CO_2 Storage Resource Catalogue

Cycle 4 Report

EUROPE

July 2024

Amounts of CO_2

Stored
0.03 Gigatonnes

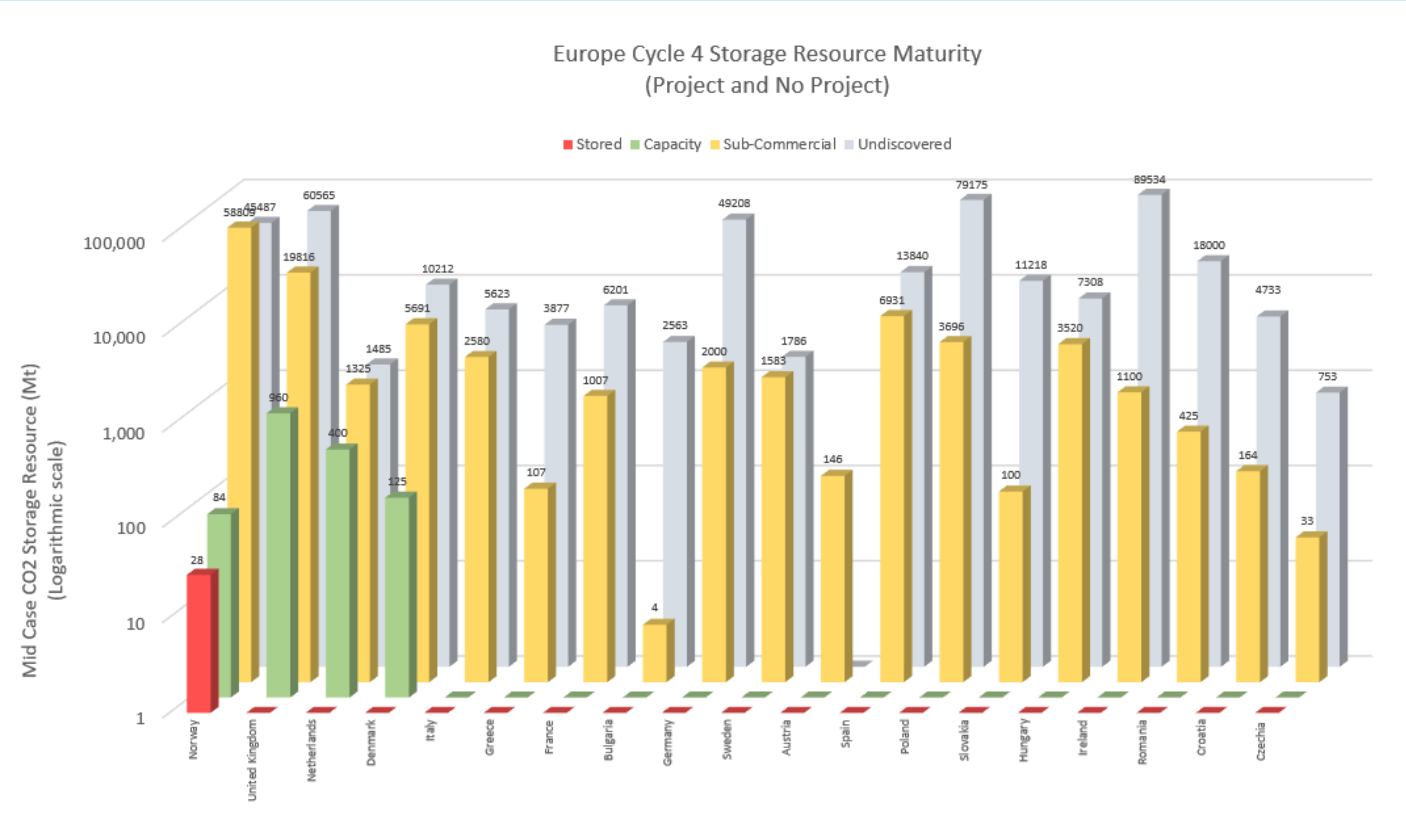
Commercial
1.6 Gigatonnes

Sub-commercial
109 Gigatonnes

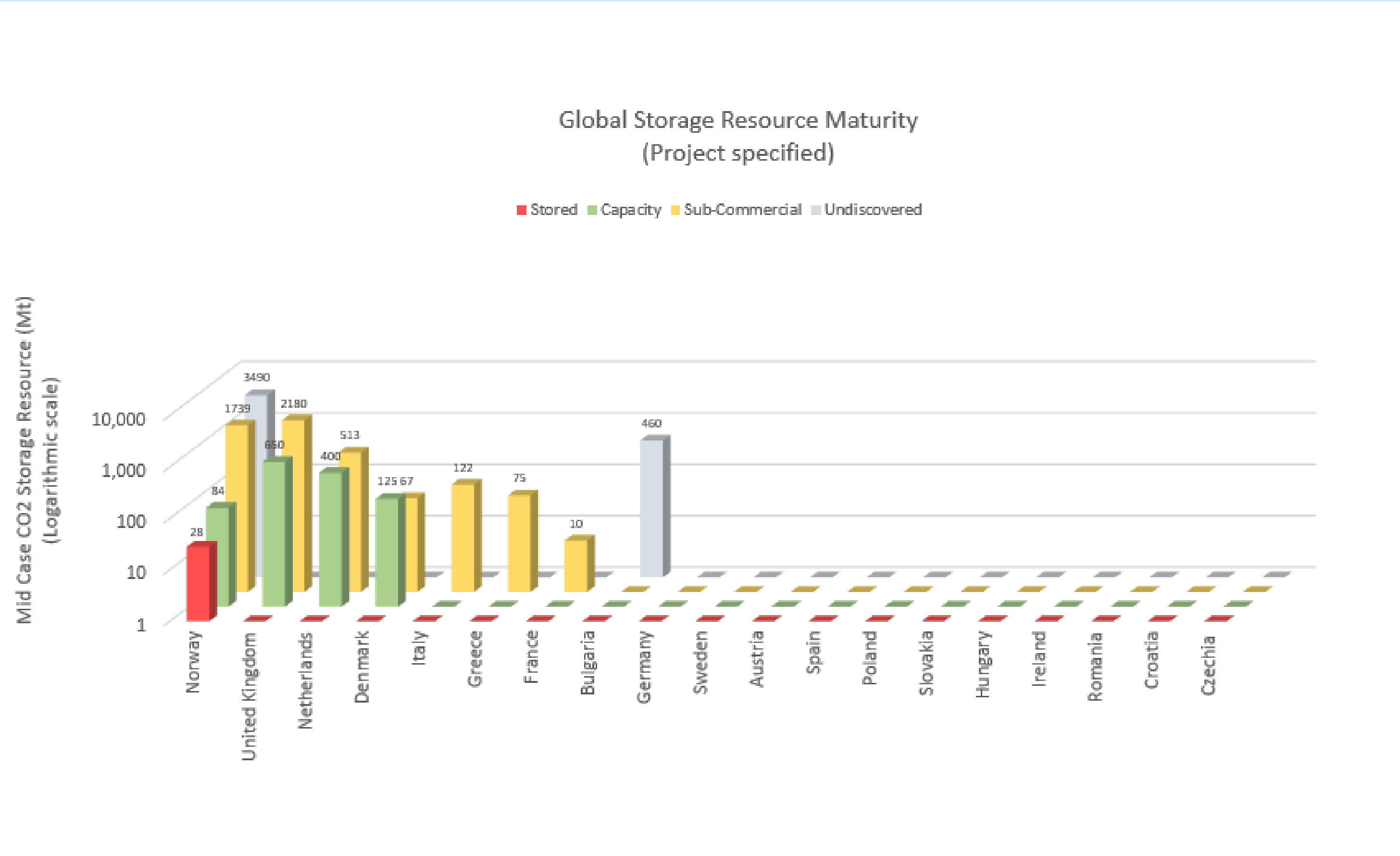
Undiscovered
412 Gigatonnes

Appendix C: Europe

Austria, Bulgaria, Croatia, Cyprus, Czechia, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Netherlands, Norway, Poland, Romania, Slovakia, Spain, Sweden, United Kingdom



Summary of Europe's CO_2 storage by capacity and maturity (project and no project) for each country assessed to date.



Summary of Europe's CO_2 storage by capacity and maturity (project specified) for each country assessed to date.

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Prepared by:	Halliburton: Shelagh Baines, Kate Evans, Montse Portet, Benjamin Panting, Krzysztof Drop GCCSI: Aishah Hatta, Joey Minervini		

Important notice

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1.1 Summary

Austria was assessed by the CSRC for the first time in Cycle 4. A summary of the CO_2 Storage resource is shown in the Table below.

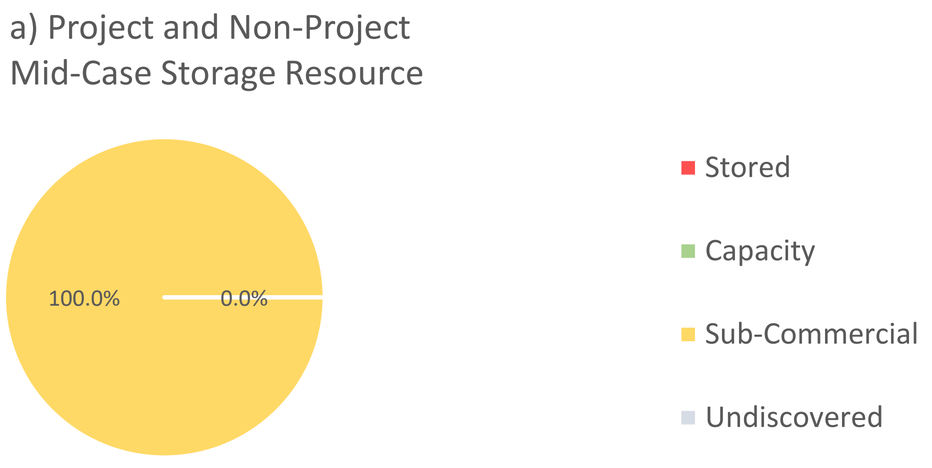
Classification	CO_2 storage resource (Gt) Project and no project	CO_2 storage resource (Gt) Project specified only
Stored	0.000	0.000
