Role of North Sea in Achieving Net-Zero: Assessing the Feasibility of Large-Scale CO_2 Storage in Saline Aquifers

LAIDLAW SCHOLARS

Humna Mujahid

Supervisor: Dr Semra Bakkaloglu

IMPERIAL

Introduction

The North Sea - A key Player in Europe's Path to Net Zero

- Carbon Capture and Storage (CCS) is vital for decarbonising hard-to-abate sectors.
- Saline aquifers offer the greatest CO_2 storage potential due to capacity, stability, and distribution.
- The North Sea provides ideal conditions — vast storage sites, existing infrastructure, and supportive policy.
- Estimated 78 gigatonnes of CO_2 can be stored in UK offshore basins.
- Study assesses feasibility based on geology, infrastructure, economics, and policy alignment.

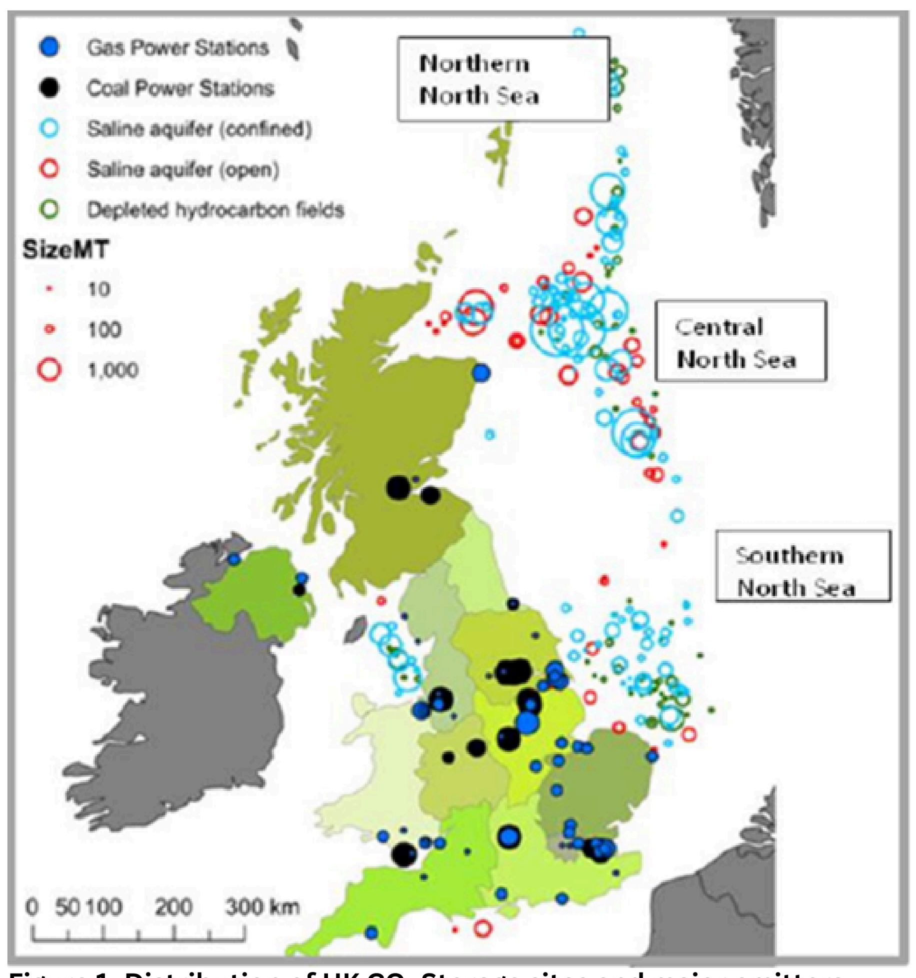

Figure 1. Distribution of UK CO_2 Storage sites and major emitters (UKSAP, Gammer 2016)

