CO_2 Storage Resource Catalogue

Cycle 3 Report

March 2022

Amounts of CO_2

Stored
0.03 Gigatonnes

Commercial
0.04 Gigatonnes

Sub-commercial
73 Gigatonnes

Undiscovered
100 Gigatonnes

Appendix C : Europe

Denmark
Germany
Norway
UK

Contents

Change record for STOR-SW-RP-0001-A01/Appendix-C

Document Summary			
Client	Oil and Gas Climate Initiative (OGCI)		
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Important notice

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Tables

1.0 Baltic Region (Denmark & Germany)

1.1.1 Summary

The Baltic region was assessed during Cycle 1 and was not updated during Cycle 2. During the Cycle 1 assessment, a series of Triassic age closures in the western Baltic region were reviewed from a GHGT-12 publication [1]. Whilst this does not portray a complete picture of the resource profile for the Baltic region, which includes countries surrounding the Danish North Sea and the Baltic Sea, it points to the availability of significant resource in that region and so has been included here. The CSRC has identified a CO_2 storage resource for the Baltic region as follows:

Denmark

Classification	CO_2 storage resource (Gt) Project and no project	CO_2 storage resource (Gt) Project specified only
Stored	0	0
Capacity	0	0
Sub-Commercial	0.093	0
Undiscovered	1.535	0
Aggregated*	1.628	0

Germany

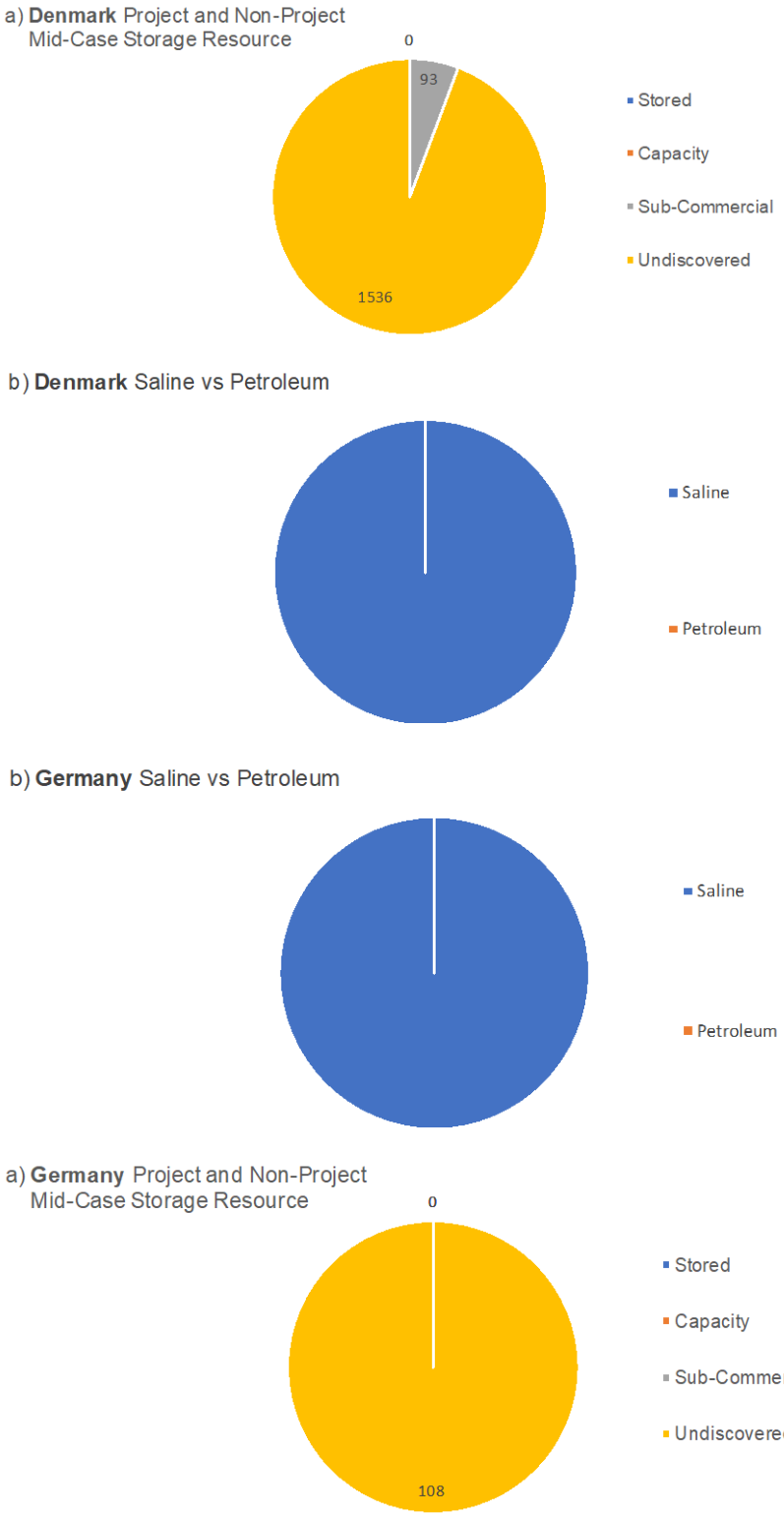
Classification	CO_2 storage resource (Gt) Project and no projec	CO_2 storage resource (Gt) Project specified only
Stored	0	0
Capacity	0	0
Sub-Commercial	0	0
Undiscovered	0.11	0
Aggregated*	0.11	0

* The aggregated resource represents the summed storage resource across all maturity classes and as such should not be viewed as representative of the potential of the country.

