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

20th -24th October 2024 Calgary, Canada

A framework for regional high-level technical screening of promising CCUS value chains

Ane Elisabet Lothe[a]*, Isaline Gravaud[b], Cathrine Ringstad[a,c], Eirik Falck da Silva[a], Ragnhild Skagestad[a], Alla Shogenova[d], Kazbulat Shogenov[d], Leandro Sousa[e], Adam Wójcicki[f], Çağlar Sınayuç[g], Betül Yıldırım[g], Sevtaç Bülbül[g], Karen Anthonsen[h], Anastasios Perimenis[i]

[a]*SINTEF Industry, Applied Geoscience Department, Postbox 4760 Torgarden, 7465 Trondheim, Norway*
[b]*BRGM , 3 avenue Claude Guillemin, 45060 Orléans Cedex 2, France*
[c]*Bellona Foundation, Rådhusgata 28, 0150 Oslo, Norway*
[d]*Tallinn University of Technology, Department of Geology, Ehitajate tee 5, Tallinn 19086, Estonia*
[e]*Ramboll, Energy Transition department, Hannemanns Allé 53, Copenhagen S 2300, Denmark*
[f] *Polish Geological Institute – National Research Institute, 4, Rakowiecka Street, 00-975 Warsaw, Poland*
[g]*Middle East Technical University (METU) Petroleum Research Center, 06800 Ankara, Türkiye*
[h]*GEUS– Geological Survey of Denmark and Greenland, Øster Voldgade 10, 1350 Copenhagen, Denmark*
[i]*CO_2 Value Europe, Avenue de Tervueren 188A, Brussels 1150, Belgium*

Abstract

There is a need to accelerate the deployment of Carbon Capture, Utilization, and Storage (CCUS) throughout Europe. As a part of this, the CCUS ZEN project has looked at identifying promising value chains based on technical mapping of emission sources, utilization options, transport infrastructure and storage sites. This high-level screening has been carried out for two selected regions: the Baltic Sea region and the Mediterranean Sea region.

First, a screening of the emission sources in each geographical region led to the identification of promising sites for CO_2 capture. The focus was on identifying clusters of emitters, where CO_2 could be captured from different industrial plants and gathered at a hub before transport to the storage site. The emitters can also be identified as promising depending on their amount of emission, location, type of industry, etc. For each emission source, information about the facility was collected, along with information about the facility's emissions. The screening of potential storage sites in the geographical region was carried out based on public and available data. For each mapped storage site, information was gathered about the type of reservoir (deep saline aquifer or depleted hydrocarbon field), the onshore or offshore location, the capacity of the reservoir and the Storage Readiness Level indicating the maturity of the capacity evaluation. For the infrastructure screening, we looked at existing infrastructure relevant for CO_2-transport with emphasis on pipelines, existing natural gas corridors, waterways and ports. If transport using pipelines or waterways were not an option, also railways and road (lorries) were evaluated.

Thereafter, one or more chains were suggested, linking one or more emission clusters to one or more storage sites. The total emission volumes of the clusters and the storage capacities were considered. It was recognised that actual volumes should be treated with caution. On the storage side, the maturity level of the capacity

---

* Corresponding author. Tel.: +47 93263605 *E-mail address:* AneElisabet.Lothe@sintef.no

Electronic copy available at: https://ssrn.com/abstract=5068864

estimation is often low, resulting in potential smaller capacities when the resource is further assessed. Also, crucial data can be missing or confidential, which makes detailed studies and dynamic reservoir modelling challenging. The total volumes of the clusters' emission do not necessarily represent the amount of captured CO_2, but rather a maximum, as not 100% of the emissions would necessarily be captured. The potential for carbon utilisation was assessed by identifying existing CO_2 use projects and looking at the potential availability of renewable energy and biogenic CO_2.

Keywords: caputure, transport, storage, mapping, Europe, CCUS

---

1. Introduction

There is an increasing demand to accelerate the deployment of Carbon Capture, Utilization, and Storage (CCUS) throughout Europe, as a part of the European Green Deal, the European Climate Law and to increase climate energy and climate targets for 2030 [1] . As part of this, the EU funded network project CCUS ZEN has connected CCUS actors in Europe, to identify promising value chains and to share knowledge and experience. We carried out a high-level technical mapping focused on emission sources, storage sites, transport infrastructure, utilization options and renewables, alongside with non-technical mapping including stakeholder needs, regulations, climate policies and funding opportunities (Figure 1). These aspects should be considered when CCUS value chain are to be developed further after the initial technical high-level screening. A high-level screening of promising value chains has been carried out for two selected regions: the Baltic Sea region and the Mediterranean Sea regions [2]. The overall screening workflow was tested in the two geographical regions and led to the definition of at least 15 CCUS value chains, several with different transport solutions included, using ships or pipelines or a combination [3].

