The Storage Play Quality Index (SPQI): a multidisciplinary CO_2 storage screening methodology

Gregor Duval[1]*, Robert Porjesz[1], Simon Otto[1], Carl Watkins[1], Mohammad Nassir[1], Alina Didenko[1], Pablo Cifuentes[1] and Carolina Olivares[1] present a method for the quantitative assessment of the subsurface suitability of saline aquifer CO_2 storage sites using a case study example from the Northern North Sea.

Introduction

The Paris Agreement (UNFCC 2016) and subsequent ratifications (COP26 2021) provided a pathway to reduce global anthropogenic CO_2 emissions with the goal of limiting global temperature rise to less than 2 degrees Celsius. An essential part of these agreements is carbon capture and storage (CCS) in geological rock formations. In the IEA Sustainable Development Scenario, CCS accounts for nearly 15% of the cumulative reduction in emissions compared with the Stated Policies Scenario (IEA, 2020). The projections for future CO_2 storage requirements, given the continued role of fossil fuels in the energy mix, necessitate a rapid increase in sequestered CO_2 volumes; from ~35.8 Mt/year today (Liu *et al*., 2023) to around 10 Gt/year by 2070 (IEA 2020;). In order to provide the CO_2 storage requirement in a short timeframe, large numbers of safe storage sites have to be identified. In this paper we present a basin-scale CCS screening methodology to help identify and prioritise suitable areas for the geological storage of CO_2.

Several CCS site screening methodologies have been published including the UK CO_2 Stored (Bentham *et al.* 2014), Norwegian Petroleum Directorate CO_2 Storage Atlas (Halland *et al.* 2013), the European CO2StoP (Poulsen *et al.* 2015) and DOE-NETL (Levine *et al*. 2016). All of these focus on high-level storage capacity estimations of the geological formations in the areas of interest and CO_2 sources, economic criteria and financial criteria (e.g. Bump *et al.* 2021; Sun *et al.* 2021). However, the limiting factor in most geological formations for CO_2 storage is not the capacity of the reservoir itself, but the injectivity (the volume of CO_2 that can be injected in a given time (Valluri *et al.* 2021) and the geomechanical properties of the reservoir and seal (Alcalde *et al.* 2021). Only a small number of published methodologies include these as key factors (e.g. Callas *et al.* 2024).

The screening process discussed here, developed by the authors, is called the Storage Play Quality Index (SPQI) and uniquely combines geology, stratigraphy, petrophysics, reservoir engineering, geochemistry, geomechanics and data science to provide a quantitative assessment of the suitability and spatial variation of key candidate storage units. The SPQI is applicable to both saline aquifer storage, and depleted hydrocarbon field storage. It identifies specific prospective areas and storage units within the basin prior to further, more detailed analyses

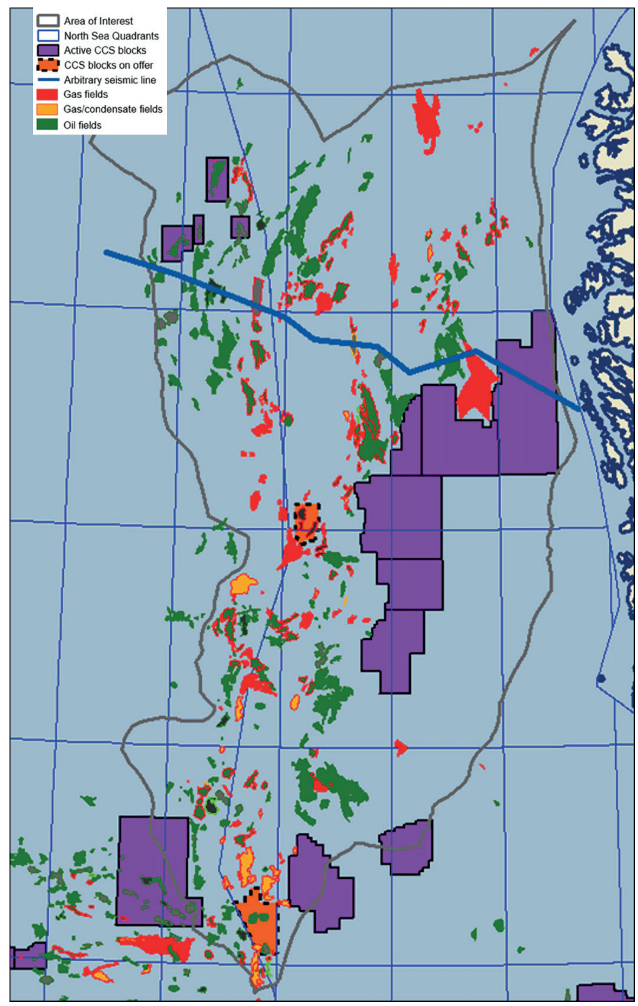

Figure 1 Basemap showing the Northern North Sea basin outline, quadrants and hydrocarbon fields in the area. The locations of the seismic section (Figure 2) and the Northern Lights licence area are also shown.

