sequences tied to key wells have been presented in order to visualize the sedimentary and structural development in the area, and the project has also summarized the main potential CO_2 storage systems (called "plays" at this early stage) within the Paleozoic, Mesozoic and Cenozoic strata. Permian (Rotliegend) sandstones are considered to be the prime reservoir of the Paleozoic "plays", with Permian (Zechstein) salts or Mesozoic shales as potential cap-rocks.

The main Mesozoic plays are systems with Triassic-Jurassic sands (Gassum Fm, Fjerritslev Fm, Haldager Sand Fm, and Skagerrak Fm) with potential Jurassic-Cretaceous shales or Plio-Pleistocene sediments seals and potential structural and stratigraphic traps. Similar systems are well-known from Denmark. Chalk as potential reservoirs also need to be considered.

Generally there are risks associated with inversion causing uplift/erosion and fault reactivation. There is a regional tilt related to onshore uplift and offshore subsidence. There are two potential Cenozoic "plays" in the Norwegian-Danish Basin that mainly contain Paleocene, and Oligocene-Miocene sands. These sands are of a different age but represent a similar "play" as the Utsira formation. These newly discovered systems in the Norwegian-Danish Basin are potentially interesting with regard to further studies aiming to uncover their eventual suitability for future CO_2 storage. The reservoir quality of the sands and their distribution is presently uncertain and regional tilt and facies changes within seals and reservoirs represent added risks. The outcome will be the basis for proposing continued investments to characterise and qualify the storage sites, including additional seismic investigations in the area. A first indicator of a defined storage site "play" could be off the coast at the town Grimstad in Norway.

3. CO_2 transport in the Skagerrak/Kattegat area

A gradual build-up of an infrastructure will take time. An initial optimal transport solution may very well be ships for the first CCS ready sources. The final infrastructure for CO_2 in the region may consist of a network of pipelines only or a combination of pipelines and ships. WP2 is providing cost estimates and defines the technological requirements in order for each point source to make use of the infrastructure. Costs of CO_2 transport is being estimated for the entire chain from sources to possible storage locations and include liquefaction facilities and intermediate storage as well as the cost of shipping and/or pipeline.

For a complete transport solution for an entire region an important challenge is to assess the CO_2 quantity to be transported as accurately as possible. The different CO_2 emission sources will most likely implement CCS incrementally over several years. Possible future emission increases due to new industries or power plants must also be addressed. Implementation of capture may in itself generate more CO_2 since capture is an energy demanding process. A ramp-up of a CO_2 transport network covering the whole region will be gradual and time consuming, finding an optimal solution will be challenging.

Transport cases

Due to the uncertainties regarding ramp-up of CCS and location of suitable storage several transport cases will be estimated. Additional cases can be included at a later time. Descriptions of the first four cases are given below:

Case 1 - Pipeline transport of CO_2 to an aquifer in the Norwegian-Danish Basin: Case 2 will easily be compared with the other cases, and will give the costs and technical solutions for transport and storage in the Norwegian-Danish Basin. This case is illustrated in Figure 3; the pipeline network layout is only indicative.

Case 2 - Combination of ship and pipeline transport to an aquifer in the Norwegian-Danish Basin

The most likely solution in a ramp-up phase is to use a combination of ship and pipeline transport. CO_2 pipelines will be installed from the major sources to permanent storage in the Norwegian-Danish Basin. The CO_2 from minor sources will be transported by ship to a hub at Stenungsund on the west coast of Sweden and pipeline transport to permanent storage. This case is not illustrated

Case 3 - Return load LNG/CO_2

The ship transportation require very cold (-50°C) CO_2. This project will look into the possibility to use the same ship for transporting LNG as return load from a hub to the CO_2 source. This case is not illustrated.

Case 4 – CO_2 by pipeline to a possible hub outside the study area: In case no suitable storage site can be found within the study area, the project will look for alternative locations

Cost model

Costs of CO_2 transport will be estimated from sources to identified permanent storage locations. The work will give a description of the technological requirements and estimate costs for industry access to the transportation system. Costs of transport will include liquefaction facilities and intermediate storage as well as the cost of shipping and/or pipeline.

