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Ship transport—A low cost and low risk CO_2 transport option in the Nordic countries

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ABSTRACT

This paper investigates CO_2 transport options and associated costs for CO_2-sources in the Nordic region. Cost for ship and pipeline transport is calculated both from specific sites and as a function of volume and distance. We also investigate the pipeline volumetric break-even point which yields the CO_2 volume required from a specific site for pipeline to become a less costly transport option than ship transport. Finally, we analyze possible effects from injectivity on the choice of reservoir and transport mode.

The emission volumes from the Nordic emission sources (mostly industries) are modest, typically between 0.1–1.0 Mt per year, while distances to feasible storage sites are relatively long, 300 km or, in many cases, considerably more. Combined, this implies both that build-up of an inland CO_2 collection system by pipeline will render high cost and that it is likely to take time to establish transportation volumes large enough to make pipeline transport cost efficient (since this will require multiple sources connected to the same system). At the same time, many of the large emission sources, both fossil based and biogenic, are located along the coast line.

It is shown that CO_2 transport by ship is the least costly transportation option not only for most of the sources individually but also for most of the potential cluster combinations during ramp-up of the CCS transport and storage infrastructure. It is also shown that cost of ship transport only increases modestly with increasing transport distance. Analyzing the effect of injectivity it was found that poor injectivity in reservoirs in the Baltic Sea may render it less costly to transport the CO_2 captured from Finnish and Swedish sources located along the Baltic Sea by ship a further 800–1300 km to the west for storage in better suited aquifers in the Skagerrak region or in the North Sea.

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1. Introduction

In order to limit the global temperature increase to 2 °C the EU has suggested that developed countries should reduce their GHG emissions by 80–95% relative to 1990 emissions by 2050 (EC, 2011). According to IEA (2013) all Nordic countries[1] have long-term climate- and energy-related targets and visions that are ambitious and often surpass EU strategies, but with differences between the countries. Thus, by the year 2050 there is little room for any CO_2 emissions from the Nordic countries.

A substantial part of the electricity generated in the Nordic region is generated by hydro and nuclear energy thus yielding low overall CO_2-emissions and this characteristic appears to become even more pronounced in the future with most of the remaining large coal power plants in Denmark and Finland having announced firm plans to switch to biomass based electricity generation (see for instance Dong Energy, 2014; Fortum, 2014). Hence, most of the *stationary* fossil based emissions in the Nordic region will, in the future, probably arise from the energy intensive industry, such as from the cement and steel sectors and from chemical plants for which CCS has been shown to be a key mitigation measure in a portfolio of measures required to achieve the substantial emission reductions described above (ZEP, 2013; Rootzén and Johnsson, 2015). IEA (2013) suggests that 50% of cement plants, and at least 30% of iron and steel and chemical industries in the Nordic countries will need to be equipped with CCS in 2050.

In 2010, there were 284 sources emitting 100 ktonnes (kt) CO_2 or more (biogenic or fossil) in the Nordic countries with numerous potential combinations into clusters (and volumes). Thus, establishing a transport network over time to connect these emissions sources will allow for different strategies both spatially and with regard to how the transportation network can evolve over time. Moreover, it can only be speculated *if* and *when* the various sites will install capture, i.e. how the CO_2 volume will evolve over time within any given cluster. At the same time it is well known that cost for pipeline transport is highly sensitive to the volume being transported and most large-scale CO_2-sources located in the Nordic region are located along the coast while storage sites are located offshore making also ship transport a potentially feasible transport option. The potential attractiveness of ship transport is further enhanced since each individual emission source in the Nordic countries have relatively low emissions and long distances to potential storage sites (most sources emit between 100 kt up to 1 Mt CO_2 per year and are located 300 km and more from a potential storage site). In Europe, industry plants are often considerably larger, more densely located and, in many cases, close to potential storage sites, at least if onshore storage can be considered relevant (Kjärstad et al., 2011). Finally, ship transport is particularly interesting during ramp-up of a CO_2 transport system due to its flexibility allowing addition of multiple capture sites and storage sites over time. Thus capacity can be added to the system (transport and/or storage) only if and when the need for increased capacity materializes and it is also possible to switch capture and/or storage sites altogether. Also, a ship may be sold after use while pipelines instead may incur decommissioning cost. For further discussions on the value of flexibility for ship and pipeline transport see for instance Knoope et al. (2015).

Also, while the western parts of the Nordic region is well endowed with suitable storage capacity the opposite appears to be the case in the eastern part, i.e. in the Baltic Sea region (Elforsk 2014a,b; Mortensen et al., 2015). Since poor storage capacity in the Baltic Sea may add up to 1400 km additional transport distance for sources located along the Swedish east coast and the Finnish west coast, the potential effect this may have on transport structure and its cost needs to be analyzed in detail.

In addition, Finland and Sweden in particular have many large-scale biogenic CO_2 emission sources which, through installation of CCS, could neutralize emissions from other sectors where significant emission reductions may be difficult to achieve in the medium term, such as in the transport sector. Finally, there is also a potential for storage through CO_2 EOR both in Danish and Norwegian oil fields which may become the driving force for start-up of CCS offsetting cost and providing the first necessary infrastructure. Thus, there are several factors that make CCS an interesting mitigation option in the Nordic countries.

Technical feasibility and cost of ship transport of CO_2 has been investigated in several works such as reported in ZEP (2011a), Roussanaly et al. (2014), Skagestad et al. (2014), GCCSI (2011, 2012a, 2013), Ozaki and Ohsumi (2011), Ozaki et al. (2013), Elforsk (2014c). Although these works undoubtedly have improved our understanding of the technological challenges associated with CO_2 ship transport and have provided relevant cost estimates they have not in detail addressed and analyzed the site specific conditions in the Nordic countries related to comparison between ship and pipeline transport. Considering the relatively small emission sources and the coastal location of the Nordic emission sources, it is of particular interest to investigate the cost and conditions for ship transport. Also, while several papers have investigated the role of injectivity on CO_2 storage (Mathias et al., 2009a, 2009b; IEAGHG 2010; ZEP 2011b; Wessel-Berg et al., 2014; Bergmo et al., 2014; Mortensen et al., 2015), site specific analysis of possible effects from injectivity on cost and consequently also on choice of reservoir and transport mode is lacking. The latter is particularly important in the Nordic region where potential storage sites in the Baltic Sea are few and believed to have limited injectivity and storage capacity (Elforsk, 2014a; Mortensen et al., 2015). Thus, the main aim of this paper is to conduct a comprehensive assessment of potential CO_2 transport options in the Nordic region taking into consideration both individual emission sites and potential storage reservoirs. Part of the work presented in this paper is based on work done in the Nordiccs project (Kjärstad et al., 2015) but with updated cost data and improved methodology.

This paper is organized as follows; Section 2 explains the methodology applied in this work. Results are given in Section 3 and these are discussed in Section 4 while main conclusions are given in Section 5.

2. Methodology

In this work costs of different CO_2 transportation options are analyzed both by comparing the cost for ship and pipeline transport from specific sites and as a function of volume and distance. This work focuses on offshore pipelines. There are two reasons for focusing on offshore pipelines; 1) there are very few onshore pipelines in

[1] In this paper, the Nordic region refers to Denmark, Finland, Norway and Sweden, i.e. Iceland has not been included.