Table 1-1: Storage resource classification summary for Baltic Region (Denmark & Germany)

The published evaluations identified 13 closures of Triassic Bunter Sandstone in the North West German Basin; 12 sit within in Denmark and one in Germany.

The aggregated storage potential for the Baltic region is 1.74 Gt (1.628 Gt for Denmark and 0.11 Gt for Germany) and is entirely held within saline aquifers within closed structures. These are classified mostly as Undiscovered Prospective Resource. No projects are defined.



*Note: None of the Baltic sites have an associated project specified.

Figure 1-1: a) Spread of storage resource for sites in Denmark and Germany across SRMS classifications. b) Split of storage resource for Denmark and Germany between saline aquifers and hydrocarbon fields, both project specified and not.

1.1.2 Resource Statement

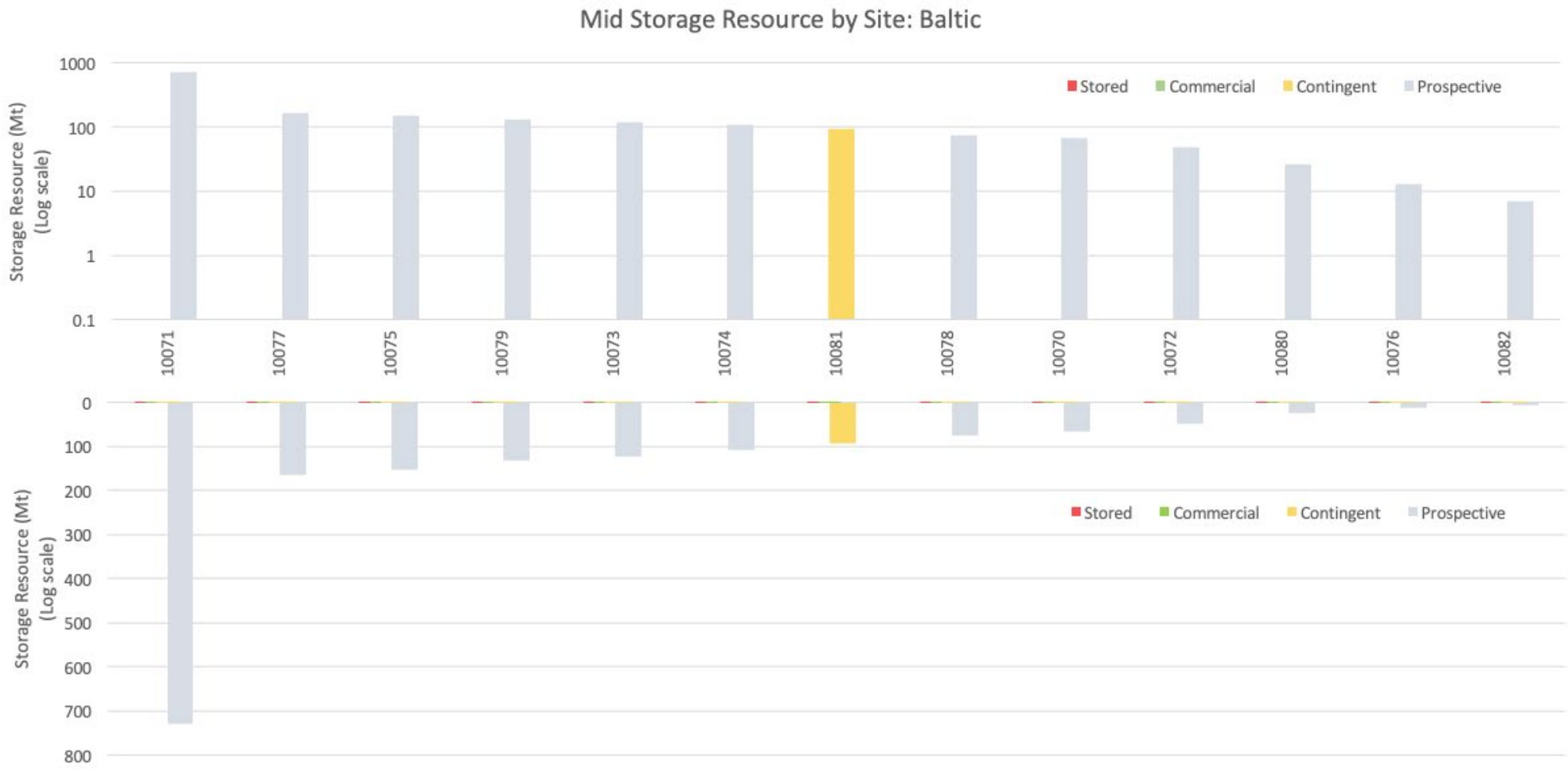


Figure 1-2: Storage resource summary for Baltic region compiled in the CSRC. Graph above is log scale and graph below is linear. Projects were not specificed for any of these sites..

1.1.3 Evaluation History

The storage resources of the Baltic region were reviewed, and a preliminary assessment carried out, during the CSRC Cycle 1. The basis of the assessment is a screening study which evaluates sites in the Southern North Sea and Southwest Baltic Sea areas [1]. This document is based on petroleum research project called Petrobaltic, which reviewed the potential storage resource offered by saline aquifers, both onshore and offshore. In the huge offshore area considered, only 11 wells were available to the study.

1.1.4 Resource Review

1.1.4.1 Major Projects

No active or developing carbon storage projects have been assessed.

1.1.4.2 Depleted Oil & Gas Fields

No depleted oil and gas fields have been considered.

1.1.4.3 Saline Aquifers

The published evaluation considered static resource assessments of large, closed structures containing Jurassic and/or Triassic formations. This included a review of reservoir and caprock potential.