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DOI: 10.3997/1365-2397.fb2024084

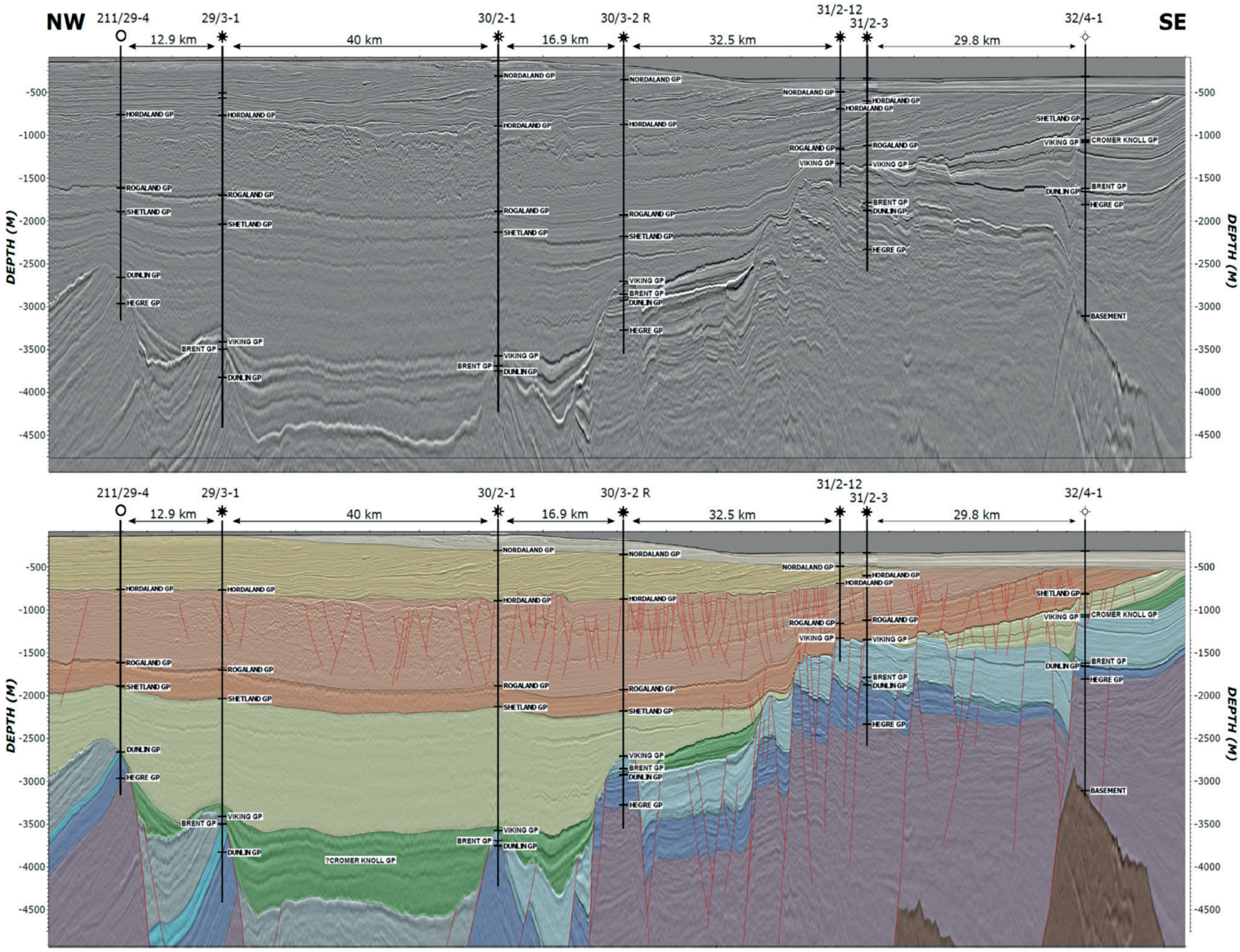

Figure 2 Representative 2D depth seismic section through the Northern North Sea Basin (above) and interpreted geoseismic section (below) highlighting the main structure styles and deposits within the basin. Selected well tops are displayed in both sections to aid the reader. The Oxfordian play interval discussed in this paper is present with the Viking Group (light blue).

(including for example prediction of injected CO_2 plume migration and detailed site integrity assessments). The methodology has been applied to multiple protractions in the shallow water US Gulf of Mexico, to basins in SE Asia and to the UK and Norway. Here we use an example of a basin-scale assessment of the Northern North Sea Basin covering an area of ~80,000 km^2 (Figure 1).

Northern North Sea tectono-stratigraphic evolution

To understand the CCS opportunities in the Northern North Sea it is crucial to understand the geology, which governs the locations, thickness, extent and quality of reservoirs and the presence and effectiveness of seals. The geological history of the Northern North Sea is characterised by major phases of extensional rifting during the Permian, Triassic and Late Jurassic periods and a good summary is provided by Underhill and Richardson (2022). A representative cross section (Figure 2) displays several of the key features in the study area, including the characteristic horst, graben and half graben structures in the pre-Cretaceous. The absence of much of the Upper Triassic and Lower Jurassic, due to the volcanic-related thermal doming that created the Mid-Cimmerian Unconformity, and the transition from active extension at the end of the Jurassic period to thermal subsidence in the Cretaceous is also evident. The latter led to the development of a thick Late Cretaceous and Cenozoic post-rift succession that overlies the heavily faulted preceding stratigraphy (Figure 2).