Methods

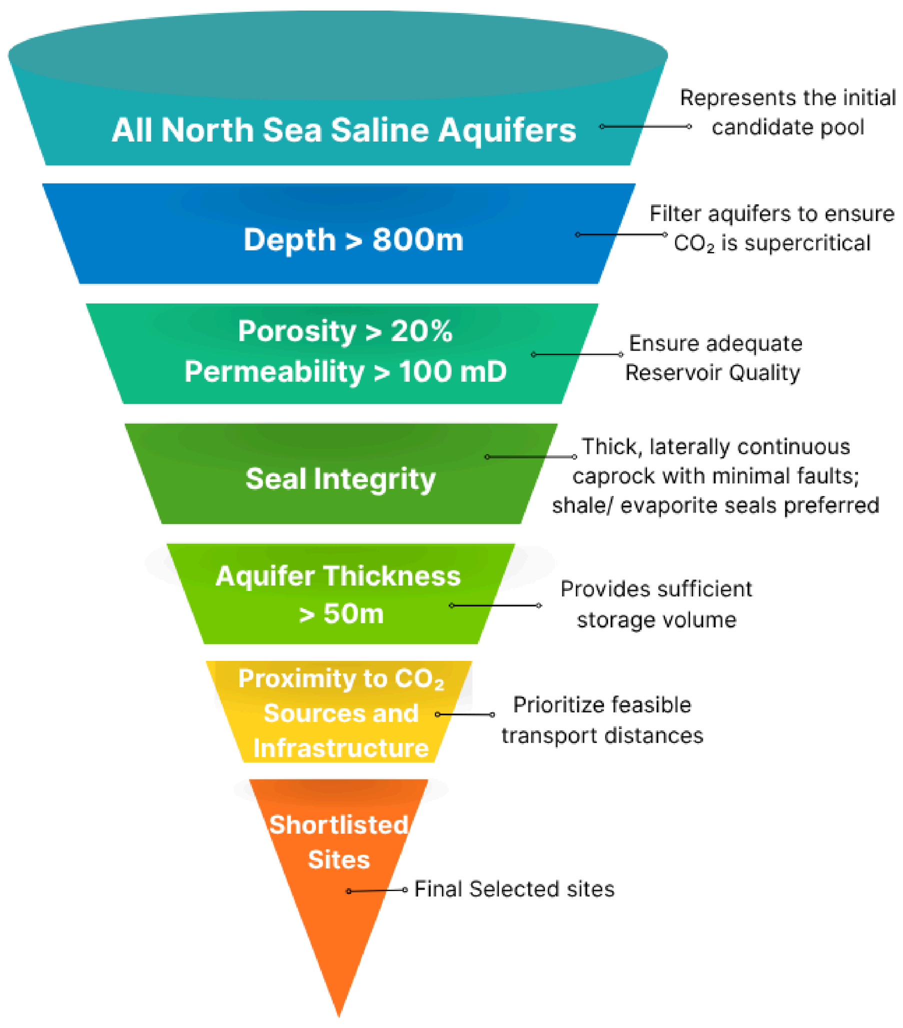

Figure 2. Site Selection Funnel for identifying optimal North Sea Saline Aquifers

Integrated Framework for Feasibility Assessment

- Multidisciplinary approach: combined geological, technical, economic, and policy analyses.
- Geological analysis: used BGS and NSTA data to evaluate porosity, depth, and caprock integrity.
- Infrastructure assessment: examined reuse of offshore oil and gas assets for CO_2 transport/injection.
- Policy–economic evaluation: reviewed EU CCS Directive, UK Net Zero Strategy, and carbon pricing.
- Benchmarked against Norwegian CCS projects (Sleipner, Northern Lights) for validation.