1.1.5 Regulatory Framework

As the Baltic area is covered by the EU CCS Directive, the area is covered by jurisdictions which are generally at an advanced state of deployment readiness. Denmark, Germany and Poland are all classed as a 'moderately performing' nations by the 2018 GCCSI CCS Readiness Index. Of these, Germany leads with the highest combination of scores for both CCS interest and readiness and with increased focus after a shift in 2019 on the government position regarding underground CO_2 storage. Poland carries a moderate readiness with a high interest due to the countries large domestic coal resource and dependent on fossil fuels. Denmark is also at a moderate readiness, but with advanced renewable energy deployment and net zero policy ambitions.

1.1.6 Issues for the Assessment

The single source of storage resource evaluation provides a very early and incomplete view of Baltic storage resource potential. The sites specified are materially immature, although large subsurface structures have been identified using seismic data.

1.1.7 Future Updates

1.1.7.1 Future CSRC cycles

Future assessment updates should review and check for published evaluations of storage progress across the Baltic states.

2.0 Norway

2.1.1 Summary

Norway was assessed during Cycle 1 and was updated in Cycle 2 & Cycle 3 to reflect continued injection of CO_2 in active projects. The CSRC has identified a CO_2 storage resource for Norway as follows:

Classification	CO_2 storage resource (Gt) Project and no project	CO_2 storage resource (Gt) Project specified only
Stored	0.026	0.026
Capacity	0.037	0.037
Sub-Commercial	56	1.4
Undiscovered	37.6	3.4
Aggregated*	93.6	4.9

* The aggregated resource represents the summed storage resource across all maturity classes and as such should not be viewed as representative of the potential of the country.

Table 2-1: Storage resource classification summary for Norway

- There is currently a total of 42 sites at both local and regional scale, located across five geological basins in the offshore sector. Most of the Norwegian storage resource is in the Norwegian North Sea.
- There is a total of 11 project-specified sites, the majority (10) of which also contain a simulation model.
- As of 2019, a total of 25.1 Mt of CO_2 has been injected to deep geological storage, at Sleipner (18.6 Mt) and Snøhvit (6.5 Mt).
- The Norwegian government has created strong foundations for a CCS market in Norway, through the introduction of a high carbon tax for fossil fuel extraction and the GHG Emission Trading Scheme. Gaps still remain, however, in CCS-specific legislation according to the GCCSI Legal and Regulatory Indicator Report [2].