Capacity	0.000	0.000
Sub-Commercial	0.146	0.000
Undiscovered	0.000	0.000
Aggregated*	0.146	0.000

* 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 Austria

Austria has a total of 6 sites that can be added to the CRSC.

- These sites are classified as discovered but inaccessible due to all sites being either an oil or gas field but inaccessible due to legislation.
- CO_2 storage is currently prohibited in Austria. This status is reviewed every five years and assessed against the progress other countries have made.
- The identified sites are all carbonate formations in the Molasse or Vienna Basin.
- The storage potential of these fields was determined as 146Mt CO_2.



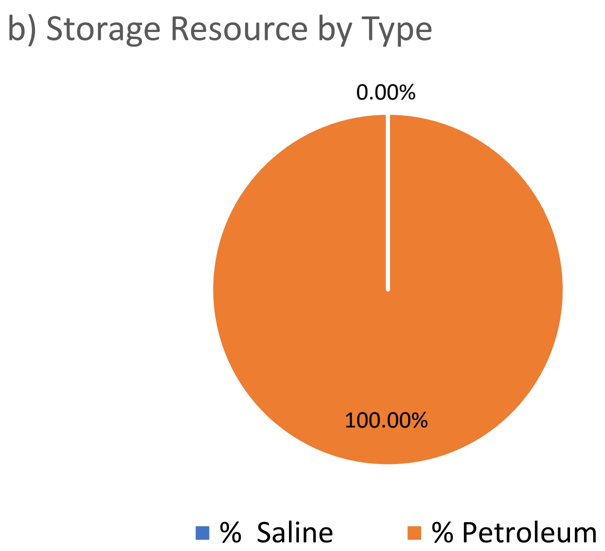


Figure 1-1: Austria Spread of Storage Sites

a) Spread of storage resource in Austria all sites across SRMS classifications; both project specified and not. b) Split of Austrian storage resource between saline aquifers and hydrocarbon fields, both project specified and not. Note: due to the large variance in the size of values, numbers in pie plots do not add up to 100.

1.2 Resource Statement

Figure 1-2: Storage resource summary for Austria compiled in the CSRC.

Graph above is log scale and graph below is linear. Green box highlights sites where a project has been specified.