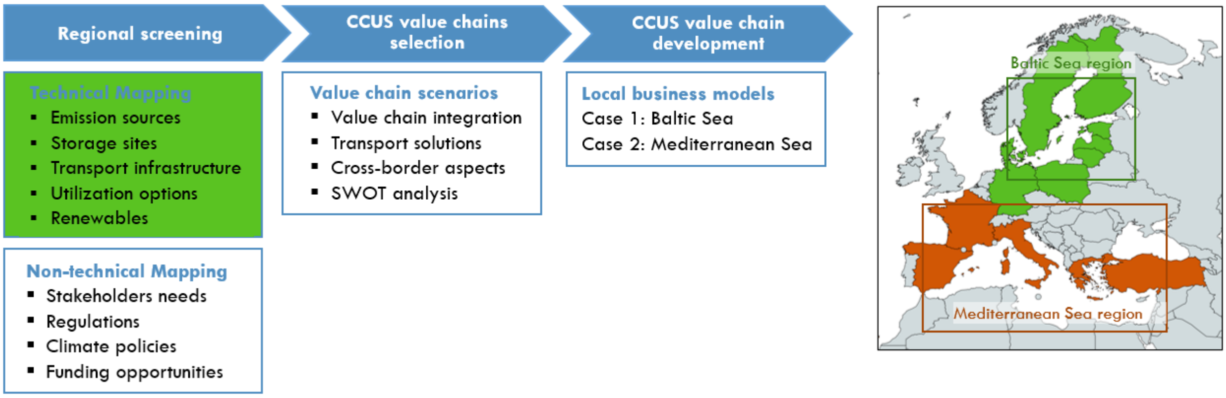

Fig. 1. Overview of work tasks in the CCUS ZEN project, with the regional high-level technical mapping marked in the green box.

2. Methodology for high-level CCUS technical value chain screening

Several studies have been carried out focusing on high-level CCUS value chain screening with scenario developments [4], infrastructures [5] or storage sites [6].

The high-level CCUS technical value chain can be subdivided into four main parts covering mapping of CO_2 emitters, infrastructure screening, storage sites screening and utilization as a final piece in the puzzle (see Figure 2). For each part of the value chain, several key input parameters are listed without ranking the importance, costs, or effort to get enough data to draw solid conclusion.

Electronic copy available at: https://ssrn.com/abstract=5068864

As part of the high-level CCUS technical screening, an open geographical information system (QGIS) has been used for mapping the emitters and storage sites from previous reports, and to illustrate emission clusters and possible transport routes, both existing and future infrastructures.

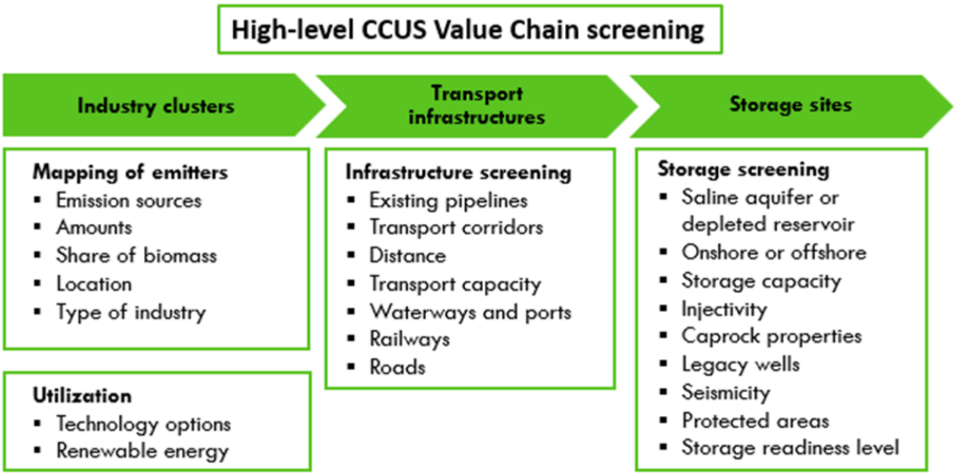

Fig. 2. Principal sketch presenting the main components to consider in the high-level technical CCUS value chain screening. From [7].