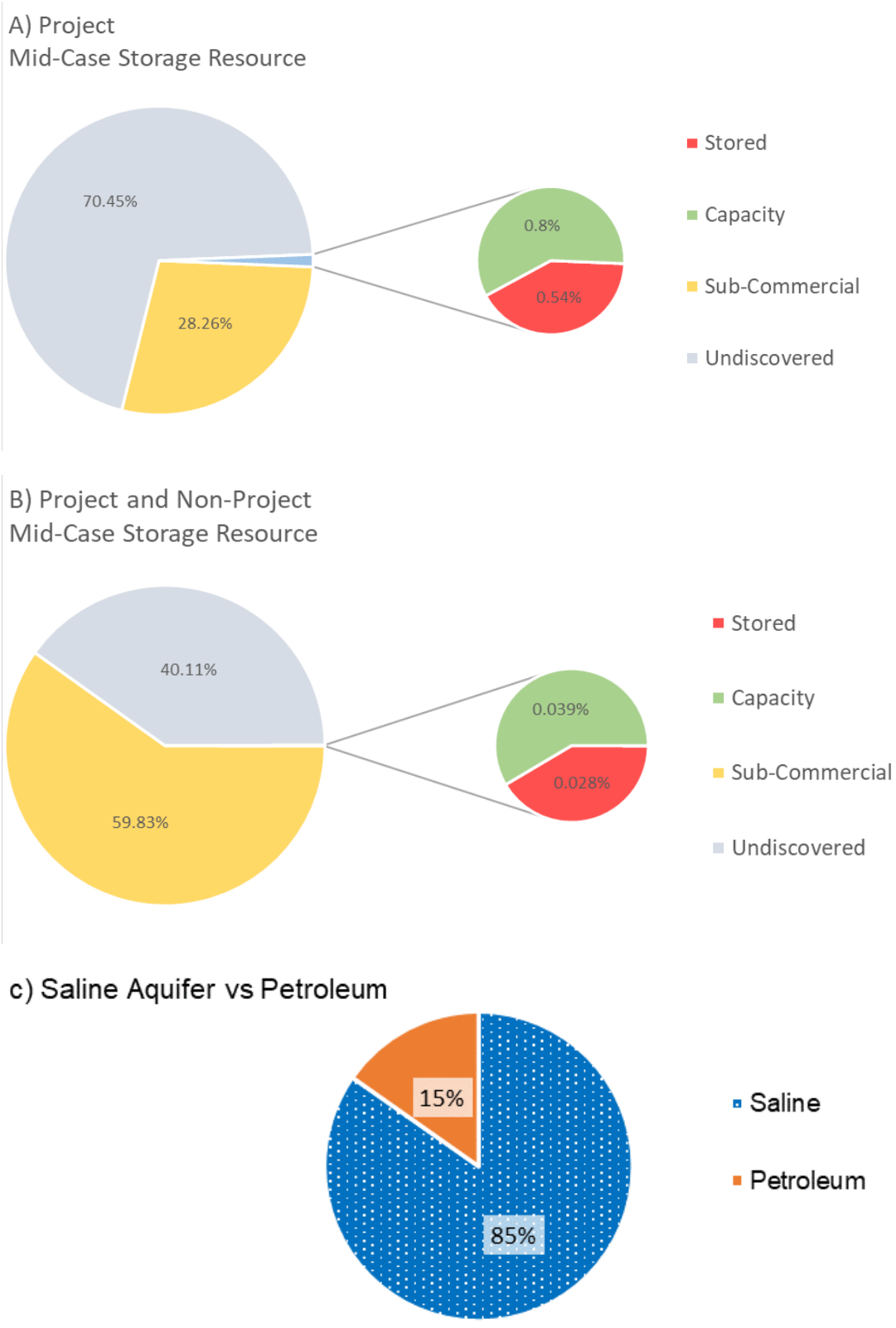


Figure 2-1: a) Spread of storage resource in Norwegian sites (42) across SRMS classifications, where a project has been specified. b) Spread of storage resource in all Norwegian sites across SRMS classifications; both project specified and not. c) Split of Norwegian storage resource between saline aquifers and hydrocarbon fields, both project specified and not.

2.1.2 Resource Statement

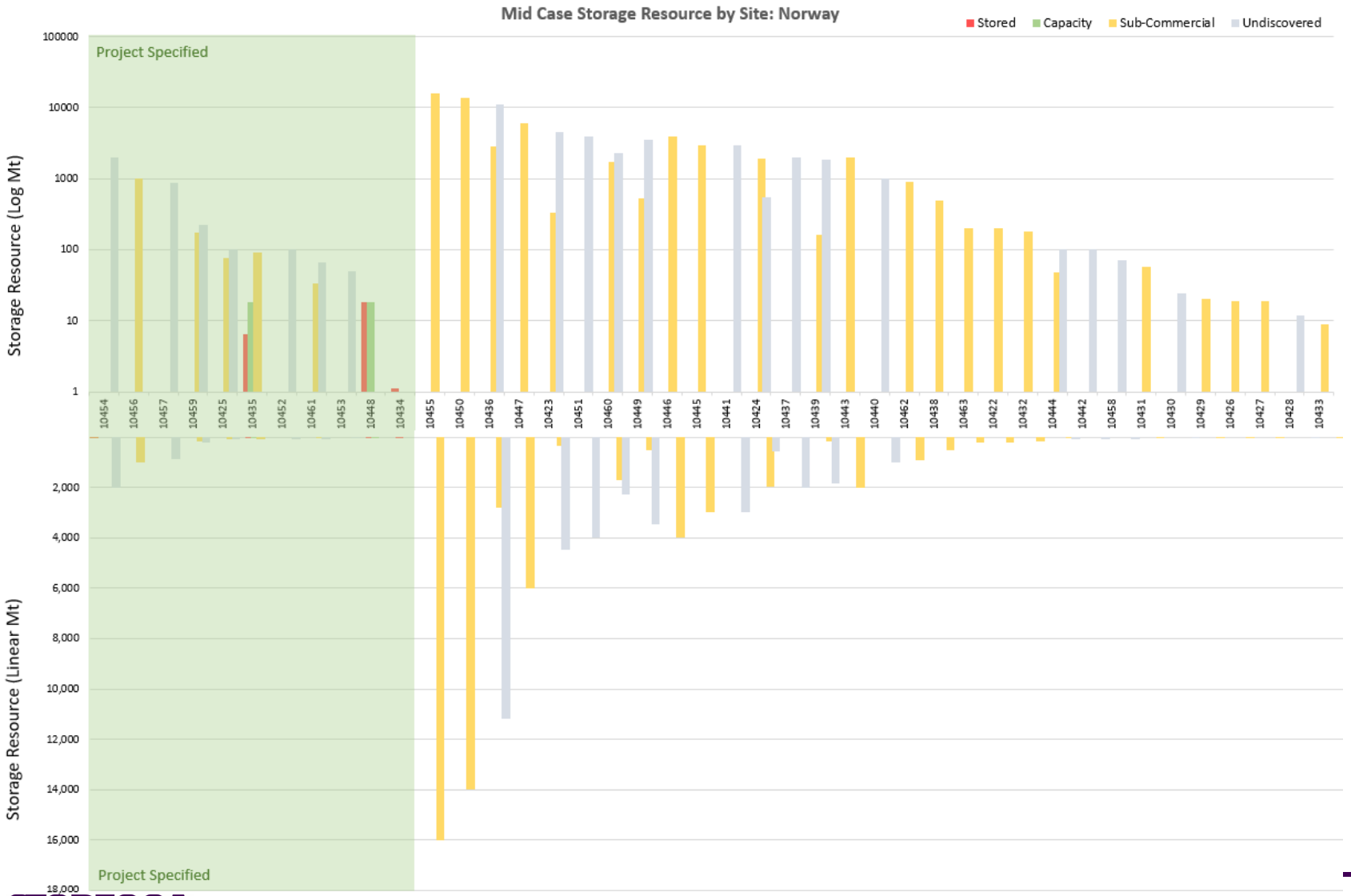


Figure 2-2: Storage resource summary for Norway compiled in the CSRC. Graph above is log scale and graph below is linear. Green box highlights sites where a project has been specified.

2.1.3 Evaluation History

The Norwegian CO_2 Storage Atlas is a key document for evaluation of the storage resource in Norway [3]. It was prepared by the Norwegian Petroleum Directorate (NPD) at the request of the Ministry of Petroleum and Energy and forms the data source for the majority of the Norwegian sites within this assessment. The Atlas is compiled from both site-specific evaluation in published literature and regional evaluation by the NPD and is composed of three regional basin atlases: the Norwegian North Sea, the Norwegian Sea and the Barents Sea. Papers published following the release of the Atlas were included to supplement and update the Norwegian assessment.