1.3 Evaluation History

Austria has extremely limited studies for CO_2 storage potential. This is likely due to the current ban on storing CO_2 in Austrian basins. Austria views CCS, and the uses of any natural CO_2 sink to reach climate neutrality negatively. As such, storage resource estimates hold great uncertainty. However, a brief study in 2006 by Sharf and Clemmens [1] identified potential areas that could have characteristics suitable for CO_2 storage in depleted oil and gas fields. This study was built on Welkenhuysen et al.'s (2016) [2] work using a techno-economic approach that modelled different simulations to integrate a range of uncertainties to understand total and matched resources. Austria has a comprehensive and well-established hydrocarbon industry and is committed to reducing CO_2 emissions and being climate neutral by 2050; a change of direction regarding CCS legislation and more extensive studies may happen in the future.

1.4 Resource Review

1.4.1 Major Projects

There are no storage projects in Austria due to CO_2 storage being prohibited. However, Austria does have projects in other parts of the CCS value chain. ViennaGreenCO_2 is a project set up to research and develop low cost, energy efficient CO_2 separation/capture technology. Austria has also considered CO_2-EOR [3], which may help initiate a transition to CO_2 storage. In addition, the Lafarge Zementwerke, Verbund, OMV and Borealis are involved in a project called "Carbon2ProductAustria" (C2PAT), which aims to develop a full-scale CCU plant (CO_2GeoNet (2021) [4].

1.4.2 Depleted Oil & Gas Fields

Hydrocarbon fields in Austria deemed suitable for CO_2 Storage are found in the Molasse and Vienna Basin. The most significant storage potential is in the Vienna Basin. The oil-producing Schenkirchen Tief reservoir includes 3 fractured reservoirs (Schoenkirchen Tief, Schoenkirchen Tief Gas and Prottes Tief), has 15 producing wells and good reservoir quality. Mid-range resource is estimated 20Mt. The Schenkirchen Ubertief is a sour gas reservoir of fractured dolomite and is estimated to provide a mid-range of 40Mt. The Aderklaa site is an abandoned gas reservoir with a reported mid-range of 25Mt storage potential. Two other reported sites are the Höflein gas condensate dolo-quarzenit with a mid-range of 15Mt and Reyersdorfer sour gas dolomite with a mid-range of 13Mt.

The Molasse Basin has the Atzbach Schwanenstadt Gas reservoir, which has an estimated mid-range storage resource of 7Mt and an upper of 18Mt, and the Voitsdorf Oil reservoir, which is estimated to have a mid-range resource of 33Mt.

There is concern cited that legacy wells may pose some of the most significant risks to CO_2 containment.

Whilst Austria may currently restrict activities for CO_2 storage, it does have a very active hydrogen storage industry. RAG Austria has several sites for hydrogen storage and operates 11 facilities. These include Puchkirchen/Haag, Haidach, Haidach 5, Aigelsbrunn, and the 7 Fields interconnected gas storage and facilities in Pilsbach and Rubensdorf. This active gas storage industry is encouraging in terms of technology and expertise for any future synergies with CO_2 storage.

1.4.3 Saline Aquifers

Austria has no identified saline aquifers for CO_2 storage. However, this may change if there is a regulatory shift to permit CO_2 storage in Austria.

1.5 Regulatory Framework

Austria's legal stance on domestic CO_2 Storage is that it is prohibited within Austria. However, Austria has defined climate challenges to meet and reviews how the country will achieve these regularly. It passed the Climate Act in 2011 and, in 2018, submitted its draft National Energy and Climate Plans (NECPs) to the European Parliament and the Council. In the "Long-Term Strategy 2050" - published by the Federal Ministry Republic of Austria, Sustainability and Tourism (2019), Austria plans to reduce greenhouse gas emissions. It notes a need for CCS in its plans. The strategy calculated and presented several pathways for Austria to use for greenhouse gas emissions and compensation from 2020 to 2050. Pathways proposed the use of CCS to varying degrees to meet the objectives, and some found routes to avoid CCS. Austria reviews its status and "Federal Act on the Prohibition of the Geological Storage of Carbon Dioxide" every 5 years [5]

Austria scores 30 on the CCS readiness scale as defined by the GCCSI [5].

1.6 Issues for the Assessment

Limited research and very limited data availability for most of the CO_2 storage resources in Austria will affect the accuracy of storage estimates. All estimates at the current sites are based on hydrocarbon replacement volumes.

1.7 Future Updates

1.7.1 Future evaluations

Future evaluations should address any legislation updates and if this has helped encourage any projects or research.

1.7.2 Future CSRC cycles

Future updates will be strongly dependent on Austria's regulations. Should CCS be permitted, any sites undergoing evaluation to transition to storage will need to be reviewed.

2 Bulgaria

2.1 Summary

Bulgaria was assessed for the CSRC in Cycle 4. A summary of the CO_2 Storage resource is shown in the Table below.

Classification	CO_2 storage resource (Gt) Project and no project	CO_2 storage resource (Gt) Project specified only
Stored	0.000	0.000
Capacity	0.000	0.000
Sub-Commercial	0.004	0.000
Undiscovered	2.563	0.460
Aggregated*	2.567	0.460

* 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 Bulgaria

- Bulgaria has been assessed by several pan-European CO_2 storage assessment projects, namely Geocapacity, CASTOR and CO_2Stop.

- Bulgaria has CO_2 storage potential in both depleted oil and gas reservoirs and saline basins. All assessments to date are volumetric.

- Bulgaria currently does not have any pilot/demonstration or commercial CO_2 storage projects. The ANARV project will be the first CO_2 capture in Bulgaria and store CO_2 in the Black Sea depleted gas field Galata, with an estimated CO_2 storage resource of 4Mt.

- A total of seven zonal aquifers are estimated as suitable for CO_2 storage. The majority are located in Northern Bulgaria and related to thick Phanerozoic sedimentary succession in the Moesian Platform

- Bulgaria follows the Directive 2009/31/EC on the Geological Storage of Carbon Dioxide.