2.1. Mapping of emitters

Inspection of the emission sources in each geographical sector leads to the identification of promising sites for CO_2 capture. The focus is put on identifying clusters of emitters, where CO_2 could be captured from different industrial sites and gathered at a hub before common transport to storage. Yet, standalone emitters could also be identified as promising for CCUS value chains, depending on their amount of emission, location, type of industry, etc. For each emission source, information about the facility is collected (facility name, company, location, coordinates, and industrial sector), along with information about the facility's emissions (annual amount of CO_2 emitted, emissions trend, share of biomass, and waste-to-energy).

The CO_2 emission database in CaptureMap, provided by ENDRAVA is sourced from the EU Emissions Trading System (EU-ETS) and the European Pollutant Release and Transfer Register (E-PRTR). The EU-ETS data mainly includes the fossil-based CO_2 emissions, whereas the E-PRTR includes both fossil-based and biogenic CO_2 emissions. The E-PRTR dataset only includes the facilities with CO_2 emissions above 100 ktpa, while the EU ETS dataset also includes the facilities with smaller emission volumes (<100 ktpa). Since CaptureMap use the E-PRTR system as their basis for facilities in European countries, many facilities with CO_2 emissions less than 100 ktpa are not included in CaptureMap database.

Data from CaptureMap provided by Endrava are used for mapping CO_2 emissions sources in the Baltic Sea region (Denmark, Sweden, Finland, Germany, Estonia, Latvia, Lithuania, Poland) and the Mediterranean Sea region (France, Spain, Italy, Greece, Türkiye). The emission data were quality-checked, and amended where necessary, by the CCUS ZEN partners in Denmark, Sweden, Finland, Estonia, Latvia, Lithuania, Poland and France. Since Türkiye is not covered in the CaptureMap database, this mapping is carried out in the project by the Türkiye partner [2] . The reported CO_2 emissions are in general from 2021, except for some facilities where only older data are available. Clusters are defined, with the total amount of emissions, the number of facilities in the cluster, and the share of each industrial sector in the total emissions.

Electronic copy available at: https://ssrn.com/abstract=5068864

2.2. Mapping of infrastructures

For the infrastructure screening, we looked at existing infrastructure relevant for CO_2-transport with emphasis on pipelines (onshore and offshore), existing natural gas corridors, waterways and ports. Existing pipelines could either be reused if they have the specification needed (temperature and pressure limitations, material etc.) or the pipeline corridor can be used as a route for a new CO_2 pipeline. Depending on the pressure requirement in the reservoir, it may be suitable to use booster pumps. If transport using pipelines or waterways are not an option, also railways and road (lorries) are evaluated.

There are multiple ways to transport CO_2 which include pipelines, ships, trucks/lorries or railways. All methods are often combined with pre- and/or post-processes such as compression and drying of the CO_2 stream, removal of impurities, liquefaction and intermediate storage solutions. Larger CO_2 quantities, such as usually estimated for a CO_2 cluster require either a pipeline or ships, or a combination of both. This sub-section presents a high-level comparison between the two transportation methods.

The best transportation is often a combination of multiple methods that balances costs with convenience, practicality and compliance with safety, and legal and environmental requirements. Pipelines are commonly the safest and most economical way to transport large quantities of CO_2 over short to medium distances. On the other hand, pipelines are not a temporary flexible infrastructure and must be considered for long-term operations. They require a high initial investment, but reduced OPEX. Re-utilisation of existing infrastructure may, therefore, be a key for such projects. OPEX may also be reduced by combining processes like drying or compression with the emitter's industrial processes which produce heat or cold. Construction of a CO_2 pipeline should consider the environmental impacts and routes might be concerned by deviations of protected areas. Residential or densely populated areas may be a risk factor for the presence of CO_2 pipelines as well. Pipelines can transport CO_2 at gaseous, liquid or supercritical phases. Currently, there are approximately 8000 kilometres of onshore CO_2 pipeline in the US today. In Norway, one offshore CO_2 pipeline is built in the Northern Light project.