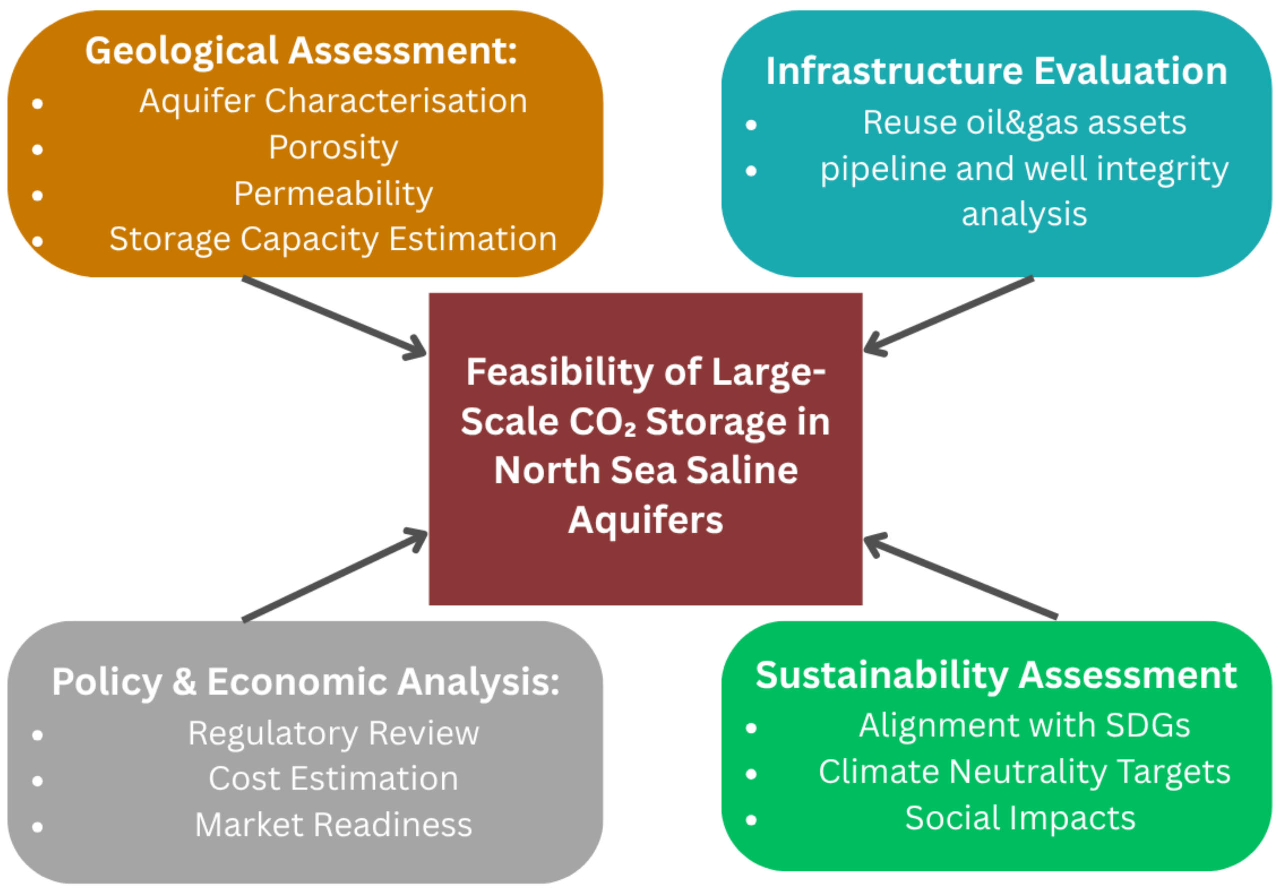

Figure 3. Integrated Feasibility framework linking geology, infrastructure, policy and sustainability

- **Site Screening Criteria**: Candidate aquifers were filtered by depth (>800 m), porosity (>20%), permeability (>100mD), and Seal integrity, ensuring supercritical CO_2 Storage and long-term containment security
- **Storage Capacity Estimation**: Applied the standard volumetric equation (**$M_{CO_2} = A \times h \times \varphi \times S \times \rho_{CO_2}$**) Where [A = area of the aquifer (m^2), h = aquifer thickness (m), φ = porosity (fraction), S_{CO2} = storage efficiency factor, ρ_{CO2} = density of CO_2 under reservoir conditions] to calculate capacity, integrating parameters such as aquifer geometry, rock properties, and CO_2 density under reservoir conditions (Ringrose, Furre et al. 2021)

Results

High-Capacity, Low-Risk Storage Opportunities in the North Sea

- Bunter Sandstone: 200–500 Mt CO_2 capacity, excellent sealing, near Teesside and Humber clusters.
- Captain Sandstone: 100–300 Mt capacity, good injectivity, near Acorn CCS hub.
- Repurposing infrastructure (pipelines, platforms) could cut costs by 20–40%.
- Geological and operational risks are low, but financial and societal uncertainties remain key challenges.
- Demonstrated long-term containment validated by Sleipner Project (no leakage since 1996).