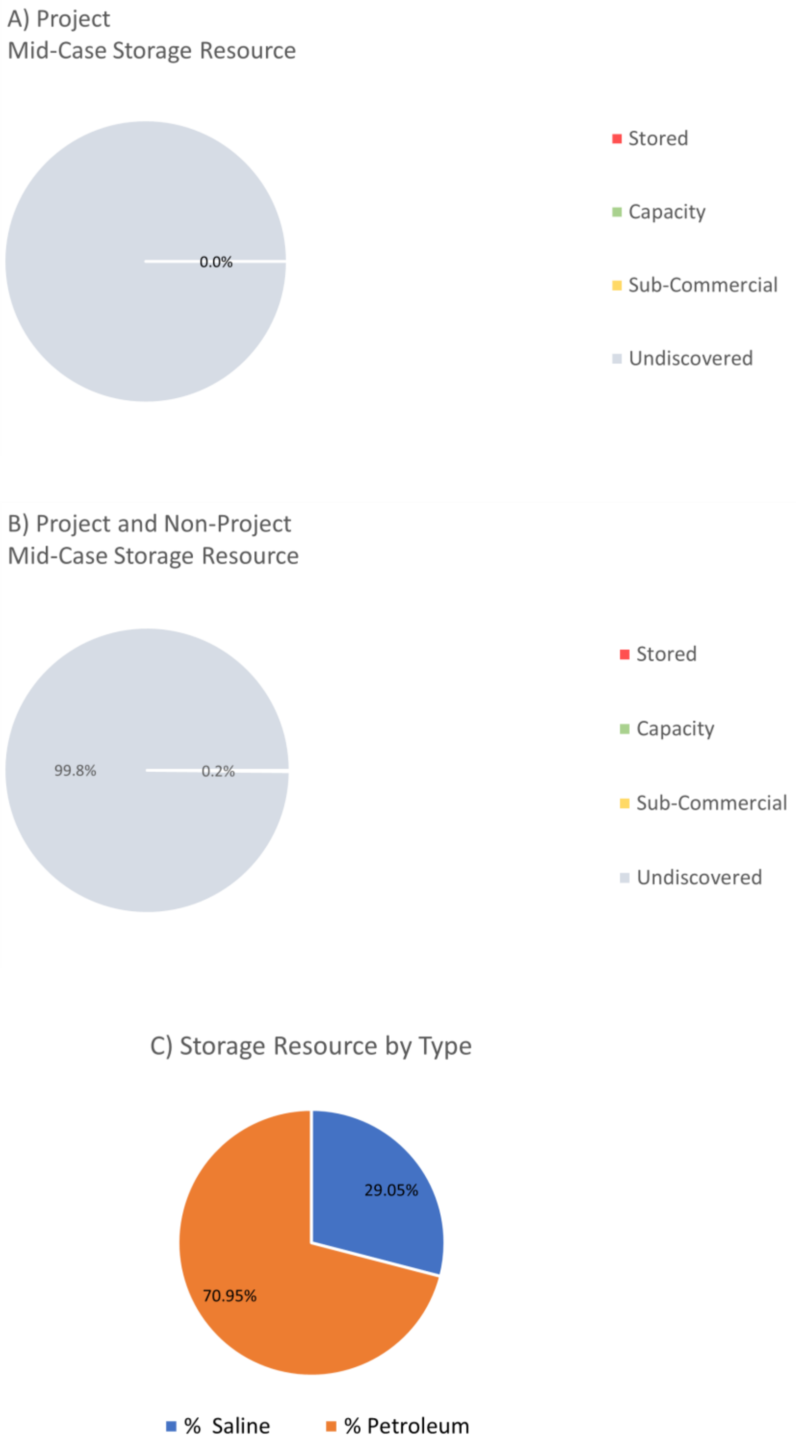


Figure 2-1: Bulgaria Spread of Storage Sites

a) Spread of storage resource in all Bulgarian sites across SRMS classifications; both project specified and not. b) Split of Bulgarian storage resources between saline aquifers and hydrocarbon fields, both project specified and not. Note: due to the large variance in the size of values, numbers in pie plots do not add up to 100.