Stratigraphy of interest

The Northern North Sea is a prolific hydrocarbon region with multiple reservoirs that are candidates for CO_2 storage. For the purposes of this study three 'plays' were selected; 1) Paleocene (the Sele and Lista Formations), 2) Late Jurassic Oxfordian (Sognefjord, Brae, Heather and Kimmeridge Clay Formations), and 3) Early Jurassic Pliensbachian (Cook and Drake Formations) (Figure 3). This paper documents the SPQI methodology using examples from the Late Jurassic Oxfordian play interval. Whereas we typically define a storage play as a reservoir-seal couplet, within the UK and European Union carbon storage sites are required to demonstrate an effective secondary seal for containment and assurance purposes (EU Directive, 2009). The play components of reservoir, primary seal and secondary seal are briefly described below.

Late Jurassic Oxfordian reservoirs

There are several lithostratigraphic units which could form suitable storage reservoirs within the Late Jurassic Oxfordian play interval, including the Oxfordian parts of the Sognefjord

Formation, the Brae Formation and sand-prone parts of the Heather Formation. The Oxfordian elements of the Brae Formation predominantly comprise coarse siliciclastics deposited within fan aprons and fan deltas developed in the SW of the study area and derived from a mixture of degrading footwall highs, associated with active extensional faulting, and hinterland erosion. The Sognefjord Formation is developed in the eastern part of the study area and comprises deltaic, delta-front, shoreface and shallow marine deposits sourced from a long-lived hinterland drainage system to the east (Patruno *et al.* 2015). The Sognefjord Formation can be over 150 m thick and thins rapidly to the west, where deposition was strongly influenced by syn-sedimentary extensional faulting. The Sognefjord Formation interfingers with the Heather Formation, which is predominantly composed of mudstone and siltstone, with

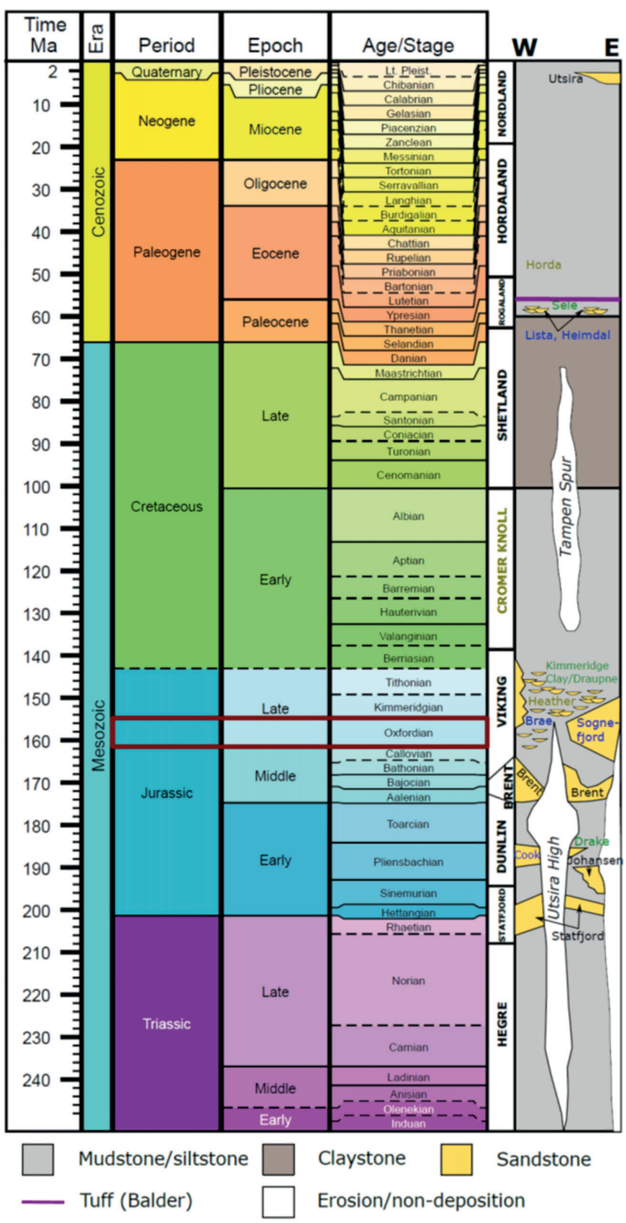

Figure 3 Example Chrono and Lithostratigraphic chart showing the geological age, lithostratigraphic terminology and typical lithologies. Blue writing indicates reservoirs, green indicates primary seals and brown indicates secondary seals within this study. Red box indicates the Oxfordian reservoir interval, the focus of this paper.

subordinate sandstones deposited in deep shelfal environments. Shallow marine shelfal sandstone units and density flow sandstones occur locally and are typically termed 'Heather Sandstones' or 'Intra-Heather Sandstones'.