Shipping is a more flexible operation and is viable for longer distances and also for smaller volumes. While the CAPEX costs are lower and the ships can be repurposed after the project closure, the OPEX costs are a main decision driver. Residential areas are not an obstacle in ship traffic and compliance to environmental restrictions is easier. On the other hand, shipping is dependent on the existence of suitable harbours and cannot travel onshore. Shipping logistics commonly require a large intermediate storage and CO_2 can only be transported in liquid phase. Commonly today, 1500 to 3000 tonnes vessels are used in the food industry, and the transport conditions are 15 bar and -28°C. It is foreseen that the ship size for CCS project will be larger, but it depends on the logistic chain.

For transportation the mapping tool developed in the CO2LOS project was used to identify opportunities in ship transport or barges, while PCI Transparency Platform, combined with OpenStreetMap, was used for pipelines. Additionally, the European Network of Transmission Systems Operators for Gas (ENTSOG) provides a yearly updated map with an overview of existing gas pipeline infrastructure and projections for future development.

2.3. Mapping of storage sites

There are two main categories for underground carbon dioxide storage; we have saline aquifers and depleted reservoirs that have been used for previous oil and gas production. Other geological storage options, like mineral carbonisation in basaltic rocks was not considered, since such sites have not been mapped in detailed in the previous projects.

The amount of CO_2 to be stored underground, is very much dependent on the media for the storage and the injectivity. The subsurface storage aquifers or permeable geological formation can be defined as a regional aquifer, a storage assessment unit, and has an upper limit defined by where the CO_2 will be in supercritical phase (approximately below 800 m depth, depending on pressures and temperature variations). The lower limit is defined by the porosity and permeability to the reservoir units and will be defined on what is seen as an acceptable injection rate. In the CCUS ZEN project, the classification of storage structures is built on methodology outlined in [8]. There exist several methods to calculate storage capacity. The storage capacity can in general terms be described as the pore volume of the aquifer in the storage assessment unit region multiplied with the storage efficiency factor (fraction of pore space where CO_2 "can" be injected). In the CCUS ZEN project, the capacity formulas [9] have been used [2] .

Electronic copy available at: https://ssrn.com/abstract=5068864

The screening of potential storage sites in the geographical sectors is carried out and based on public and available data from projects such as GESTCO, GeoCapacity, CO2Stop, NORDICCS, Strategy CCUS, PilotSTRATEGY, and national projects. For each mapped storage site, information is gathered about the type of reservoir (deep saline aquifer or depleted hydrocarbon field), the onshore or offshore location, the capacity of the reservoir (mean value), and the SRL level indicating the maturity of the capacity evaluation based on [10].

2.4. Mapping of utilization

Carbon Capture and Utilization includes many technologies that can capture CO_2 directly from the air or from industry facilities and use it as feedstocks to produce products like chemicals, fuels and materials. Further details and description of different CCU technologies can be found in [10, 11 and 12].

In the high-level screening of utilization, the main source has been the CO_2 Value European database on CCU, that has been developed though previous EU projects like SCOT and IMPACTS and contains approximately 150 ongoing and upcoming projects at different TRL levels.

3. Results of the high-level screening mapping

Figure 3 shows the results of the high-level screening mapping for the Baltic and Mediterranean regions, with emission sources and storage sites marked. The number of facilities and CO_2 emission sources varies largely between the countries, with large emitters in both regions (Table 1). Large emitter clusters are seen in Poland and Germany in the Baltic region and Italy and Turkey in the Mediterranean Sea Region. For the storage sites, large deep saline aquifers with large storage capacities are mapped for Denmark, with total capacity of 16 042 Mt, where depleted hydrocarbon fields are not included, and Poland with 8 885 Mt storage capacity. In the southern region, Spain, Italy and Greece show large storage capacities (around 3.1 – 4.8 Gt).