Whilst Norway has a similar overall resource character to the UK, it enjoys larger areas of undrilled potential and therefore storage resource prospectivity. It also has operational and developing CO_2 injection projects, which together creates a spread of resource across the SPE SRMS classifications. Significant storage resource is recognised in the numerous supergiant petroleum fields within the Norwegian sector. However, as they have the potential to continue production beyond 2050, the storage resources in these petroleum provinces have been classified as discovered but inaccessible at this time.

In general, a volumetric method was adopted to estimate potential storage resource. For a limited number of sites, a more detailed evaluation was made, sometimes including a simulation model. Where possible, the pore volume has been estimated using seismic and well data. Storage efficiency has been either evaluated using a bespoke reservoir simulation model, based upon a reasonable development plan, or sourced from a representative analogue. For hydrocarbon fields, a fluid replacement methodology was adopted.

In the Norwegian Atlas, the maturity of a site, and the subsequent methodology used to evaluate the storage potential of that site, is dictated by data availability. This approach is described by the maturation pyramid, where the evaluation of a site only moves up the pyramid and becomes more mature when more data becomes available for the evaluation. When the site reaches a different maturity level, a different methodology will be deployed to estimate the site's storage resource. In Norway, the vast amount of data and experience built through the petroleum industry allows some sites to be placed high up in the pyramid.

The maturity pyramid methodology adopted in the Atlas is only weakly mappable to the SRMS, which uses an increase in chance of commerciality to mature a site. Furthermore, the storage resource nomenclature within the Norwegian Atlas contrasts with the SRMS. It defines "Prospectivity" as the potential to find a commercially viable CO_2 storage project, rather than as the potential to find "accessible pore volume being suited to containment", as described in the SRMS. As a result of this, structures with reservoirs already proven by wells are held as "Prospects" rather than "Discoveries". Finally, in saline aquifers, the presence or absence of structures is not always clear, however sites described as “Prospects” have been considered as structures in this assessment.

No probabilistic work was reported within the Atlas.

2.1.4 Resource Review

2.1.4.1 Major Projects

In Norway, there are two commercial-scale CCS projects currently injecting CO_2: Sleipner and Snøhvit. Operated by Equinor since 1996, Sleipner was the world's first offshore CCS facility. Natural gas produced at the site contains naturally occurring CO_2, which is separated and stored within the Utsira Formation, in the Norwegian North Sea. Sleipner has a stored CO_2 volume of 18.6Mt, (end-2019; P Ringrose, pers. comm; [4]) [5].

Snøhvit is an LNG facility, that is similarly operated by Equinor but located in the Barents Sea. The natural gas produced from the Snøhvit, Albatross and Askeladd fields contains CO_2 which is separated and injected into the Stø Formation.

Both projects are referenced in the Atlas, however evaluations focus largely on additional storage potential within their respective saline aquifers.

The Snøhvit project is evaluated in more detail in the Atlas, however at the time of publication (2014), operations at Snøhvit had ceased due to an unexpected and rapid pressure build-up in the Tubaen Formation. It is reported that 1 Mt of CO_2 was stored during this time [3]. The asset has since been developed in the Stø Formation, which is believed to have greater hydraulic connectivity which should allow sufficient dissipation of pressure. No recent publications were found in the CSRC Cycle 1 that provide up-to-date stored volumes at Snøhvit, however the Atlas estimated a mid-case storage resource of 24 Mt.

2.1.4.2 Depleted Oil & Gas Fields

The Aggregated Storage Resource within hydrocarbon fields in the Norwegian sector is 14 Gt, where 13 Gt lies in the Norwegian North Sea and 1 Gt in the Norwegian Sea. A small volume (0.2 Gt) lies in the Barents Sea, however as no date for the cessation of production (CoP) was provided for these fields, the resource has been classified as "Discovered Inaccessible" in the CSRC Cycle 1. The fields within the Norwegian North Sea and Norwegian Sea are either abandoned or are due to be abandoned by 2050, however no sites are reportedly undergoing active appraisal for CO_2 storage in the published literature. As such, they have been classified as "Discovered Development Not Viable".

These data are all sourced from the Atlas, as no further publications were identified for depleted hydrocarbon fields in the CSRC.

2.1.4.3 Saline Aquifers

The storage resource for saline aquifers in Norway is spread across a range of the SRMS classifications, with Aggregated Storage Resource as follows; 37.6 Gt Undiscovered, 41.7 Gt Sub-commercial, 0.044 Gt Capacity and 0.019 Gt Stored. The Undiscovered portion is largely classified as "Sequence Play", with some sites classified as "Lead" where a nominal storage site was identified, or "Prospect" where a drill-ready target was present. The Capacity and Stored storage resource is from Sleipner and Snøhvit, where CO_2 has already been stored and further CO_2 is licensed for injection.

The storage resource is spread across a wide range of formations; however, the majority lies within the formations: Bryne and Sandnes, Utsira and Skade, and Sognefjord Delta.

Similar to the depleted hydrocarbon fields, little has been published assessing the storage resource of Norwegian saline aquifers since the Atlas was published. Recent work has been focussed on the Utsira Formation and Garn Formation, where simulation modelling has identified optimal locations for CO_2 injection, across the regional aquifers [6], [7].

2.1.5 Regulatory Framework

Norway has the highest CCS Policy-Indicator of the countries within the GCCSI Carbon Policy Indicator Report [8]. This is the result of the high level of carbon tax and Greenhouse Gas Emission Trading Act implemented by the Norwegian government in 1991, which has facilitated the permanent storage of CO_2 at both Sleipner and Snøhvit [9]. Additionally, the Norwegian government has funded several R&D projects and facilities, including the initiation of Gassnova, a state-owned CCS enterprise, and the Technology Centre Mongstad, an R&D facility to test CCS technologies.