Late Jurassic primary seal

The Oxfordian reservoir units described above are likely to be intraformationally sealed by the shelfal mudstones of the Heather Formation. However, parts of the Sognefjord Delta persisted into the Kimmeridgian and consequently the Kimmeridgian-Thithonian-aged black shale succession was selected as the primary seal for the Oxfordian reservoirs due to its regional extent, thickness and lithological consistency. These shales form the Kimmeridge Clay Formation and the Draupne Formation on the UK and Norwegian sides of the Northern North Sea, respectively. The Kimmeridge Clay-Draupne (KCD) Formation comprises organic-rich black shales that are the primary oil source rock in the region, and consequently the lateral extent and thickness is well documented. In the northern part of the Northern North Sea Basin the KCD Formation is thick and lithologically consistent, whereas in the south the shales are locally interbedded with sandstones of shallow marine and turbiditic origin, including, for example, the 'Intra-Draupne' sandstone unit that forms the main reservoir in the Johan Sverdrup field.

Late Jurassic secondary seal

The geological properties required for an effective secondary seal are similar to those required for a primary seal, that is a thick succession of laterally continuous and consistently impermeable strata. Although there are several potential candidates, the Cromer Knoll Group that comprises several lithostratigraphic formations that are predominantly composed of mudstones deposited in a shelfal depositional environment was identified as the secondary seal for our analysis. The formations include the Asgard, Valhall, Carrack, Sola and Rødby.

SPQI methodology

The SPQI methodology includes a two-stage process, with the first stage involving a targeted filtering process to determine the likelihood of reservoir presence and fundamental depth cut-offs. The second stage comprises a quantitative discipline-specific investigation that includes geology, petrophysics, reservoir engineering, geochemistry and geomechanics data analysis and interpretation (Table 1). In total 15 'technical storage components' were evaluated and individually mapped. Ultimately, the results are combined using a proprietary ranking calculation to generate a final SPQI output map that high-grades areas favourable for storage. The methodologies for the individual disciplines are briefly outlined below and the outputs of some disciplines inform and provide inputs for other disciplines.

To facilitate the integration of data from widely varying data types within a spatial (GIS) framework it was necessary to convert individual technical storage component values into a standardised index value, as outlined in Table 2. The index system consists of five categories (0 to 4) that define a simple traffic light system. The final SPQI value is based on a multiplication of the individual indices and represents an implementation of common risk segment

First pass filtering			Description
	1	Top depth (m)	Storage reservoir should be between 800 and 4000 m TVD
	2	Reservoir presence	Required storage reservoir should be present
Discipline	**Technical storage component**		
Geology	1	Net sand thickness (m)	Higher net thickness preferred for increased capacity and injectivity
	2	Primary caprock thickness (m)	Higher primary caprock thickness favoured to reduce containment risk
	3	Secondary caprock thickness (m)	Higher primary caprock thickness favoured to reduce containment risk
	4	Primary caprock lithology	Suitable facies needed to reduce containment risk (mudstone, shale or evaporites)
	5	Secondary caprock lithology	Suitable facies needed to reduce containment risk (mudstone, shale or evaporites)
Petrophysics	6	Reservoir effective porosity (%)	Higher porosity preferred for increased capacity and injectivity - Petrophysically-derived porosity utilising core and log data
	7	Reservoir effective permeability (mD)	Higher permeability preferred for increased capacity and injectivity – Petrophysically-derived permeability utilising core and log data
Reservoir engineering	8	Injectivity	Assessment of injectivity test from production data
Geochemistry	9	Pressure (Bar)	Reservoir pressure is a control on CO2 dissolution rates and density
	10	Temperature (C)	Reservoir temperature is a control on CO2 dissolution rates and density
	11	pH	Formation water pH is a control CO2 dissolution rates
	12	Salinity (mg/L)	Formation water salinity is a control CO2 dissolution rates
Geomechanics	13	Pressure Room (kPa)	Pressure room has an impact on ultimate storage capacity and containment
	14	Reservoir Shear Strength Level	Reservoir SSL indicates risks of existing faults reactivation due to shear stress within the reservoir interval
	15	Caprock Shear Strength Level	Caprock SSL indicates risks of existing faults reactivation due to shear stress within the reservoir interval

Table 1 List of the inputs for the SPQI methodology and a description of their use. Each technical storage component is itself derived from a methodology which is outlined in the text.

mapping as commonly applied in both the hydrocarbon exploration industry and for CCS (e.g. Bump *et al.* 2021). Importantly, a ‘zero’ score for any property indicates that the area is considered inappropriate for CO_2 storage, regardless of the other scores.

Data

The study utilised a large amount of data selected from more than 8000 exploration, appraisal, development and production wells from the UK and Norway, released by the North Sea Transition Authority and the Norwegian Offshore Directorate respectively. The released data is of variable quality and inconsistent format, reflecting the range of vintages and operators. The data from the well inventory amounts to hundreds of thousands of individual data files, which are impractical to review manually for a basin-scale screening study. Data science workflows developed by Viridien were executed to identify data coverage and to extract and format data into a workable digital database. The well data were used in combination with pre-existing Viridien multi-client datasets and studies, generated over several decades, and similarly converted into a single consistent database (GeoVerse™). Coupled with in-house experience and expertise, these rich and consistent databases formed the starting point for subsequent analyses. The primary data types and wells used for this study are outlined in Figure 4.