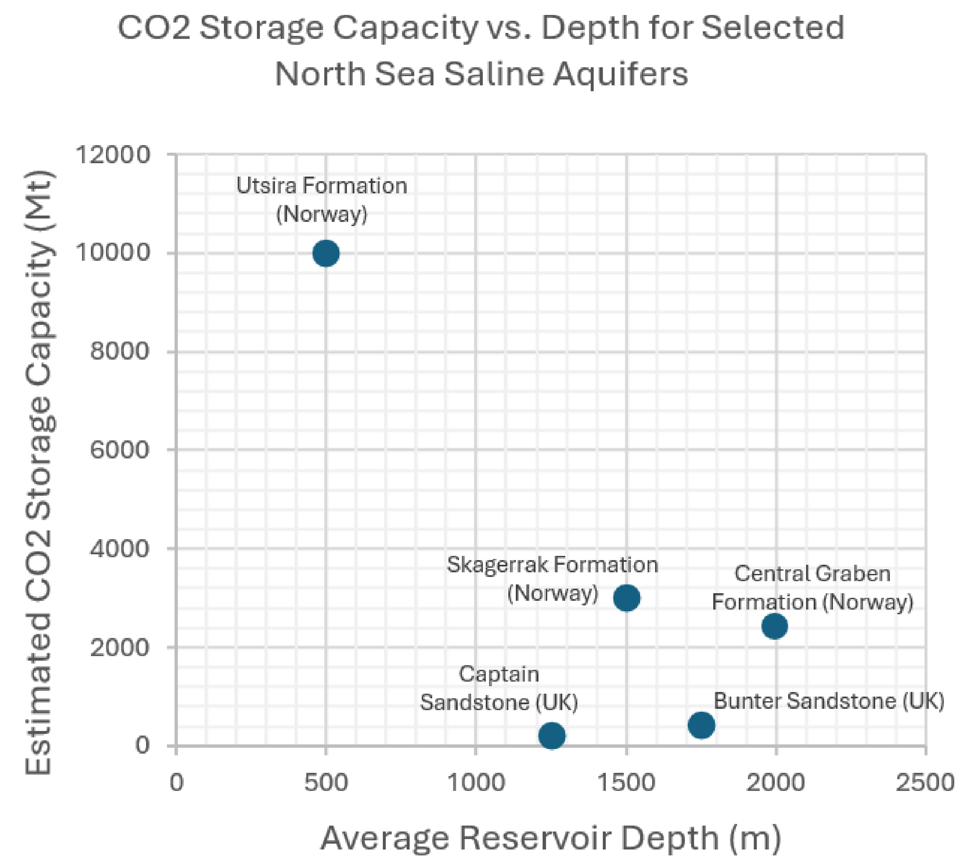

Figure 4. Relationship between reservoir depth and CO2 Storage capacity in North Sea aquifers