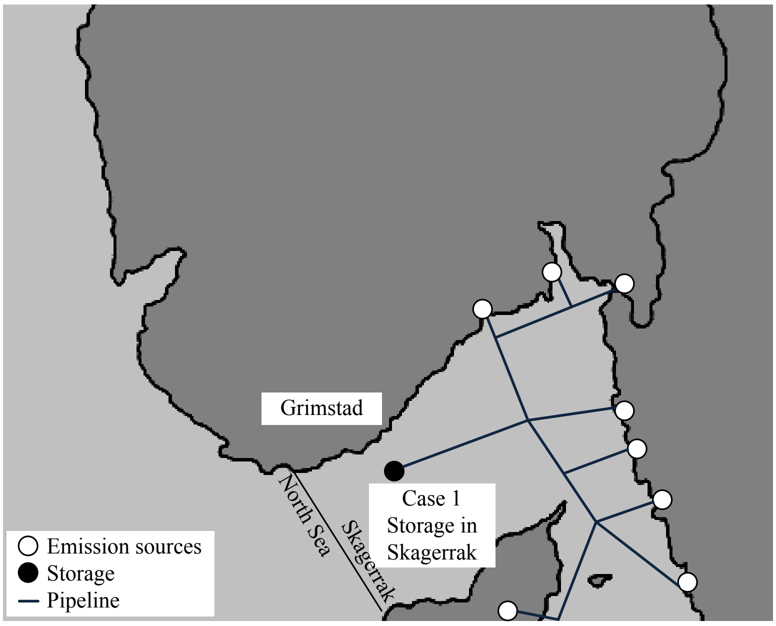

Figure 3: Illustration of case one. The case is based on a pipeline network in the Skagerrak/Kattegat area with permanent storage in a suitable formation in the Norwegian-Danish Basin.

4. CCS infrastructure

WP 3 is assessing the build-up of a complete CCS infrastructure from a system perspective, covering economical, practical and judicial aspects. The project group explores the economic potential for capture at each individual site including looking at other CO_2 mitigation options. For capture of CO_2, Post Combustion Carbon Capture (PCCC) is evaluated. One major cost for PCCC is the heat for the stripper. In contrast to traditional power plants, the process industry is rather complex and often offers opportunities for heat recovery by means of Process Integration (PI) which could enable substantial cost reduction for the heat supply. One major contribution in this project will be the evaluation of different PCCC options (MEA and chilled ammonia), different levels of net heat of desorption, four different alternatives for heat supply (use of excess heat, natural gas combined cycle, biomass heat and power plant, heating pump) in combination with different energy scenarios [3]. By embracing the view that the Emission Trading System (ETS) will need to include CO_2 from renewable sources, and applying this to the effects of CO_2 capture in the process industries an overall picture emerges as illustrated in Figure 4.

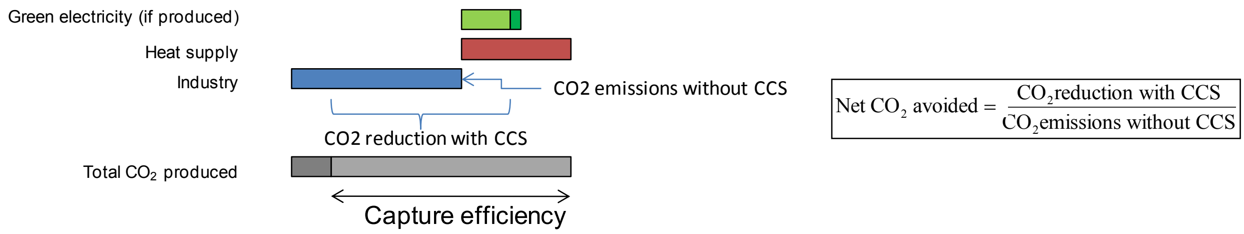

Figure 4: Evaluation of CCS measures including global CO_2 emission effects.

As seen in Figure 4, the effect of off-site CO_2 emissions is taken into account and influences the net CO_2 avoided. The electricity produced will replace marginal produced electricity as outlined in [4].

The analysis will give predictions of the heat supply costs (investment cost as well as operational costs) for each industry assuming different PCCC technology and heat supply options. Since, for each case the PCCC heat demand is defined and the heat supply process is relatively well known, these cost estimates will be very accurate. By comparing the future price for CO_2 emissions and the cost predictions for heat supply, the cost of CO_2 transportation (from WP2) and storage (from WP1), the "maximal investment cost", will be defined as the difference between CO_2 emission price and the other "known" costs. By using this methodology, much of the debate about the costs for CO_2 absorption (given the large variation in equipment size and process design) will be circumvented. A subsequent discussion is thus enabled that can focus on whether CCS is a viable option for the process industry and under what circumstances it may be profitable.

Along with site specific evaluation of capture, pathways for CCS will be developed, like the phasing-in of capture plants defining CO_2-flow and transport requirements over time. The phasing in of capture plants over time is central for the development of the transportation system. A large bulk CO_2 pipeline transportation system may consist of collecting pipelines from each individual source, bulk pipelines carrying the CO_2 from several sources and injection pipelines. Typically, collecting pipelines will have a moderate CO_2-volume and stretch over relatively modest distances, bulk pipelines may carry large amounts of CO_2 over large distances while injection pipelines may carry between one and two million tons per year over a few kilometers. In the case of boat transport collecting pipelines will be required if the capture plant is not located at the coast. Boat transport may be a least-cost solution during the ramp-up period offering flexibility and enabling the CO_2-volume to build up to a plateau volume, so that when a pipeline transportation system is developed, it will be a large bulk system that is cost efficient with minimal impact on the environment.