Lithology storage component	Very good (4)	Good (3)	Acceptable (2)	Bad (1)	Very poor (0)
Primary seal lithology	Mudstone	Sandy mudstone	Siltstone	Argillaceous sandstone	Sandstone or conglomerate
Secondary seal lithology	Mudstone	Sandy mudstone	Siltstone	Argillaceous sandstone	Sandstone or conglomerate

Table 2 Cut-off values for the primary and secondary seal lithology as an example on the conversion of discipline-specific data outputs for direct comparison with other data types.

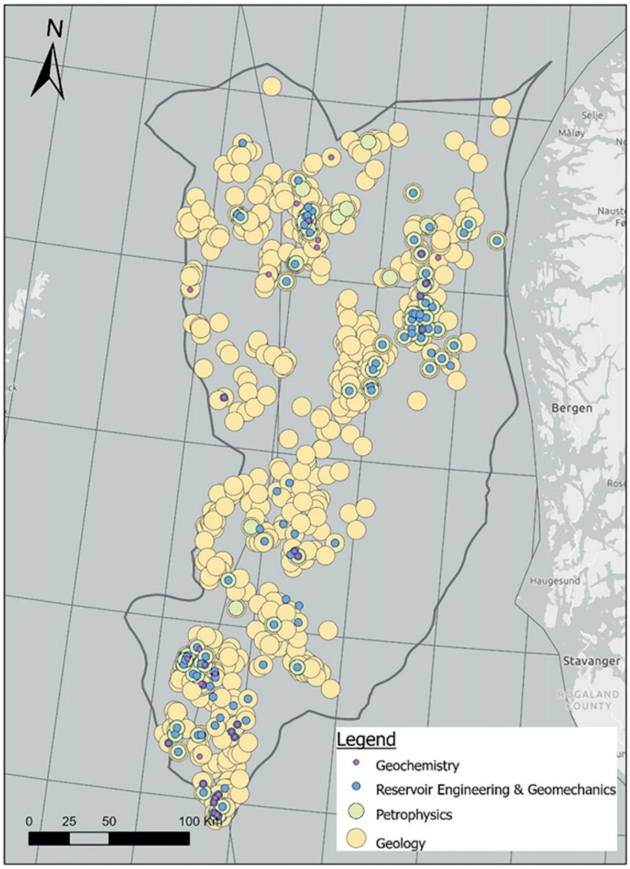

Figure 4 Map showing the well locations and data coverage utilised in this study.

First-pass criteria

The well database was first limited to the stratigraphic intervals of interest using chronostratigraphic and lithostratigraphic search terms to return wells with data for the identified play elements (reservoirs, primary seals and secondary seals). A depth cut-off was then applied to the reservoirs of interest. At the critical temperature and pressure, 31.0°C and 7.377 MPa respectively (Ringrose *et al.* 2021), CO_2 becomes supercritical and behaves like a gas but with the density of a liquid, occupying just 0.32% of the volume of gaseous CO_2 at surface conditions (Ringrose 2020). These temperature and pressure conditions are typically encountered at a depth of approximately 800 m True Vertical Depth (TVD) and beyond, providing an upper depth cut-off to the reservoir data. A lower depth cut-off of 4000 m TVD was applied due to complications associated with pressures and reservoir quality. Interval depth maps were constructed, constrained for key wells by ties to recent multi-client 3D seismic. A guided depth contour algorithm was used to contour the well tops data using the pre-existing mapped contours and fault data as controls.

Geology

New Gross Depositional Environment (GDE) and lithology maps were generated for the reservoir, primary seal and secondary seal using a combination of pre-existing Viridien multi-client data, extracted data from the public domain and published work. The maps identify the distribution within each play of lithologies considered as candidate reservoirs. A similar process was carried out for the primary and secondary seals. In common with all other data types, the derived data values are converted to index values to facilitate the subsequent multidisciplinary integration. In the case of the primary and secondary seals the mapped lithologies were converted to index scores as shown in Table 2. Integrating the reservoir, primary seal and secondary seal defined a new set of polygons that defined the play-specific focus areas for subsequent analysis.

Petrophysics

Petrophysical data is a bridge between physical rock data, geomechanical and geophysical rock properties. The analyses used in this study incorporated both pre-existing public domain and in-house datasets. QC included integration of core, log and reservoir engineering data and the generation of new petrophysical evaluation on a limited number of key wells to support the generation of geomechanical 1D Mechanical Earth Models (MEMs).

The main petrophysical outputs for the screening study (total porosity, water saturation and permeability constrained by core data) were used to define net reservoir cut-offs with porosity and permeability mapped as technical storage components.

Mean net sand data provided a proxy for net reservoir thickness and was mapped and subsequently converted to an index map, guided by reservoir depth maps, fault data and pre-existing isopach maps. The petrophysics was also used to provide a proxy for 'net primary seal thickness' and used to construct net primary seal thickness maps, although a lack of petrophysically determined net to gross data for the secondary seal precluded using this method and consequently the secondary seal is represented by gross thickness.