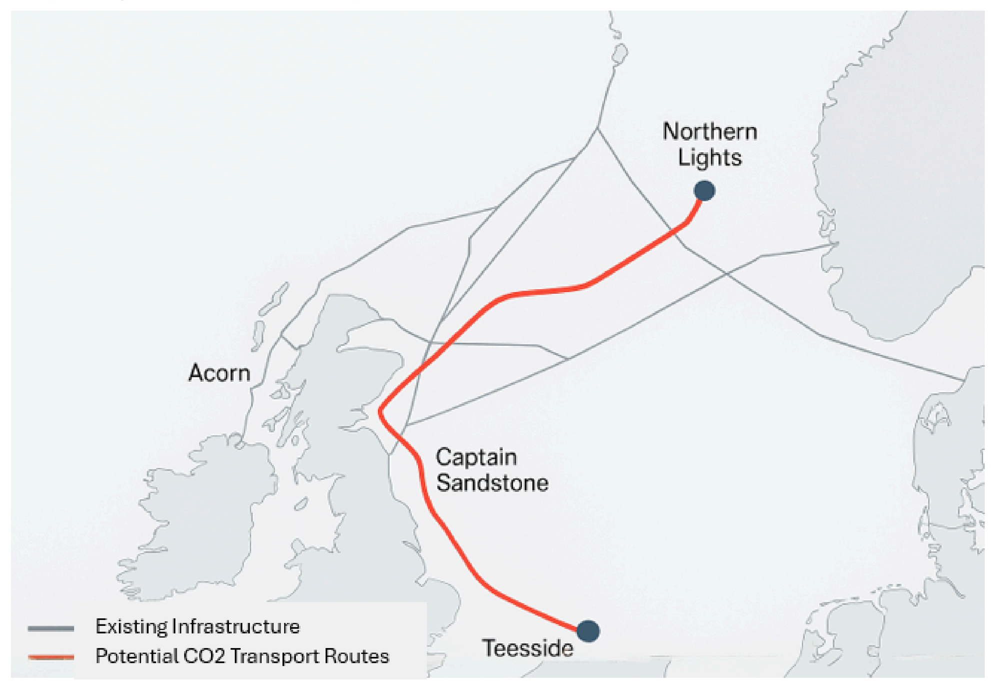

Figure 5. Potential transport routes linking CO_2 storage sites to UK industrial clusters