2.2 Resource Statement

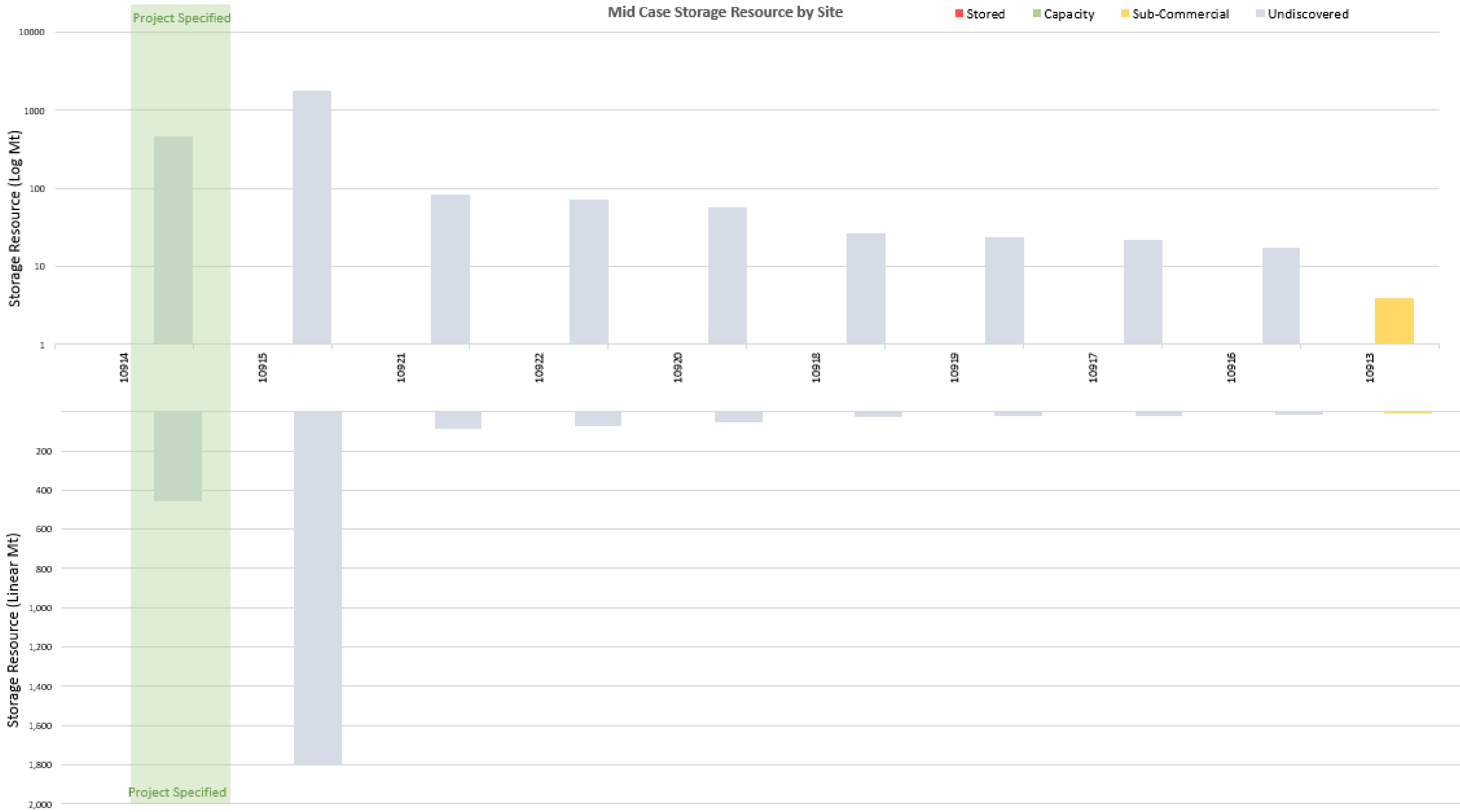


Figure 2-2: Storage resource summary for Bulgaria compiled in the CSRC.

Graph above is log scale and graph below is linear. Green box highlights sites where a project has been specified.

2.3 Evaluation History

The first evaluation of potential storage resources in Bulgaria took place with the CASTOR project (2004 – 2005). This was updated and enlarged with the EU GeoCapacity project (2006-2008). During the GeoCapacity project, the CO_2 storage potential was estimated for onshore saline aquifers, depleted hydrocarbon fields and coal fields.

The most promising potential for CO_2 storage in Bulgaria is related to karstifed and fractured carbonate reservoirs in the Devonian and Upper Jurassic - Valanginian, and coarse-grained clastic reservoirs in the Lower Triassic, Middle Jurassic and Middle-Upper Eocene stratigraphic units [1]. They have been proven by results from numerous drilled oil and gas exploration wells. The evaluation of CO_2 storage resources in Bulgaria's deep saline aquifers is based on estimating two individual structures and seven local zones. Six of the selected aquifers are in Northern Bulgaria, and the other two are in Southern Bulgaria [2].

All sites reported in the CRSC have used the GeoCapacity volumetric approach, hence carrying some uncertainty around over-estimation.

2.4 Resource Review

The largest emission sources in Bulgaria are located near the Black Sea coast and in central Bulgaria. The storage regions are in the easterly part of the country, with a total storage resource of 2563Mt in deep saline aquifers and 4Mt in hydrocarbon fields [1].

2.4.1 Major Projects

Bulgaria has been in involved in two CCS projects. The first is the Maritsa project. This was a proposed CCUS project and was due to start in 2013 but was cancelled due to the lack of budget. There is limited information available on this project. The second is the ANRAV project. This will be the first CCS Project in Eastern Europe and the first CO_2 capture project in Bulgaria. Storage of CO_2 will be in the Galata depleted oil field in the Black Sea. ANRAV, will link CO_2 capture facilities at Heidelberg Cement's (HEIG.DE) Devnya cement plant in north-eastern Bulgaria with offshore permanent storage in the depleted Black Sea gas field of Galata. Operations are expected to start in 2028, aiming to capture 800,000 tonnes of CO_2 yearly. The storage potential of the Galata field is estimated to be 2.0 billion m3 at STP conditions [4], corresponding to 4Mt of CO_2

2.4.2 Depleted Oil & Gas Fields

A review of storage potential in Bulgaria's depleted oil and gas fields is provided in the GeoCapacity project [5]. Most discovered economic oil and gas fields in Bulgaria are outside the depth range interval of 800-2500m (suitable for effective CO_2 storage). Only three gas fields (Pleven, Marash and Galata) are within the right depth interval. Bulgaria has an underground gas storage operation in Chiren, which started in 1974 and is still operating. Only the Galata gas field, located offshore, was considered for CO_2 storage and has an estimated storage potential of 6Mt.

2.4.3 Saline Aquifers

Saline aquifers in Bulgaria have more promising CO_2 storage potential. A total of 7 aquifers are estimated as suitable for CO_2 storage. The majority were located in Northern Bulgaria and related to thick Phanerozoic sedimentary succession in the Moesian Platform. Good reservoirs with appropriate geological parameters for CO_2 storage are present in Devonian, Lower Triassic, Middle Jurassic, Valanginian and Eocene sedimentary sequences. In Southern Bulgaria, dominated by igneous and metamorphic rocks, the only aquifers with CO_2 storage potential are related to the narrow distribution of the Paleogene sedimentary sequence in the Thracian depression.

2.5 Regulatory Framework

Carbon capture and storage EU laws were introduced in Bulgaria, with the draft legislation being approved by the Government on 22 September 2011 and sent to Parliament for further approval on 28 September 2011 [6]. Amendments and supplements from the third implementation of the Directive 2009/31/EC on the geological storage of carbon dioxide ("CCS Directive") have been transposed into Bulgarian legislation.

Bulgaria scores 34 out of 100 in the CCS readiness index as defined by the GCCSI [7].

2.6 Issues for the Assessment

The only data available for Bulgaria on CO_2 storage potential is provided by G. Georgiev from Sofia University (as reported in the GeoCapacity project). Any subsequent publications found are still based on his estimations. Some show discrepancies in the storage resource values, but because no justification accompanies the published values, the GeoCapacity values are entered in the Cycle 4 CSRC database. A lack of dynamic modelling and ready access to site-specific data was the main issue for this assessment cycle and a limitation for understanding storage site potential in this country.

2.7 Future Updates

2.7.1 Future evaluations

Future evaluations should seek to address if there are any refinements to the GeoCapacity estimates, which are now quite dated.

2.7.2 Future CSRC cycles

Should any further development in the Bulgaria storage systems occur, this should be reviewed annually to ensure the Global Storage Catalogue is up to date. Future updates should also include observations of progress with the ANRAV project.

3 Croatia

3.1 Summary

Croatia was assessed for the CSRC in Cycle 4. A summary of the CO_2 Storage resource is shown in the Table below.