The role of climate policies and their potential effect on the development of CCS will be investigated, including the European Emission Trading Scheme (ETS) and the potential impact of banking, carbon leakage, carbon negative and emission performance standards. However, looking at long-term GHG-emission reductions as proposed by the EU, it is unlikely that there can be any emissions of carbon dioxide from the stationary sector in 2050[2] (power sector and industry) if these emission reductions are to be met. Given that there are only five options available to reduce emissions[3], CCS may have to play a significant role in meeting long-term emission targets. Therefore, the long-term deployment of CCS will depend on the future political will to carry out strict emission reduction targets, possibly on a global level since it is difficult to envisage a unilateral strict emission reduction policy over time from the EU only.

The juridical part of the project analyzes the legal preconditions for deployment and operation of CCS according to the pathway that is developed. The analysis comprises international and EU perspectives but is grounded in the specific characteristics of the Skagerrak-Kattegat area. Of particular significance are issues pertaining to potential conflicts and coordination between domestic legislation in the states concerned and the implementation and use of the CCS-directive (2009/31/EC) in the domestic legal orders. The CCS-directive only provides limited alignment of national rules. This is due both to the fact that the directive requires minimum harmonization, allowing for individual states to go further in their protective measures, and to the fact that several significant issues are not addressed by the directive. These include liability issues outside the framework of the EU ETS and the environmental liability directive (2004/35/EC), issues of access to land and safety standards for pipeline transport, e.g. transport of highly pressurized CO_2 pipelines in city-centers or through densely populated areas.

Of significance is also that the pathway is being built around a presumption of transboundary transport of captured CO_2. Unlike any domestic CCS scheme this makes the allocation of rights and responsibilities between private and public (government) agents in two or more countries a defining feature of the legal preconditions. This is pertinent e.g. in relation to transboundary pipeline or ship-transports and the storage of CO_2 in a different country from that in which it was captured. The development of international and EU standards in this field, and their incorporation and application within the national and regional legal contexts, are thus closely analyzed. The ultimate question for the legal analysis is how CCS regulation may be designed in the region so as to be protective of humans and the environment while supporting the efficient deployment of CCS and navigating the complications of a plurality of interacting legal systems.

5. Dissemination of results

There are several activities under this work package (WP 4). Apart from regular contacts between the project and the project sponsors, results will be disseminated through all common channels such as publications in journals, news media, in conferences and through the web. The project has its own web site, http://www.ccs-skagerrakkattegat.eu/. The project also aims at establishing a Scandinavian CCS forum in cooperation with other ongoing initiatives like a similar project encompassing the Baltic Sea province and the Nordic Top-level Research Initiative [5].

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[2] According to [4], the industrial world should reduce GHG emissions by 80 to 95% by 2050 relative to 1990. As emissions of carbon dioxide account for around 83% of all GHG emissions and the transport sector accounts for around 23% of all CO_2-emissions (without LULUCF in 2007), it is obvious that there is little room for CO_2-emissions from stationary sources if EU:s long-term reduction proposals shall be met.

[3] In the short-term up to 2020, there is basically only three options; renewables, efficiency improvements on all levels in all sectors and switch of fuel from coal to gas. After 2020, nuclear energy and CCS may also play a role to reduce CO_2-emissions.

6. Industry perspective

The Scandinavian industry partners and Climit have an interest in the entire CCS chain. Examples of important topics for the investigations of the CCS chain are: Can the CO_2 volumes and storage possibilities in the region create an economically and practically feasible CCS system? How to introduce and ramp-up such a system? Is it necessary to connect a regional infrastructure to a larger infrastructure for economy of scale?

Strength is that different industry businesses are represented, all having a need to reduce CO_2 emissions. These businesses are ammonia production from hydrocarbons (Yara), oil refineries (Preem AB and Esso), chemicals and plastics (Borealis), energy utilities (Vattenfall, Göteborg Energi and Skagerak Kraft) and oil producers (Statoil). Expected development from the integrated project and the partnerships can in an industry perspective be summarized as follows:

- Continued mapping of CO_2 storage opportunities near-shore the coastal areas of Northern Denmark, Western Sweden and Southern Norway.
- Further develop and disseminate knowledge to create a CCS infrastructure in the Scandinavian region.
- Further develop co-operation between industries emitting CO_2, and investigate their common possibilities for CCS.
- Competence building within the academies in Scandinavia, and increased co-operation on CCS between industry and academies

7. References

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