Norway has a lower rating of Band B (40/87) in the GCCSI Legal and Regulatory Indicator Report [2]. The rating shows that Norway has "CCS specific laws or existing laws that are applicable across parts of the CCS cycle".

2.1.6 Issues for the Assessment

There is a risk of double counting in the Utsira Formation between the regional, theoretical evaluation made in the NPD Atlas and a later study that considers injection into optimal structures within the aquifer [6]. In accordance with the SRMS guidelines on aggregation of resources, the double counting cannot be avoided as due to the different maturity of the sites against the SRMS classification system [10].

2.1.7 Future Updates

2.1.7.1 Future evaluations

It is recommended that future publications should focus on:

- **Probabilistic storage resources**. It states in the SRMS, that published volumes should provide a range of capacities, where possible, to account for variability. The leading work in the Atlas could be enhanced by including the range of storage resource to highlight the uncertainty of the estimation.
- **Current stored volumes for Sleipner and Snøhvit.** The recent release of 4D seismic data and simulation models over the Sleipner field may help stimulate further research in this area.
- **Published storage resource estimates for the Northern Lights project.** Following the successful drilling the Northern Lights injection well, updates on the storage resource of the site in the published literature would be welcome for future updates to this study.

3.0 United Kingdom

3.1.1 Summary

The United Kingdom was assessed during Cycle 1 and was updated in Cycle 2 only to reflect recent changes in licensing and UK Government funding announcements. The CSRC has identified a CO_2 storage resource for the United Kingdom as follows:

Classification	CO_2 storage resource (Gt) Project and no project	CO_2 storage resource (Gt) Project specified only
Stored	0	0
Capacity	0	0
Sub-Commercial	17	2.3
Undiscovered	60.6	0
Aggregated*	77.6	2.3

* The aggregated resource represents the summed storage resource across all maturity classes and as such should not be viewed as representative of the potential of the country.

Table 3-1: Storage resource classification summary for United Kingdom

- There is currently a total of 87 sites at both local and regional scale, located across five geological basins in the offshore sector. There are currently no evaluated storage sites onshore UK.
- There is a total of 11 project-specified sites, the majority of which also contain a simulation model developed.
- There are numerous active projects in the UK all at different stages of development, however as there is no record of this within the published literature, they could not be included in the CSRC.
- The UK Government has outlined strong ambitions for CCUS deployment in the Energy White Paper, and also announced the intention to provide £1 billion to support the development of several CCS hubs and clusters across the UK by the end of the decade.