Classification	CO_2 storage resource (Gt) Project and no project	CO_2 storage resource (Gt) Project specified only
Stored	0.000	0.000
Capacity	0.000	0.000
Sub-Commercial	0.164	0.000
Undiscovered	4.733	0.000
Aggregated*	4.897	0.000

* 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 Croatia

- Croatia has a total of 18 sites that can be added to the CSRC.
- Seven of these sites are classified as discovered due to a history of oil and gas production or drilling campaign.
- There are extensive pipeline networks, hydrocarbon fields and saline aquifers in close proximity to major emitters in the Sava and Drava depression regions, both of which have large saline aquifers. This area may hold potential for hub developments in the future.
- Additional saline aquifer storage is identified in defined structures in the Adriatic or in large saline basins in the north of the country.
- CCS is currently permitted in Croatia, and the country has an active research program on various aspects of the CCS life cycle. There are several projects underway through the full CCS value chain.
- Regulations are contradictory, which is a crucial reason for the advancement of limited storage assessments to date.

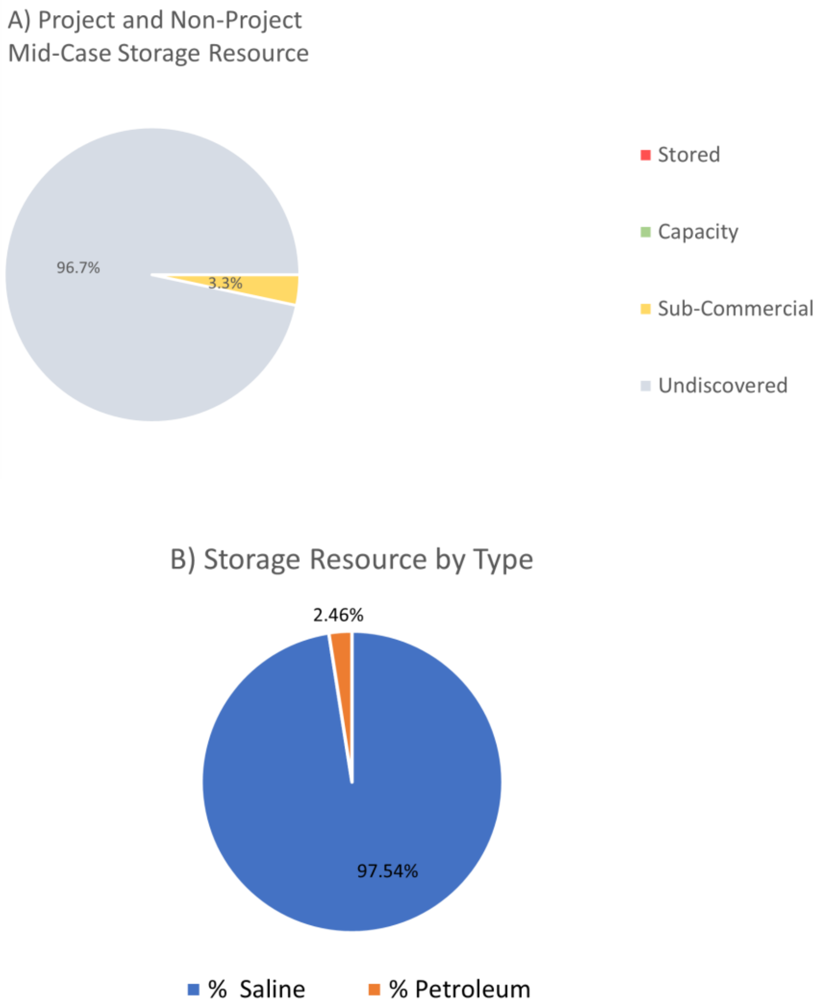


Figure 3-1: Croatia Spread of Storage Sites

a) Spread of storage resources in Croatian sites across SRMS classifications; both project specified and not specified. b) Split of Croatian storage resource between saline aquifers and hydrocarbon fields, both project specified and not. Note: due to the large variance in size of values, numbers in pie plots do not add up to 100.

