17th International Conference on Greenhouse Gas Control Technologies **GHGT-17**

20th -24th October 2024, Calgary Canada

A case study for the development of a large-scale CCUS value chain integrating Germany, Denmark and Sweden: CCUS ZEN project study

Leandro Sousa[a]*, Maria Bonto[a], Jimmy Andersen[a], Ingvild Ombudstvedt[b], Lena Østgaard[b], Laurianne Bouvier[c], Peter Frykman[d], Anastasios Perimenis[e]

[a]Ramboll, Energy Transition department, Hannemanns Allé 53, Copenhagen S 2300, Denmark
[b]IOM Law, Linerleveien 6 1554 Son, Norway
[c]AXELERA, Rond-point de l'échangeur Les Levées 69360 Solaize
[d]GEUS, Øster Voldgade 10, Copenhagen K 1350, Denmark
[e]CO_2 Value Europe AISBL, Avenue de Tervueren 188A, 1150 Brussels, Belgium

---

Abstract

With an urgent global mandate to reduce CO_2 emissions, governments, industries, and academia worldwide are rigorously venturing towards a large-scale development and implementation of Carbon Capture Utilisation and Storage (CCUS). However, many of these initiatives tend to focus on optimising individual facets of the CCUS value chain (e.g., capture, transportation, storage) rather than the comprehensive integration of these elements. The consequence is potential misalignment between CO_2 emitters and sinks such as storage sites or utilisation projects, which can inhibit project viability. Hence, while distinct, localised efforts contribute to a greater understanding of specific aspects of CCUS, a holistic approach is essential to materialise CCUS initiatives successfully. The CCUS Zero Emission Network (ZEN) has embarked on an effort to understand how to connect diverse actors in Europe to develop a large-scale project from source to sink, by performing a case study that could contribute to the achievement of the European decarbonisation goals.

This paper aims to set forth a systematic approach for the development of CO_2 clusters across the Baltic region, predominantly encompassing Sweden, Denmark, and Germany. The objective is to link major industrial emitters set on decarbonisation with the most promising CO_2 storage sites and use options, offering insights into the creation of a cross-border network to avoid the emission of significant CO_2 volumes.

Our methodology enables the comprehensive creation and analysis of extensive CCUS networks, as follows. Initially, a granular assessment of major industrial emitters in the analysed countries was performed, wherein industrial plants were selected based on their CO_2 emissions, geographic locations, and propensity for undertaking CO_2 capture assessed based on market opportunities and public statements committing to study such solutions. These emitters, once identified, were then aggregated into distinct clusters to optimise CCUS operations. In parallel, an examination

---

* Corresponding author. Tel.: +45 51612289, *E-mail address:* lhcs@ramboll.com

was conducted on the logistics side, focusing on the capacity, injectivity, and readiness level of potential CO_2 sinks. This evaluation spanned across diverse categories such as onshore, near-shore, and offshore storage sites and factored in variables like geographical and geological conditions. Central to our technical approach was the utilisation of Geographic Information System (GIS) tools. Leveraging this technology, we shaped an optimized transportation network that effectively connected the identified emitters, clusters, and storage sites, accounting for factors like distance, terrain, obstacles (cultural, environmental, population) and infrastructure capacity. Another key technical element was the design and sizing of essential compression and liquefaction facilities. To ensure seamless compatibility with the established transportation network and storage specifications, these facilities were strategically placed and calibrated to work under a range of CO_2 conditions and volumes. The results of this assessment can be further used for a cost estimation and constructing a competitive business plan.

Complementing this in-depth technical exploration, non-technical factors such as economic considerations and regulatory frameworks were also evaluated, creating a balanced and comprehensive blend of technicalities and socio-economic aspects in our CCUS research. A legal mapping was conducted of the national, regional and international legal frameworks applicable to the countries included in the study. This was done with the view of identifying the regulatory readiness for deploying CCUS value chains and determining where storage activities are permitted. The findings contributed towards the selection of case studies.

The synthesis of the examined building blocks has culminated in the creation of a diverse array of scenarios. Each scenario offers a combination of capture and storage capacities, infrastructural timeline evolution, and applicability of different transportation methods. As such, this provides a comprehensive comparative model capable of delivering crucial insights for an informed investment decision.

The selection process has identified 33 significant emitters with a collective capture capacity of approximately 20.1 million tonnes of CO_2 annually. From this pool, 20 stand out for their high potential to adopt carbon capture solutions. On the storage front, eight sites within the Danish vicinity were shortlisted, cumulatively featuring a mean capacity of around 928 Mt. Among these, Bifrost and Greensand possess the highest readiness levels. The selection comprises a mix of three onshore, four offshore, and one near-shore storage locations. Fifteen projects of CO_2 use options are illustrated in this area elaborating CO_2 conversion into methanol and synthetic jet fuel. The choices of transportation interconnecting these emitters and storage sites run the gamut from backbone high-pressure pipeline networks receiving CO_2 from low-pressure local pipelines, batch transportation via trucks or ships, to direct shipping lines to storage. Given the variation in CO_2 conditions and specifications at the point of capture, relative to those needed for dense phase transport or storage, it was crucial to strategically situate, design, and size the indispensable compression and liquefaction facilities to suit all defined scenarios. This approach ensures reliable and efficient CCUS operations, optimized for the specifics of each scenario.