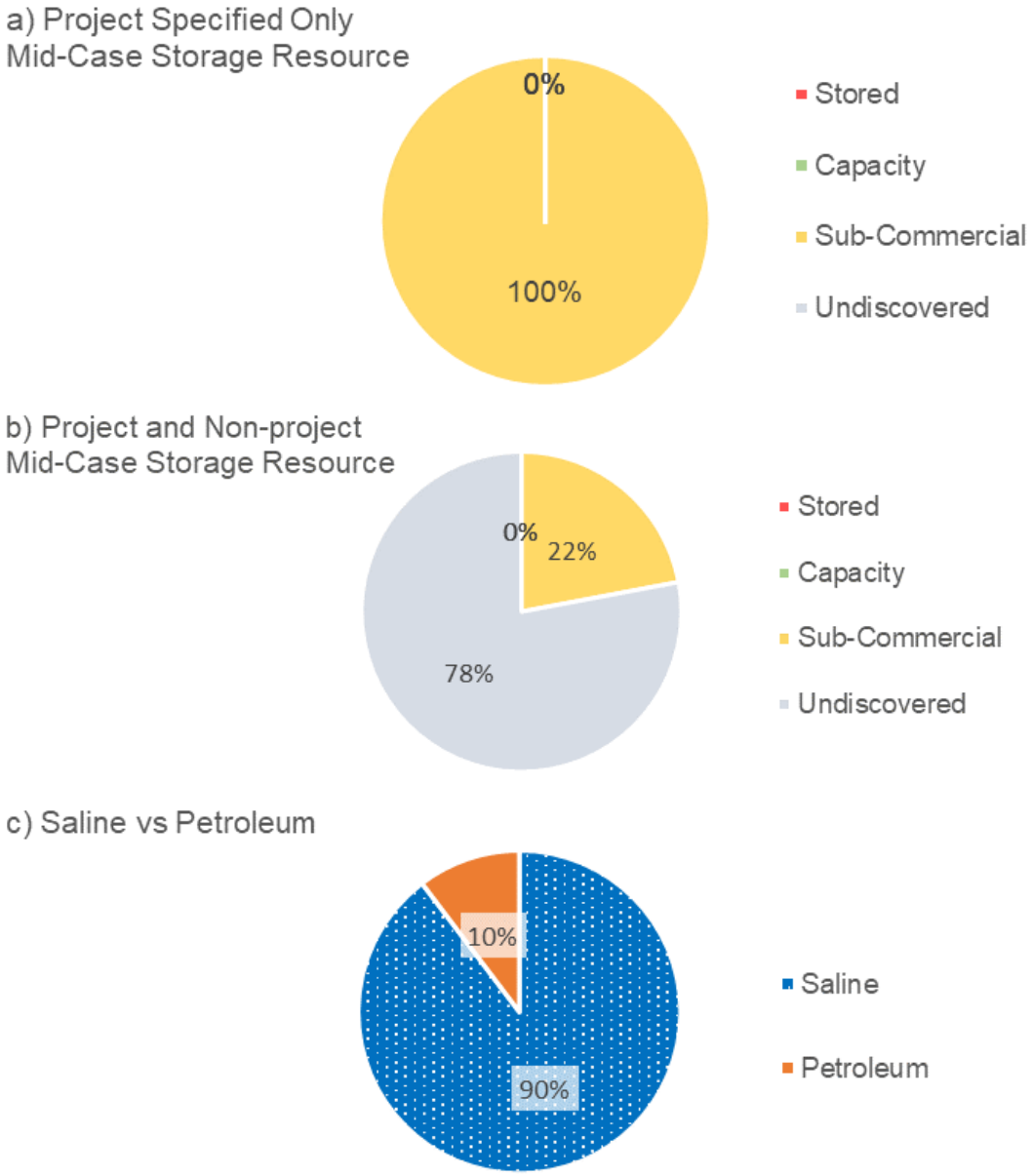


Figure 3-1: a) Spread of storage resource in UK sites (87) across SRMS classifications, where a project has been specified. b) Spread of storage resource in all UK sites across SRMS classifications; both project specified and not. c) Split of UK storage resource between saline aquifers and hydrocarbon fields, both project specified and not.

3.1.2 Resource Statement

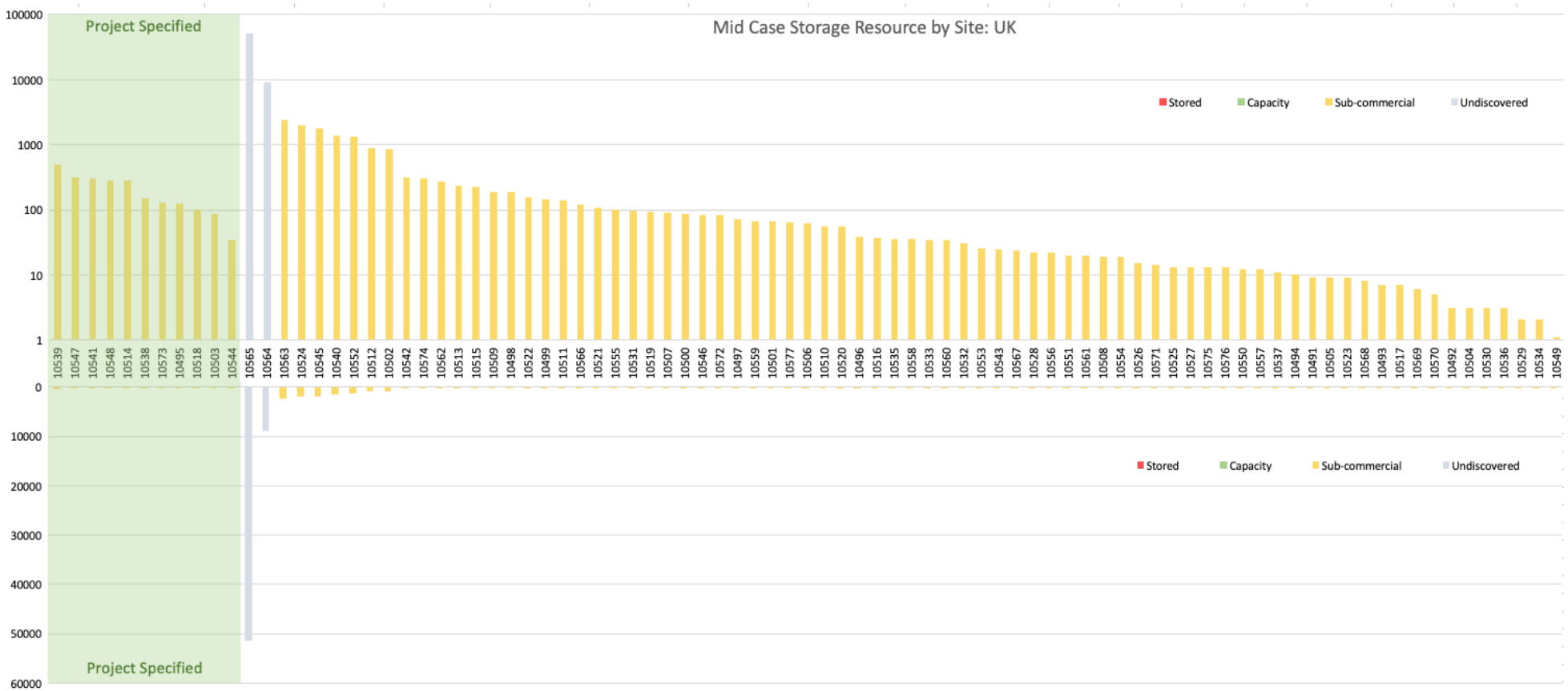


Figure 3-2: Storage resource summary for the UK compiled in the CSRC. Graph above is log scale and graph below is linear. Green box highlights sites where a project has been specified.

3.1.3 Evaluation History

The most widespread source for the estimation of CO_2 storage resource within the UK is from CO_2Stored, the UK CO_2Storage Evaluation Database, hosted and under development by the British Geological Survey and The Crown Estate and under license from the Energy Technologies Institute (ETI). The original data in CO_2Stored was developed by the UK Storage Appraisal Project (UKSAP), which was commissioned and funded by the ETI. CO_2Stored provides an overview of CO_2 storage data for over 500 potential CO_2 storage sites around offshore UK. To date, the database excludes the large tracts of acreage to the west of the Shetland Islands and in the South-Western Approaches, however the East Irish Sea is included. Unfortunately, due to the restriction of the CO_2Stored license to non-commercial use, it could not be used directly in the CSRC. As such, the UK individual entries are restricted to sites where the database is referenced in the published literature, including resource summaries created by the Energy Technologies Institute (ETI). To account for this and ensure that the storage resource for the UK is not under-represented, the remaining storage resource not captured in individual entries, is included in the CSRC database as four aggregated entries under the groupings: 'Sandstone aquifers', 'Chalk aquifer's, 'Oil fields' and 'Gas fields'.