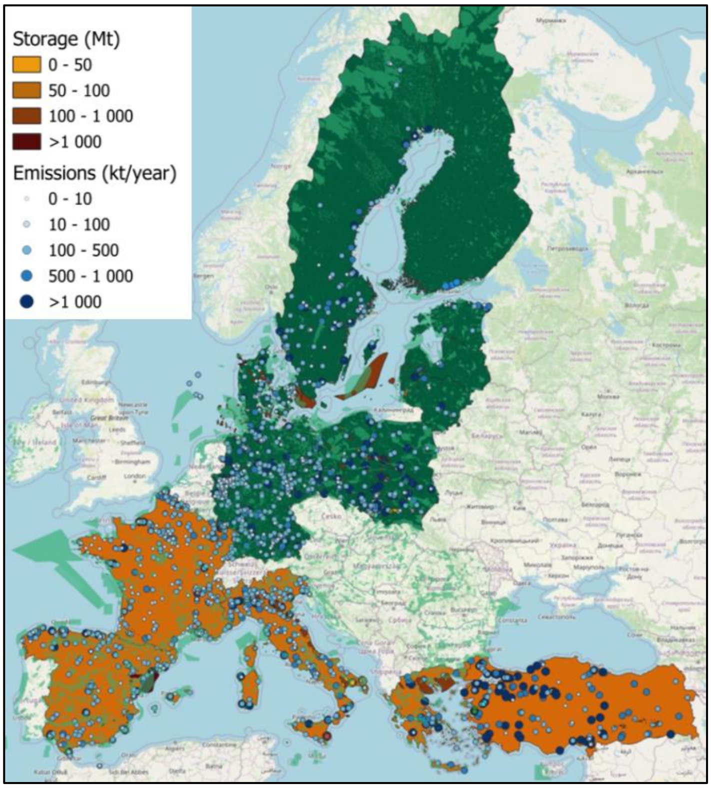

Fig. 3. High level mapping of emission sources and storages sites for the Baltic region (dark green colour) and Mediterranean region (orange colour). Natura 2000 area is marked with light green colour. From [2].

Electronic copy available at: https://ssrn.com/abstract=5068864

Table 1. Number of facilities and corresponding CO_2 emissions for countries in the CCUS ZEN Baltic Sea and Mediterranean Sea regions.

Country	Number of facilities	Facilities with CO_2 emissions above 100 kton/year [kton/year]
Denmark	33	11 834
Sweden	95	51 036
Finland	74	46 033
Germany	405	365 840
Estonia	13	8 643
Latvia	3	1 654
Lithuania	9	5 588
Poland	164	189 159
Sum Baltic Sea region	**796**	**689 347**
France	258	99 995
Spain	199	90 475
Italy	204	120 538
Greece	39	32 242
Türkiye	175	357 888
Sum Mediterranean region	**875**	**701 137**

Table 2. Potential storage sites in the CCUS ZEN Baltic Sea and Mediterranean Sea regions.

Country	Number of deep saline aquifers	Number of hydrocarbon fields	Total capacity (Mt)	References
Denmark	27	Not included	16 042	[14, 15]
Sweden	9	0	3 420	[16]
Finland	0	0	0	-
Germany	34	Not included	3 539	[15, 17]
Estonia	0	0	0	-
Latvia	17	0	1172	[18, 19, 20, 21,22]
Lithuania	12	5	299	[17, 19, 23]
Poland	55	39	8 885	[24], Pers. com. Wójcicki, A. (2023): Calcul. based on the pore volume published in [15] and using the CSFL methodology with SEF = 20% which is comparable to other German and Polish site calculations.
Sum Baltic Sea region			**33 357**	
France	4	20	739	[9, 25]
Spain	17	Not included	4 816	[9, 17, 25]
Italy	14	11	4 699	[9]
Greece	5	2	3 174	[9, 26]
Türkiye	Not evaluated	109	109	[27]
Sum Mediterranean Sea region			**13 537**	

Electronic copy available at: https://ssrn.com/abstract=5068864

4. Discussion

There are several challenges in the mapping of a CCUS value chain and this will vary along the value chain. For emission sources, there are some complexities in deciding which industry sites should be prioritized for CCS. The emission sources are subdivided depending on type of industry, varying from refineries, chemicals, power, hydrogen, energy from waste, cement, paper and pulp, iron and steel and others. For some industries CCS is the obvious option to reduce emissions, while in other cases CCS may be one of several options (some form of electrification often being another). The level of CO_2 emissions in the future and longevity of an industrial plant can also be a factor in considering the deployment of CCS. Information on this is however difficult to obtain. Information can be commercially sensitive and there may also be political considerations that are hard for us to assess. For this reason, in this high-level screening, only the current emission levels from different industries are considered.

When choosing the emitters hub, several factors were evaluated. The type of industry, the number of emission sources and not least location are very important factors. If there are several large industry clusters that can share common infrastructure, like pipelines and/or buffer storage and/or ship transport, this can be very central for building out an emission hub. In addition, the possibility to share a storage site would be beneficial for the emitters and for the one owning the storage site.