Reservoir engineering

Reservoir engineering data were collated to support the assessment of injectivity and to provide inputs for geomechanical analysis. Conversion of well test-derived permeability-thickness (KH) to an injectivity index for CO_2 (J) was carried out using the method described by Valluri *et al.* (2021) and the validity of the results was assessed by comparing them with an injectivity index derived from Pressure Transient Analysis (PTA)-derived Productivity Index (PI) and Pressure-Volume-Temperature (PVT) properties of hydrocarbons and CO_2. The reservoir engineering data were used to construct an injectivity index map and other properties, including temperature, pressure, LOT and flow test data, used as inputs for the reservoir and seal geomechanical analyses.

Hydrodynamics

Temperature, pressure, water salinity and pH data were collected from the identified key wells and are useful in determining the rate of CO_2 solution in the reservoir. The geochemical index cut-offs are nonlinear and arranged differently from the other disciplines, reflecting CO_2 phase transition and the effects that pressure and temperature have on CO_2 solubility and mineral trapping (Akono *et al.* 2019). We consider a pressure range between 73.8-600 bar as 'good' and a temperature range of 31-128°C 'very good' and >128°C as 'poor'. Salinities of less than 10,000 mg/l are considered 'very good' for CO_2 dissolution and greater than 70,000 mg/l 'poor'.

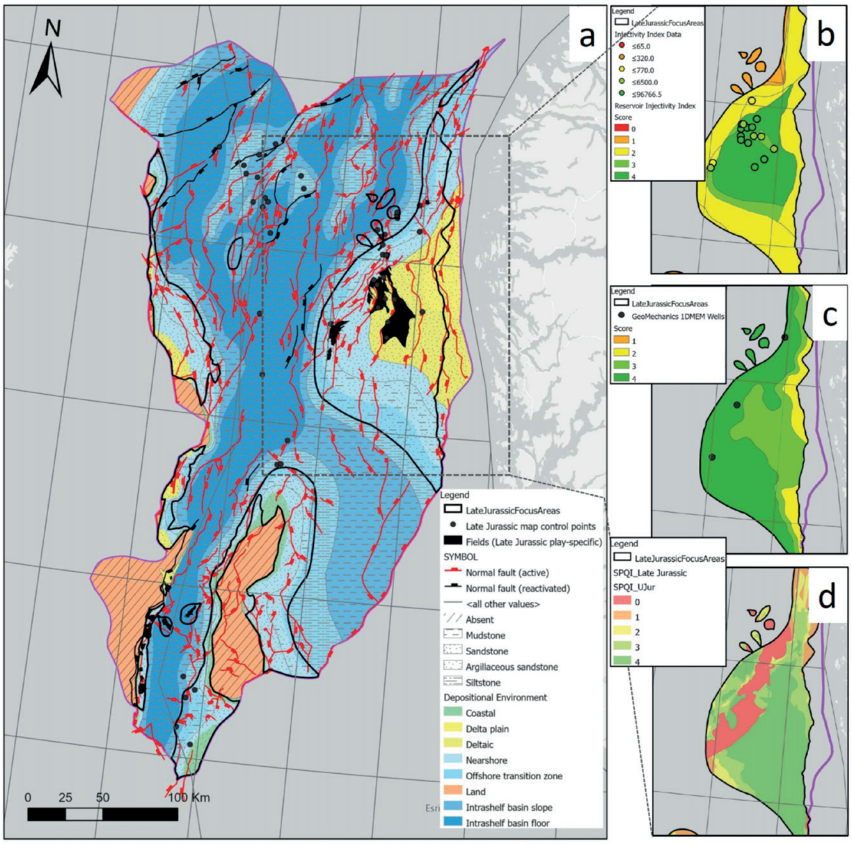

Figure 5 Examples of maps which form the SPQI. a) results of the geological mapping showing reservoir lithology, gross depositional environments, faults, fields in play and control point data. The resulting focus areas are displayed in black and cropped examples over the Sognefjord delta area displayed in figures b-d, b) injectivity index map utilising flow test permeability and perforation reservoir thickness data, c) Reservoir pressure room index map utilising reservoir engineering and geomechanical data, d) Final SPQI map identifying areas with promising storage potential.

Geomechanics (Pressure room and Shear Strength Level (SSL))

The geomechanical properties of both the reservoir and primary seal are essential for evaluating the risk of containment as, critically, stress in either is considered a red flag for injection operations. Geomechanical properties were assessed using two components; 1) the pressure room within the reservoir, and 2) the Shear Strength Level (SSL) of both the reservoir and primary seal. 1D MEMs were generated at five key well locations.

The pressure room indicates the available (or remaining) pressure before over-pressure and tensile failure and is a proxy for the availability of injection space within the reservoir. It is defined as the minimum stress gradient minus the current pressure gradient, calculated from the 1D MEM's and makes use of a tuned pressure prediction model and a match to measured stress data (e.g. mini-frac, LOT/FIT). The pressure room was calculated by subtracting the current pressure gradient output map from the minimum stress output map. Shear Strength Level (SSL) provides an indication of how close the rocks are to failure due to shear stress, as defined by the equations of Fjær *et al.* (2008).