3.1.4 Resource Review

3.1.4.1 Major Projects

To date four carbon storage licenses have been, or are being, held in the UK Continental Shelf (UKCS), in addition to one further licence application made in 2021 which is currently undergoing review. The past and current licences are:

1. CS001 Endurance Licence. Held by National Grid. Active from November 2012 till present. Storage site for the previous White Rose Project and now a potential target site for both the Humberside and Teesside projects. No published updates since the cancellation of the White Rose Project in 2015.
2. CS002 Peterhead Licence (Goldeneye field) held by Shell U.K. Limited. Active between July 2013 and August 2016. Licence terminated by Shell U.K. following the withdrawal of government funding in 2015. The evaluated area is now part of the current Acorn Licence.
3. CS003 Acorn Licence. Active from January 2018 till present. The licence is held by Pale Blue Dot Energy and combines both the Goldeneye field and ACT Acorn Storage Site which have both been subject to extensive study during many phases, but most recently the CCS Commercialisation Programme, funded by the UK Government. The Acorn Project is currently in FEED. There are currently no published evaluations of the storage resource within the newly defined Acorn site and as such, it could not be included in the CSRC Cycle 1.
4. CS004 Hamilton and Lennox Licence. Active from October 2020 till present. The licence is held by Eni and covers the depleted hydrocarbon fields Hamilton, Hamilton North and Lennox. It is the potential storage site for the HyNet Project which is currently under development.

The absence of reporting for active projects results in the notable absence of Commercial Storage Resources within the UK. Should any of the active project publish updated evaluations of the storage sites, they will be included in future assessments.

3.1.4.2 *Depleted Oil & Gas Fields*

All oil and gas fields can be classified as Discovered due to the presence of a proven reservoir. In the UK the majority of the hydrocarbon fields are further classified as "Development Not Viable" due to the absence of an active appraisal program. The two exceptions to this are the Hamilton Gas Field where the resources are classified as "Development On Hold" a storage licence is held for the site but suffers from a developed UK CCS business model, and Goldeneye, where resources are classified as "Development on Hold" as the retraction of government funding has caused significant delay.

It has been assumed that the UKCS hydrocarbon fields in the CSRC Cycle 1 will reach the end of their productive life before 2050 and therefore become available for CO_2 storage before that time, due to the maturity of the North Sea basin.

The majority of sites have been assessed using a fluid replacement methodology, with the exception of the sites; Goldeneye Gas Field, Viking A Storage Site, Hewett Gas Fields Storage Site, and Hamilton Gas Field, which have a simulation model and published results.

3.1.4.3 *Saline Aquifers*

The UK, like many other countries within the North Sea region, benefits from a wealth of experience and data acquired through a well-established hydrocarbon industry. Furthermore, the requirement for operators to share key subsurface data through the National Data Repository, have allowed both academia and industry to accelerate the assessment of many UK sites for CO_2 storage. Consequently, the reasonably high well density in many of the UK saline aquifers has allowed many of the sites to be classified as Discovered.

The overwhelming majority of the discovered resource is classified as "Development Not Viable", due to the lack of an active appraisal or evaluation plan presented for any of the sites. The two aggregated entries for sandstones aquifers and chalk aquifers, mentioned in 3.1.3, are all classified as "Undiscovered Basin Play", due to the aggregated nature of the entry. It is noted that this is not a true reflection of the maturity of the storage resource and portions of it will undoubtedly be Discovered due to significant hydrocarbon exploration in the North Sea. Should the licensing conditions for the CO_2Stored database change, or should evaluations be published for sites included in these aggregations, then the resource can be classified more appropriately.

The site 'Endurance Bunter Closure' has been classified as "Development On Hold" following the retraction of government funding detailed in 3.1.4.1, which has led to significant delay in the projects.

3.1.5 Regulatory Framework

The UK has the second most highly rated country in the GCCSI Policy Indicator Report [8] due to the ambitions for CCUS deployment outlined in the Clean Growth Strategy in 2017. Additionally, there are a range of policies which support emission performance standards and CCS research and development projects. In 2020 and 2021, the UK Government released their Energy White Paper detailing how UK energy supply will meet Net Zero ambitions and also pledged £1 billion towards the development of a series of clusters and hubs across the UK, further demonstrating their commitment to the UK CCS industry.

3.1.6 Issues for the Assessment

Lack of commercial access to the CO_2Stored database. Due to restrictions on the database for commercial usage, the data for the UK sites was restricted to publications that reference the database. Many of the sites in CO_2Stored could not be found in other publications, leading to the undesirable work around detailed in 3.1.3, to prevent significant under-representation of the storage resource in the UK.

Lack of reporting on active projects. As detailed in 3.1.4.1.

3.1.7 Future Updates

3.1.7.1 Future evaluations

Published evaluations for the sites currently active in the UK would be welcome for future updates to the CSRC. This would better represent the maturity of the storage resource associated with these projects.

3.1.7.2 Future CSRC cycles

A full update for the UK storage resource potential is recommended for future updates to the CSRC to capture changes in the rapidly advancing CCS industry.

4.0 Bibliography

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