For CO_2 emitters, a hub structure is attractive [28] to reduce the risk for each industry actor. A hub structure also reduces the risk that transport, and storage infrastructure will be underutilized. A hub with more emitters will be less dependent on the emissions of a single industrial site for maintaining a high degree of utilisation.

As a result of the development of common infrastructures for transporting and storing emissions from different industries, there is likely to be a need for common specifications for fluid composition and pressure/ temperature conditions [29] . A better understanding of the reasons behind the limitations of the impurities given for the transport and storage infrastructure will make it easier to find solutions that is optimal in a whole chain perspective, and not only for parts of the chain. There is an ongoing debate if a common specification should be given to make it easier to transport CO_2 from different sources to several logistic network, or if each network should find its own specification based on the need for limitations related to their material choice, storage possibilities etc. The cost for extra purification is often high, and trying to find the lowest possible purification steps needed could potentially reduce costs.

In the screening, the total emissions amount of the clusters and the storage capacities are considered. However, it is recognised that actual total CO_2 emission volumes should be treated with caution. On one side, the total amount of the clusters' emission does not exactly represent the amount of captured CO_2, but rather a maximum, as not 100% of the emissions would necessarily be captured. For some industries transitioning to renewables or biogenic feed stocks may be more attractive and easier to implement.

To develop a high-level value chain, all the present and future stakeholders along the value chain need to be informed and aligned. There are several main actors and driving forces that would be shaping CCUS value chains, and these should be involved in the workflow. There is a strong interdependency of stakeholders with different interests, from industry with emitters, to transport and storage owners. To be able to reduce the risks, both economically and in terms of time spent, partnerships (or collaboration between stakeholders) across the value chain should be in place. Reducing the uncertainty, both in storage capacity, storage injectivity and longevity of a storage site, is important. One major bottle neck at present, is the lack of open geological datasets, both 2D and 3D seismic dataset, and/or data from wells for potential storage formations. In the CCUS ZEN project we had project partners from the two geographical regions in the project. Even with many research institutes and key industry actors involved, it was challenging to get access to datasets to make reliable estimates for storage potential. The underlying datasets needed such as interpreted 2D seismic or 3D seismic, data from existing wells, geological models and/or reservoir models are seldom publicly available. Scarce data cover is a major challenge in many regions, and in CCUS ZEN project, the mapping of storage sites was heavily relying on previous research projects. As the screening of potential storage sites was based on public and available data, it resulted in varying mapping coverage.

Another challenge related to storage sites mapping is the capacity of these potential storage sites. Indeed, databases present a large number of sites with too little storage capacity for an operational CCS project to take place. For example, in Southern France, existing capacity data are on the order of few tens of Mt, even smaller, per site. It is then challenging to find sufficient storage capacity for the identified emission clusters and build large-scale value chains. This is also a reason why transnational scenarios were developed. Finland is lacking any storage potential,

Electronic copy available at: https://ssrn.com/abstract=5068864

since they have only bedrocks, and therefore the selected value chain suggested in CCUS ZEN is pipeline or ship transport from Helsiniki, Finland to Rødby, storage site in Denmark [3]. Sweden has sedimentary deposits in the Baltic Sea, like the Cambrian Faludden Formation, but with low storage potential e.g. dipping aquifer, with small natural closures e.g. [30]. However, the structures continue southwards at Polish side, and may serve as a potential storage structure.

Mapped in a number of European countries, extensive and relatively deep onshore regional Mesozoic aquifers including local traps (e.g. anticlinal structures) can be used both for CCS and geothermal purposes. For example, regional Lower Jurassic aquifer covering large part of Poland is deemed as one of primary geothermal reservoirs of the country and is utilized in a number of district heating (and other) geothermal installations and many such geothermal projects are being completed or planned now. However, if CCS projects would use local traps/structures located outside population centres where district heating could be switched to geothermal, then such competition could be mitigated.

Both in the northern and southern North Sea are competing interests with the oil and gas industry, not so much on the areas, as CO_2 licences are awarded by the governments, but we foresee on the pore pressures. If CO_2 storage will lead to higher pressures in some reservoirs or aquifer, these may have an impact on neighbouring CO_2 storage sites and/or oil and gas production. However, these challenges have not been evaluated in the CO_2 storage screening but should be considered in future dynamic simulations.

5. Conclusions and recommendations

The high level CCUS value chain screening can be summarised in Figure 2, with mapping of emitters, transport infrastructure and storage sites, and utilization as a theme closely connected to capture screening.