The legal analysis showed that Denmark in particular has an advanced and favourable legal framework for storage of CO_2, making it a suitable storage country in a value chain from a legal point of view. Also, Sweden, Denmark and Germany are all members to the London Protocol, with Denmark having enabled cross-border collaboration on their part pursuant to the Protocol criteria. Sweden has similarly enabled cross-border collaboration under the Protocol, having also submitted a declaration of provisional application. Germany has not yet submitted a declaration, which is necessary before export can occur under the Protocol if the intended storage site is offshore.

In essence, this paper provides detailed visibility into the construction of an extensive, cross-border CCUS initiative - an invaluable blueprint for future endeavours aimed at achieving significant CO_2 abatement in alignment with broader emission reduction goals.

Keywords: CCUS, Baltic region, CO_2 clusters, technoeconomic analysis

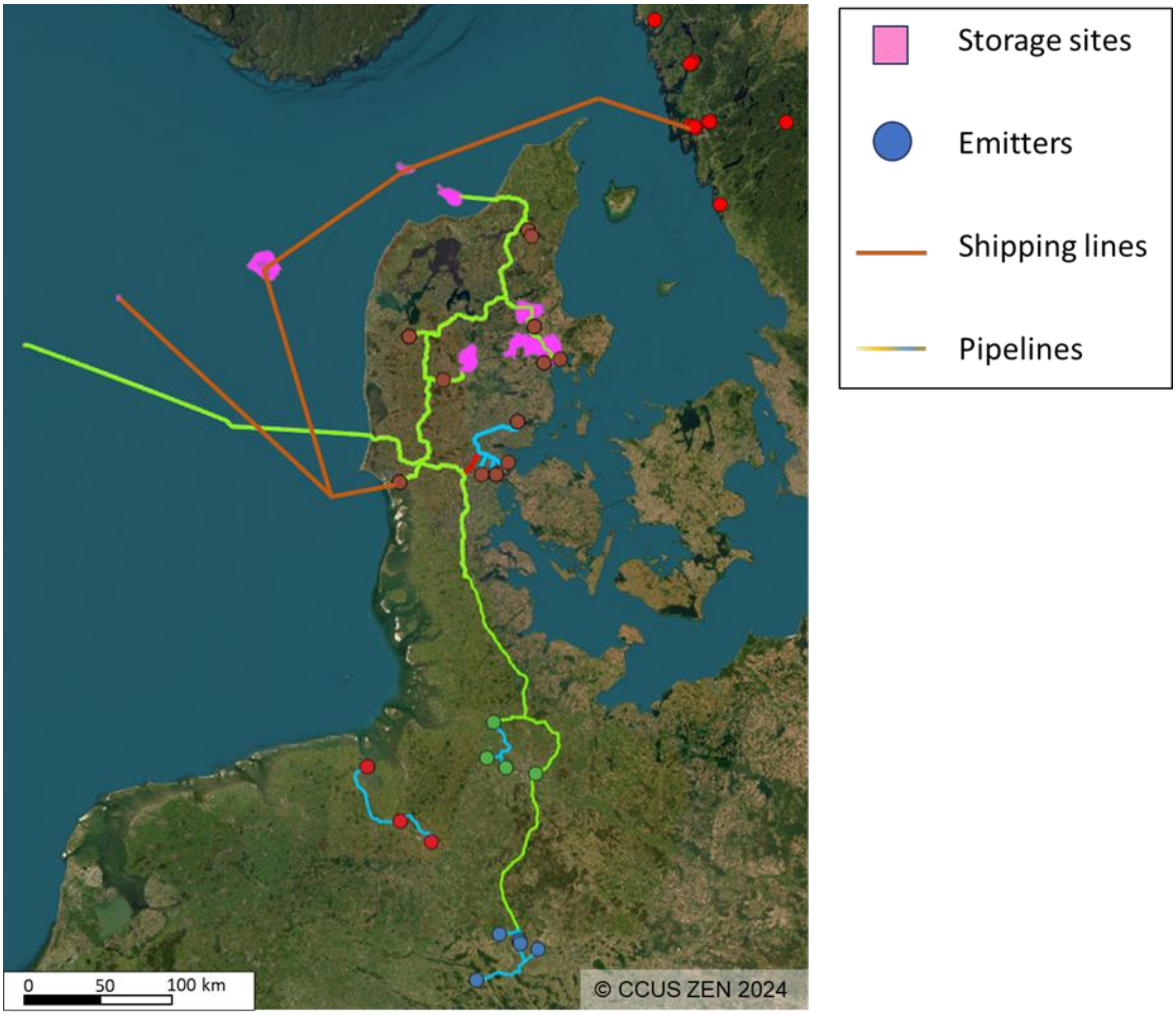

Figure 1: Schematic representation of the Baltic-2 CCUS network (Germany, Denmark and Sweden).