3.2 Resource Statement

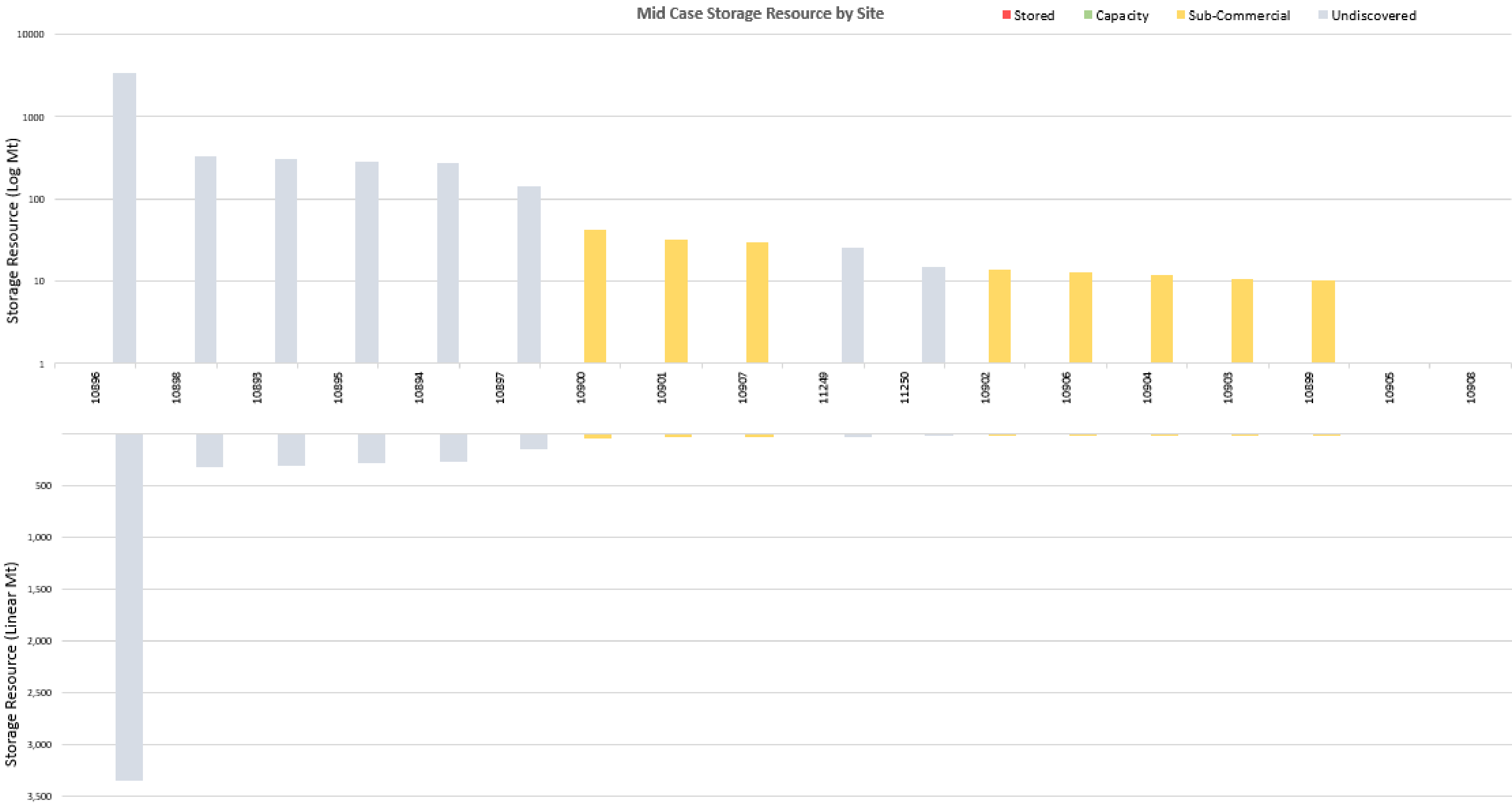


Figure 3-2: Storage resource summary for Croatia compiled in the CSRC.

Graph above is log scale and graph below is linear. Green box highlights sites where a project has been specified.

3.3 Evaluation History

Croatia has benefited from several of the pan-European assessment studies. Croatia was part of the GeoCapacity (2008) project and also underwent a comprehensive study for storage resources in the CASTOR (2008) project (https://cordis.europa.eu/project/id/502586/reporting). Since then, two extensive reports have used storage resource values similar to those reported in earlier studies but have attempted to revise some of these calculations or assess resource potential based on country advancement and emissions status. STRATEGY CCUS [1], a project completed in 2021, was funded by the EU. It assessed the storage resource data from each designated region and provided a maturity and readiness status for implementing CCUS projects. The report evaluated previous volumetric estimates with a qualitative assessment and then ranked the resources based on data maturity and understanding of resource potential. In most cases, this approach has increased Croatia's storage potential in saline aquifers. These values have been used in the CSRC. Croatia was also part of the CCS4CEE [2] study, which was completed in 2022. This report did not revise the estimates to any greater extent but did report many more hydrocarbon sites – most of which are too small to be included in the CSRC database. Other studies by Saftic et al. (2019) [3] published more extensive assessments of the Adriatic potential. Resources were based on volumetric methods incorporating compressibility calculations and have been used as the preferred values in the CSRC.

Plans have been made to establish a National Feasibility Study on CCS and evaluate a national CO_2 storage resource. However, no public reporting on this has been done to date.

3.4 Resource Review

3.4.1 Major Projects

Croatia is active in several areas of the CCS value chain. There are 3 projects operated by INA/MOL:

1. An active CO_2 EOR project has been in operation since 2014 and is run at the gas treatment plant at the Molve Municipality. The injection is onshore at the Ivanić & Žutica gas field.

2. A full chain CCS project at the Petrokemija Plant. Here, the Ammonia plant CO_2 will be captured and transported via pipeline to store at the depleted Ivanić & Žutica gas field. Injection is planned in 2026 [4].

3. A biorefinery project focused on industrial capture and underground storage aims to be operational by 2024 and capture 55,000 tonnes per year. The injection is in depleted oil and gas fields, although these are not specified. Collectively, these projects aim to capture 1.96Mt [4].

A further project is the CCGeo project (Closed Carbon Geothermal Energy), a full chain CCS project that intends to generate electricity and heat from geothermal brine. Then, the produced

CO_2 will be injected back into the same reservoir. This will be operated by AAT Geothermae, CLEAG. This site is in the Pannonian basin at Draškovec and started in 2022. To date, the project has completed the research phase [4]. An additional geothermal project, Velika Ciglena, has operated since 2018 and aims to capture 0.15Mt [2]. Finally, a large-scale project called KOdeCO net Zero seeks to be the first net zero cement plan in Croatia and the Mediterranean. CO_2 will be captured and taken to the Mediterranean Sea for storage (the site is not yet named) [5].

3.4.2 Depleted Oil & Gas Fields

A total of 17 oil and gas fields have been identified as having CO_2 storage potential. However, due to their small size, only 6 have been added to the CSRC. Two prospective sites (which are currently CO_2 EOR projects) that have been identified as higher potential targets for CCS are the Ivanić and Žutica oil fields (central Croatia) and the Beničanci oil field (eastern Croatia). Both Beničanci and Ivanić are too small to be included in the CSRC. In addition, all these sites are close to both CO_2 emitters and pipeline infrastructure, so they could potentially present a hub and cluster solution in the future when combined with other sites in the vicinity. Most sites have targets in Upper Miocene formations - the Ivanić Grad, Kloštar Ivanić and Vinkovci Formations. There is limited data for these fields due to confidentiality. Most potential storage fields are in the Sava and Drava depressions, and three fields (Ida, Ika and Marica) are in the Adriatic. Marica's 9.7 Mt CO_2 storage potential is too small to be included in the CSRC database.

3.4.3 Saline Aquifers

Most of Croatia's potential storage sites sit within the Pannonian Basin, specifically the Sava and Drava Depressions. These depressions were formed during the Neogene–Quaternary tectonic evolution of the south-west part of Pannonian Basin. As with depleted oil and gas fields, all saline aquifer sites are in Upper Miocene sandstones. The Upper Miocene sediments are characterised by marls and sandstones initially deposited in a turbiditic pro-delta, then delta slope to delta plain environments. This area then developed into Lake Pannon. The Pliocene and Quaternary sediments are deposited in the terrestrial environment and comprise of fine-medium grain clastics. The Sava depression has three overlapping key units previously classified as one. They are the Iva, Okoli and Poljana aquifers. The Drava Depression has the Drava and Osijek aquifers. Combined with the Dugi Otqok aquifer in the Adriatic, these three saline aquifers can potentially provide over 90% of Croatia's CO_2 storage resource. None of these resources have been extensively explored despite the presence of over 120 wells the Poljana area. It has not been possible to determine how many of these provide data for the aquifer. These sites are classified as Undiscovered due to great uncertainty surrounding data availability for such large areas. However, these sites are near several emission sources and pipeline networks, so they have the potential to present a hub and cluster solution if data is sought on their suitability.