Results

The results of the first pass of the SPQI methodology define a focus area in the Oxfordian reservoir interval that covers approximately 20,500 km^2 (black polygons in Figure 5a), reflecting the westward prograding deltaic reservoirs of the Oxfordian-aged Sognefjord Formation. The southernmost part of the basin in the UK sector could provide additional CO_2 storage reservoirs in Brae Formation reservoirs. Although these can be thick (>1000 m), they are often deeply buried (>3000 m), display poor reservoir properties, are of limited lateral extent and may display poor connectivity due to extensive syn-sedimentary faulting. Uplifted areas to the south and west of the basin have been identified as having potential for CO_2 storage reservoirs as there is likely to be land-attached shoreface or coastal deposits typically represented by sandstones with good primary and secondary seals.

In total, 15 discipline-specific index maps were generated (Table 1) and Figure 5 shows examples of index maps for both injectivity (Figure 5b) and reservoir pressure room (Figure 5c) for the Late Jurassic over the Sognefjord delta area. Note that pressure room is very good in the west, where the reservoir is thicker, but decreases to the east as the reservoir thins. All 15 of the discipline-specific technical storage components were multiplied using a weighted proprietary ranking calculation to provide a single SPQI map (5d) that highlights specific zones for further investigation (green) or isolates areas as less favourable for CO_2 storage (orange and red).

The SPQI map results suggest that the area around and to the south of the Troll gas field are potentially 'very good' for CO_2 storage. This is considered encouraging as this area is currently being developed as the main storage target for the Northern Lights project (Figure 1). The injection target for the Northern Lights project is the Johansen Formation, which is only marginally deeper than the Sognefjord Formation. This work suggests that the younger Sognefjord Formation may also be a suitable storage reservoir and therefore provide future near-field expansion opportunities for other projects in the area.

Discussion

The basin-scale integrated SPQI methodology presented here utilises well data and interdisciplinary expertise in geology, petrophysics, geochemistry, reservoir engineering and geomechanics to provide a relatively quick, cost-effective and efficient means of identifying suitable reservoir zones for CCS. The methodology is based on the processing of large amounts of data in a relatively short period of time and allows for basin-scale CO_2 storage screening that considers all of the key subsurface risks. The SPQI methodology is differentiated from many other screening tools by including the calculation of an injectivity index and predicting its distribution over geologically- and depth-constrained focus areas. CO_2 injection rates are arguably more important in determining sequestration effectiveness than absolute capacity estimations.

Fluid geochemistry can influence the rate of CO_2 solubility in formation waters (solubility trapping). The SPQI methodology utilises fluid geochemistry data to predict the water characteristics within the focus areas, which can be used to predict the rates of CO_2 solubility. Basin modelling was deemed unnecessary for predicting the water pressure and temperature in the reservoir zones as the 'good-very good' pressure and temperature ranges were large and the data were converted to an index score (0-4). However, full basin analysis would provide additional support for pressure and temperature prediction, and more detailed assessment of porosity, permeability and mineral diagenesis. Geomechanical properties of the seal and reservoir are included in the SPQI methodology, including pressure room and SSL calculated for both the reservoir and primary seal. For the Late Jurassic, Oxfordian reservoirs investigated here, both the reservoir and primary seal are well below shear failure. Our full analyses suggests that the geochemical properties of the reservoir water are expected to be of the least concern, whilst the geomechanical properties of the reservoir and primary seal are of critical importance.

The Northern North Sea region contains more than 8000 wells and the data for most of those wells is readily available. However, the number of files and data types means that utilising all of this data is challenging in realistic time frames. The application of automated data science workflows allowed the rapid identification of 1087 key wells, and the extraction and databasing of data to support our workflows. The rapid development of data science workflows including machine learning and AI is allowing more of the data to be used more of the time and these tools are being employed in ongoing applications of our SPQI methodology.

The SPQI methodology provides a means of rapidly screening large areas and multiple stratigraphic targets for their CO_2 storage potential. Subsequent more detailed analysis of high-graded areas might include the incorporation of 3D seismic data and detailed site evaluation that builds on the SPQI analysis. It is at this later stage that reliable calculations of CO_2 storage capacity estimation and containment risks would be generated and used for ranking criteria such that the most appropriate sites can be selected for potential CCS development.

Conclusions

The SPQI methodology outlined here provides a time and cost-effective tool for CO_2 storage screening of large areas based on realistic criteria to assess storage opportunities. The SPQI methodology allows reservoir play intervals across entire basins to be screened, based on a wide range of interdisciplinary analyses, including geology, geochemistry, petrophysics, geomechanics and reservoir engineering. The resulting data and interpretations are converted into a series of index maps which are combined within a weighted calculation to form a single SPQI map, in a similar method to common risk segment maps, familiar to the petroleum explorationist. This tool helps to highlight specific areas of interest for further detailed storage capacity estimations and risk assessment (e.g. integrating seismic data) to help build towards a portfolio of risked and ranked CO_2 storage sites for final investment decision (FID). The SPQI methodology can be applied and adapted to any geographic region and modified to local regulation requirements for CCS. The SPQI methodology can also be tailored for hydrogen storage in porous media, integrated with surface infrastructure and local industrial hubs to optimise storage site selection.