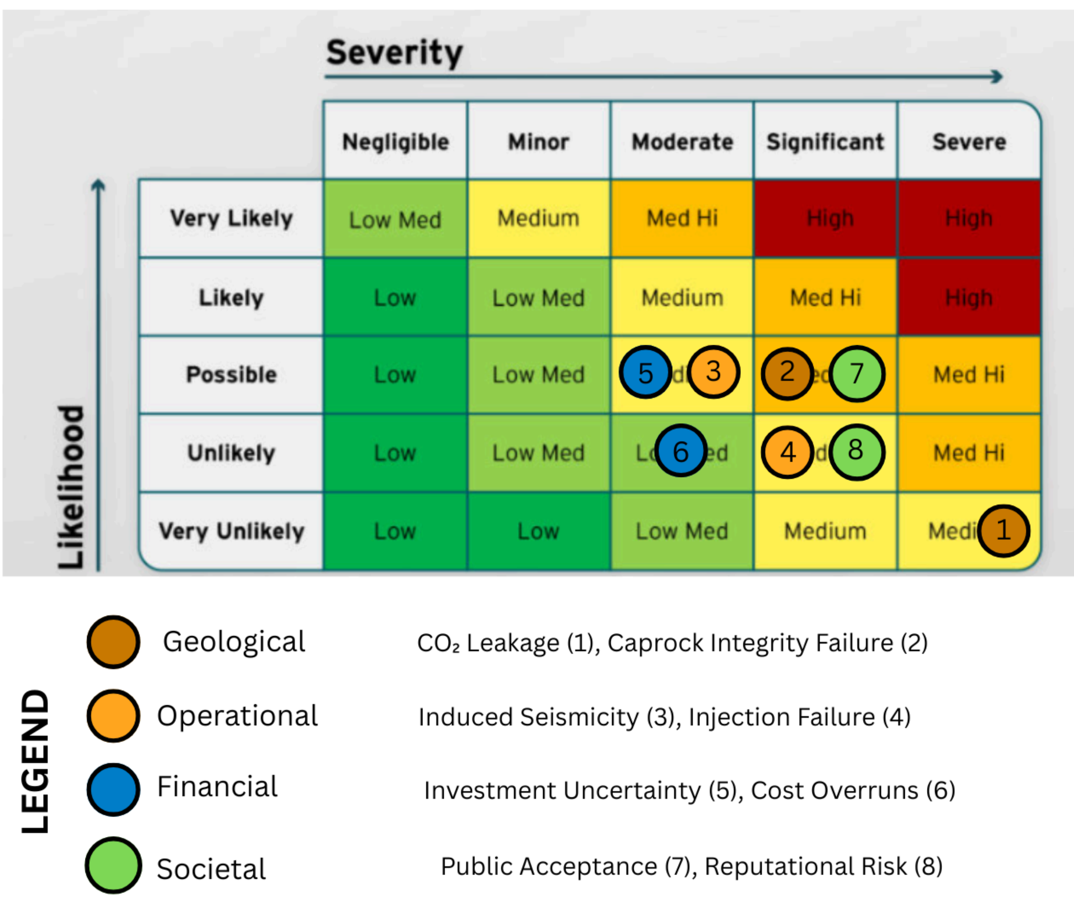

Figure 6. Risk Matrix showing low geological but moderate financial and societal risks

- ***Comparative Basin Analysis:*** Formations like Bunter Sandstone and Captain Sandstone (UK) show comparable integrity and injectivity to the Utsira Formation (Norway), validated by 20+ years of successful Sleipner CO_2 injection data.
- ***Economic Viability***: Estimated transport + storage costs (€10–40/tCO_2) are well below current carbon prices (€70–80/t), confirming that large-scale CCS in the North Sea is economically feasible under existing market conditions.

Conclusion

North Sea Saline Aquifers - Technically and Economically Ready for CCS

- Formations like Utsira and Bunter meet global best-practice standards for CO_2 storage.
- 200–300 MtCO_2/year storage potential by 2050 supports UK and EU net-zero targets.
- Existing oil & gas assets can be repurposed to accelerate deployment and cut costs.
- Stable policy frameworks and public acceptance are essential to scale CCS.
- Supports multiple UN SDGs: 7 (Clean Energy), 9 (Industry & Innovation), 13 (Climate Action), and 14 (Life Below Water).

Further Research

Next Steps for a Sustainable Carbon Storage Future

- Develop advanced monitoring systems to ensure long-term containment.
- Study ecosystem impacts of offshore CO_2 storage to protect marine environments.
- Model pressure management and cross-border CO_2 transport for regional coordination.
- Strengthen public engagement and transparent reporting to enhance societal trust.

References:

Baig, A. R., et al. (2025). "Comprehensive Insights into Carbon Capture and Storage: Geomechanical and Geochemical Aspects, Modeling, Risk Assessment, Monitoring, and Cost Analysis in Geological Storage." Sustainability 17(19): 8619. Chen, H., et al. (2023). "Storage mechanism and dynamic characteristics of CO2 dissolution in saline aquifers." Energy & Fuels 37(5): 3875-3885. Izadpanahi, A., et al. (2024). "A review of carbon storage in saline aquifers: Mechanisms, prerequisites, and key considerations." Fuel 369: 131744. Luo, A., et al. (2022). "Review of CO2 sequestration mechanism in saline aquifers." Natural Gas Industry B 9(4): 383-393. Rigby, S. P. and A. Alsayah (2024). "Storage Sites for Carbon Dioxide in the North Sea and Their Particular Characteristics." Energies 17(1): 211. Ringrose, P. S., et al. (2021). "Storage of carbon dioxide in saline aquifers: physicochemical processes, key constraints, and scale-up potential." Annual review of chemical and biomolecular engineering 12(1): 471-494. Tillero, E. (2024). "Machine learning-based modelling for geologic CO2 storage in deep saline aquifers. Case study of bunter sandstone in Southern North Sea." International Journal of Greenhouse Gas Control 133: 104077. Uliasz-Misiak, B. and J. Misiak (2024). "Underground gas storage in saline aquifers: geological aspects." Energies 17(7): 1666. Worden, R. H. (2024). "Carbon dioxide capture and storage (CCS) in saline aquifers versus depleted gas fields." Geosciences 14(6): 146. UK Governmnet, 2024. Traded carbon values used for modelling purposes. [online] Available at: https://www.gov.uk/government/publications/traded-carbon-values-used-for-modelling-purposes-2024/traded-carbon-values-used-for-modelling-purposes-2024).IEAGHG Technical Report (2019). EU Directive 2009/31/EC. On the Geological storage of carbon dioxide and amending Council Directive.