High-level CCUS value chain screening is the first step, evaluating the main tasks and research tasks that needs to be addressed. The screening should be a tool to gather interesting stakeholders for further work and future in-depth analysis. Thereafter, more input data, further analysis and modelling are needed to mature and qualify a CCUS value chain.

From the technical screening work performed, the main recommendations we can draw from for further development of CCUS value chains are:

- Include and anchor with all entities; also include research institutes and academia, in addition to government and NGOs in the process.
- Have all key stakeholders involved – actors from the whole CCUS chain.
- Design the value chain from an industrial and regional reality in order to provide a solution to an identified need.
- Improve geological knowledge to decrease uncertainties related to storage capacity and leakage risks.
- Improve access to data: Aim for open data and sharing of data. This is especially important for dataset linked to storage sites, to mature the site and level the Storage Readiness Level.
- Consider emitters from hard-to-abate industries (cement, etc.) as potential anchors for the clusters
- We also recognise that non-technical aspect, such as legal regulations, social acceptance and economic factors, are important factors also for the technical mapping.

Acknowledgements

This study is supported by the CCUS ZEN project which has received funding from the European Union’s Horizon Europe research and innovation programme under grant agreement No 101075693. CCUS ZEN is grateful for the contribution given by the networking partners BGR (Federal Institute of Geosciences and Natural Resources, Germany), SGU (Geological Survey of Sweden) and IGME (Geological and Mining Institute of Spain, Spanish National Research Council) to the mapping of potential storage sites in their respective countries. We are also grateful to CERTH (Centre for research and technology Hellas) for their contribution to the capacity estimates for storage sites in Greece.

Electronic copy available at: https://ssrn.com/abstract=5068864

References

[1] Commission Communication on industrial carbon management (COM/2024/62)

[2] Ringstad et al. (2023), Deliverable 1.1 High-level regional mapping of CO2 emission sources, utilization industry and infrastructure in the Baltic Sea and Mediterranean Sea regions. Open report in EU Horizon Europe CCUS ZEN. Project 101075693.

[3] Gravaud et al. (2024) Deliverable 1.2 Identification of promising CCUS value chains in the two ZEN regions for further analyses in WP3. Open report in EU Horizon Europe CCUS ZEN. Project 101075693.

[4] Jakobsen JP, Brunsvold A. Development of Scenarios for Carbon Capture and Storage ECCO - European value chain for CO2. Energy Procedia 2010; 4, 2677-2684.

[5] Kjärstad J, Johnsson F, Ramp-up of large-scale CCS infrastructure in Europe. Energy Procedia 2009; 4201-4208.

[6] Anthonsen KL, Aagaard P, Bergmo PE, Gislason SR, Lothe AE, Mortensen GM, Snæbjörnsdottir SO. Characterisation and selection of the most prospective CO_2 storage sites in the Nordic region. Energy Procedia 2014; 63, 4884-4489.

[7] Lothe et al. (2024) Deliverable 1.3 A framework for regional high-level technical screening of promising CCUS value chains. Open report in EU Horizon Europe CCUS ZEN. Project 101075693.

[8] Gammer D, Green A, Holloway S, Smith G. The Energy Technologies Institute's UK CO2 Storage Appraisal Project (UKSAP). SPE Offshore Europe Oil and Gas Conference and Exhibition held in Aberdeen, UK, 6–8 September 2011. SPE number 148426.

[9] Vangkilde-Pedersen T, Anthonsen K, Smith N, Kirk K, NF, Van der Meer B, Le Gallo Y, Bossie-Codreanu D, Wojcicki A, Le Nindre Y, Hendricks C, Dalhoff F, Christensen N. Assessing European capacity for geological storage of carbon dioxide – the EU GeoCapacity project, Energy Procedia 2009; 2663-2670.

[10] Akhurst M, Kirk K, Neele F, Grimstad A, Bentham M, Bergmo P. Storage Readiness Levels: communicating the maturity of site technical understanding, permitting and planning needed for storage operations using CO2. International Journal of Greenhouse Gas Control 2021; 110, 103402. https://doi.org/10.1016/j.ijggc.2021.103402.

[11] IEA (2019) Putting CO2 to use: Creating value from emissions, 86 p.

[12] Chavez, E & Partenie, O (2020) Global CCU infrastructure market assessment, ECCSELRATE, Deliverable D1.3, 13 p.