References

Akono, A.T., Druhan, J.L., Dávila, G., Tsotsis, T., Jessen, K., Fuchs, S., … Werth, C. J. [2019]. A review of geochemical–mechanical impacts in geological carbon storage reservoirs. *Greenhouse Gases: Science and Technology*, **9**(3), 474–504. https://doi.org/10.1002/ghg.1870

Alcalde, J., Heinemann, N., James, A., Bond, C.E., Ghanbari, S., Mackay, E.J., … Allen, M. J. [2021]. A criteria-driven approach to the CO2 storage site selection of East Mey for the acorn project in the North Sea. *Marine and Petroleum Geology*, **133**(August), 105309. https://doi.org/10.1016/j.marpetgeo.2021.105309

Bentham, M., Mallows, T., Lowndes, J. and Green, A. [2014]. CO2 STORage evaluation database (CO2 Stored). The UK's online storage atlas. *Energy Procedia*, **63**(2014), 5103-5113. https://doi.org/10.1016/j.egypro.2014.11.540.

Bump, A.P., Hovorka, S.D. and Meckel, T.A. [2021]. Common risk segment mapping: Streamlining exploration for carbon storage sites, with application to coastal Texas and Louisiana. *International Journal of Greenhous Gas Control*, **111**, 103457. https://doi.org/10.1016/j.ijggc.2021.103457

Callas, C., Davis, J.S., Saltzer, S.D., Hashemi, S.S., Wen, G., Gold, P.O., Zoback, M.D., Benson, S.M. and Kovscek, A.R. [2024]. Criteria and workflow for selecting saline formations for carbon storage. *International Journal of Greenhouse Gas Control*, **135**, 104138.

Directive 2009/31/EC of the European Parliament and of the Council of 23 April 2009 on the geological storage of carbon dioxide and amending Council Directive 85/337/EEC, European Parliament and Council Directives 2000/60/EC, 2001/80/EC, 2004/35/EC, 2006/12/EC, 2008/1/EC and Regulation (EC) No. 1013/2006

Fjær, E., Holt, R.M., Horsrud, P., Raaen, A.M. and Risnes, R. [2008]. Chapter 12 Reservoir geomechanics. In E. Fjær, R.M. Holt, P. Horsrud, A.M. Raaen, & R.B. T.-D. in P.S. Risnes (Eds.), *Petroleum Related Rock Mechanics* 2nd Edition, **53**, 391-433. https://doi.org/10.1016/S0376-7361(07)53012-8

Halland, E.K., Riis, F., Magnus, C., Johansen, W.T., Tappel, I.M., Gjeldvik, I.T., … Pham, V.T.H. [2013]. CO_2 storage atlas of the Norwegian part of the North Sea. *Energy Procedia*, **37**, 4919-4926. https://doi.org/10.1016/j.egypro.2013.06.403.

Levine, J S., Fukai, I., Soeder, D.J., Bromhal, G., Dilmore, R.M., Guthrie, G.D., … Goodman, A.L. [2016]. U.S. DOE NETL methodology for estimating the prospective CO2 storage resource of shales at the national and regional scale. *International Journal of Greenhouse Gas Control*, **51**(November 2018), 81–94. https://doi.org/10.1016/j.ijggc.2016.04.028

Liu, Z., Deng, Z., Davis, S.J. *et al.* [2024]. Global carbon emissions in 2023. *Nat Rev Earth Environ,* **5**, 253-254. https://doi.org/10.1038/s43017-024-00532-2

Patruno, S., Hampson, G.J., Jackson C. and Whipp, P. [2013]. Geomorphology, facies character and stratigraphic architecture of an ancient sand-prone subaqueous delta: Upper Jurassic Sognefjord Formation, Troll field, offshore Norway. *Search and Discovery*, 20193, 7. https://doi.org/10.13140/2.1.1861.8247

Poulsen, N., Bocin-Dumitriu, A., Holloway, S., Kirk, K., Neele, F. and Smith, N. [2015]. Reserves and resources for CO2 storage in Europe: the CO2StoP project. *Geological Survey of Denmark and Greenland Bulletin*, 85–88. https://doi.org/10.34194/geusb.v33.4516.

Ringrose, P. [2020]. How to Store CO_2 Underground: Insights from early-mover CCS Projects. *SpringerBriefs in Earth Sciences*. Springer Nature Switzerland AG. https://doi.org/10.1007/978-3-030-33113-9.

Sun, X., Alcalde, J., Bakhtbidar, M., Elío, J., Vilarrasa, V., Canal, J., … Gomez-Rivas, E. [2021]. Hubs and clusters approach to unlock the development of carbon capture and storage – Case study in Spain. *Applied Energy*, **300**(July). https://doi.org/10.1016/j.apenergy.2021.117418

Underhill, J.R. and Richardson, N. [2022]. Geological controls on petroleum plays and future opportunities in the North Sea Rift Super Basin. *AAPG Bulletin*, **106**(3), 573-631.

Valluri, M., Mishra, S., and Ravi Ganesh, P. [2021]. Injectivity index: a powerful tool for characterizing CO_2 storage reservoirs—a technical note. *Greenhouse Gases: Science and Technology*, **11**(2), 251-265. https://doi.org/10.1002/ghg.2046.