[13] NASEM (2019) Gaseous carbon waste stream utilization – status and research needs

[14] Hjelm L, Anthonsen KL, Dideriksen K, Nielsen CM Nielsen LH, Mathiesen A. Evaluation of the CO2 storage potential in Denmark (GEUS rapport 2020/46).

[15] Anthonsen KL, Bernstone C, Feldrappe H. Screening for CO2 storage sites in Southeast North Sea and Southwest Baltic Sea. Energy Procedia 63 (2014) 5083 – 5092.

[16] Mortensen GM, Sopher D. Rapportering av regeringsuppdrag. Geologisk lagring av koldioxid i Sverige och i grannländer - status och utveckling 2021. In Swedish. https://resource.sgu.se/dokument/publikation/rr/rr202104rapport/RR2104.pdf

[17] Poulsen N, Holloway S, Neele F, Smith NA, Kirk K. CO2STOP Final Report. Assessment of CO_2 storage potential in Europe 2014. https://energy.ec.europa.eu/publications/assessment-co2-storage-potential-europe-co2stop_en

[18] Šliaupiene R. Prospects of CO2 Geological storage in the Baltic Sedimentary Basin. PhD thesis, in Lithuanian. 2004, 170 pp.

[19] Shogenov, K., Shogenova, A., Vizika-Kavvadias, O. (2013). Petrophysical properties and capacity of prospective for CO2 geological storage Baltic offshore and onshore structures. In: Energy Procedia. (5036−5045). Elsevier. DOI: 10.1016/j.egypro.2013.06.417.

[20] Shogenov K, Shogenova A, Vizika-Kavvadias, O. Potential structures for CO_2 geological storage in the Baltic Sea: case study offshore Latvia. Bulletin of the Geological Society of Finland 2013; 85 (1), 65−81.

[21] Shogenova A, Sliaupa S, Vaher R, Shogenov K, Pomeranceva R. The Baltic Basin: structure, properties of reservoir rocks and capacity for geological storage of CO2. Estonian Journal of Earth Sciences 2009; 58 (4), 259−267.

[22] Simmer K. Estonian-Latvian Transboundary Carbon Dioxide Capture, Transport and Storage (CCS) Scenario for the Cement Industry. Master Thesis. Tallinn University of Technology; 2018:1-48.

[23] Šliaupienė R, Šliaupa S. Prospects for CO_2 geological storage in deep saline aquifers of Lithuania and adjacent territories. Geologija. 2011. Vol. 53. No. 3(75). P. 121–133.

[24] Wójcicki A, Nagy S, Lubaś J, Chećko J, Tarkowski R. Assessment of formations and structures suitable for safe CO2 storage (in Poland) including the monitoring plans 2014 (https://skladowanie.pgi.gov.pl/twiki/pub/CO2/WebHome/seq-summ.pdf) and updates by Wójcicki, A. (2023).

[25] Veloso FML. Maturity level and confidence of storage capacities estimates in the promising regions 2021; EU H2020 STRATEGY CCUS Project 837754, Report, pp 125.

[26] Koukouzas N, Tyrologou P, Karapanos D, Carneiro J, Pereira P, de Mesquita Lobo Veloso F, Koutsovitis, P, Karkalis C, Manoukain E, Karametou R, Carbon Capture, Utilisation and Storage as a Defense Tool against Climate Change: Current Developments in West Macedonia (Greece), Energies 2021 Vol. 14 Issue 11 Pages 3321, DOI: 10.3390/en14113321

[27] Bas D, Akpulat O. Technical Assistance for Developed Analytical Basis for Formulating Strategies and Actions Towards Low Carbon Development – Turkey capacity Report 2019; EuropeAid/136032/IH/SER/TR.

[28] Wang, R. Status and perspectives on CCUS clusters and hubs. Unconventional Resources 4 (2024)100065.

[29] Neerup, R. et al. A call for standards in the $_{CO2}$ value chain. Environmental Science & Technology 2022; 56, 17502-17505.

[30] Lothe AE, Bergmo PES, Emmel BU, Mortensen,GM. CO_2 storage capacity estimates for a Norwegian and a Swedish aquifer using different approaches - from theoretical volumes, basin modelling to reservoir models, In: Singh TN, editors. Geologic Carbon Sequestration: Understanding Reservoir Concepts. Springer International Publishing; 2016, p. 98-117.

Electronic copy available at: https://ssrn.com/abstract=5068864