The Dugi Otok forland basin and 5 structures form the potential saline aquifer sites in the

Adriatic. Again, none of these sites have been extensively assessed. Three storage formations are found in this area:

1. Pliocene and Pleistocene sands (oil and gas reservoirs – see above)

2. Miocene sandstones (in Dugi Otok basin)

3. Triassic-Cretaceous Limestones (structures).

One structure is deemed too small to be counted in the CSRC database. Drilling activity is present in this region, and likely, some structures have been drilled, although the extent of this activity is unclear in the literature. One structure does have a well penetrating it (Kate-1), but limited data is available. This structure is classified as discovered.

Croatia is not tectonically benign, and earthquakes have been recorded in the CO_2 resource regions. However, the majority are concentrated in the south of the country, where there are currently no identified sites.

3.5 Regulatory Framework

Croatia's legislative framework aligns with existing EU Directives on carbon capture and geological storage. The Hydrocarbon Exploration and Exploitation Law and the Law on Permanent carbon dioxide storage in geological formations represent the transposition of the Directive 2009/31/EC. Croatia's ordinance on 'Permanent carbon dioxide storage in geological formations (ordinance on permanent storage of gases in geological structures) outlines procedures and testing necessary for permanent storage of CO_2 within geological formations. It also defines the conditions under which CO_2 can permanently store in geological structures. The conditions for obtaining concessions, exploration and storage permits are in the Hydrocarbon Exploration and Exploitation Law. However, it is reported that these two laws can contradict each other, and this aspect has been deemed to be a limiting factor to Croatia's progression and implementation of CCS. Croatia scores 60.5 on the CCS readiness scale as defined by the GCCSI.

3.6 Issues for the Assessment

Low research and a very limited amount of data for most of the CO_2 storage resources in Croatia will affect the accuracy of storage estimates. All estimates at the current sites are based on hydrocarbon replacement or theoretical volumes.

3.7 Future Updates

3.7.1 Future evaluations

Future evaluations should seek to address any updates to sites or potential projects. Future updates should also seek any insight from the planned national CO_2 storage assessment, which could provide more insight into the characteristics of potential storage sites.

3.7.2 Future CSRC cycles

An update for all sites is recommended for future updates to the CRSC. Many sites currently at the formation level may have increased studies to evaluate the lead and prospect levels. The prospective nature of the northern area for hub and clusters and current EOR activity could make this area quite attractive for future storage development.

4 Cyprus

4.1 Summary

Cyprus was assessed during Cycle 4. The CSRC has identified that Cyprus has no published storage resource estimates, and so has zero sites to enter into the CSRC database:

Classification	CO_2 storage resource (Gt) Project and no project	CO_2 storage resource (Gt) Project specified only
Stored	0.00	0.00
Capacity	0.00	0.00
Sub-Commercial	0.00	0.00
Undiscovered	0.00	0.00
Aggregated*	0.00	0.00

* 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 4-1: Storage resource classification summary for Cyprus

4.2 Evaluation History

Cyprus was reviewed during Cycle 4. Cyprus is a gas-producing country with recent offshore discoveries undergoing development. No CO_2 storage evaluations have been carried out at the federal level, nor are any available in the public domain. Assessment of storage potential in the saline formations in the offshore Levantine Basin should form the subject of any future evaluation effort.

4.3 Regulatory Framework

The Cypriot government has a strategic goal to "participate proportionately in the commitment towards a climate-neutral economy at EU level and to contribute to the European Green Deal promoted by the European Commission" (Department of Environment Mistry of Agriculture, Rural Development and Environment, 2022 Long-term low GHG emission development strategy Cyprus (unfccc.int)). The roadmap to achieving these emissions' goals is not yet established, and CCS is not highlighted as a potential technology. However, The EU CCS Directive was fully transposed to National Law in 2012 (Law L.71(I)/2012 and amended in 2015 by Law L.174(I)/2015. As of 2023, no assessment of the available storage potential in Cyprus has been undertaken (Ap (europa.eu)).

4.4 Future Updates

4.4.1 Future Updates for Evaluators

A comprehensive, country-wide assessment of Cyprus' geologic CO_2 storage resources is required for both saline formations and any future opportunities in depleted hydrocarbon fields.

4.4.2 Future CRSC Cycles

Updates to the Cycle 4 assessment should be completed if studies on Cyprus' CO_2 storage resources become available.

5 Czechia

5.1 Summary

Czechia was assessed for the CSRC in Cycle 4. A summary of the CO_2 storage resource is shown in the Table below.

Classification	CO_2 storage resource (Gt) Project and no project	CO_2 storage resource (Gt) Project specified only
Stored	0.000	0.000
Capacity	0.000	0.000
Sub-Commercial	0.033	0.000
Undiscovered	0.753	0.000
Aggregated*	0.786	0.000

* 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 5-1: Storage resource classification summary for Czechia

- There is limited information on storage sites in the literature and to date only 10 saline aquifer sites and sites exist to include in the CRSC. These numbers are considered to carry some uncertainty due to limited data availability in the saline aquifer sequences.

- Storage is estimated to be around 753 Mt in saline aquifers within Central Bohemian Upper Paleozoic Basins, Vienna Basin and the Carpathian Foredeep.

- Storage in hydrocarbon fields is estimated at 33 Mt CO_2 and 54 Mt CO_2 in coal fields (mainly in the Upper Silesian Basin).

- Despite limited published material on CO_2 resources in Czechia, the country has a very active history and participation in research projects across the full CCS value chain both nationally and with collaboration on European projects. This demonstrates a growing level of expertise and knowledge in the country for all components of a CCS project.

- The country has one commercial project identified in the Moravia region to capture CO_2 from cement production.

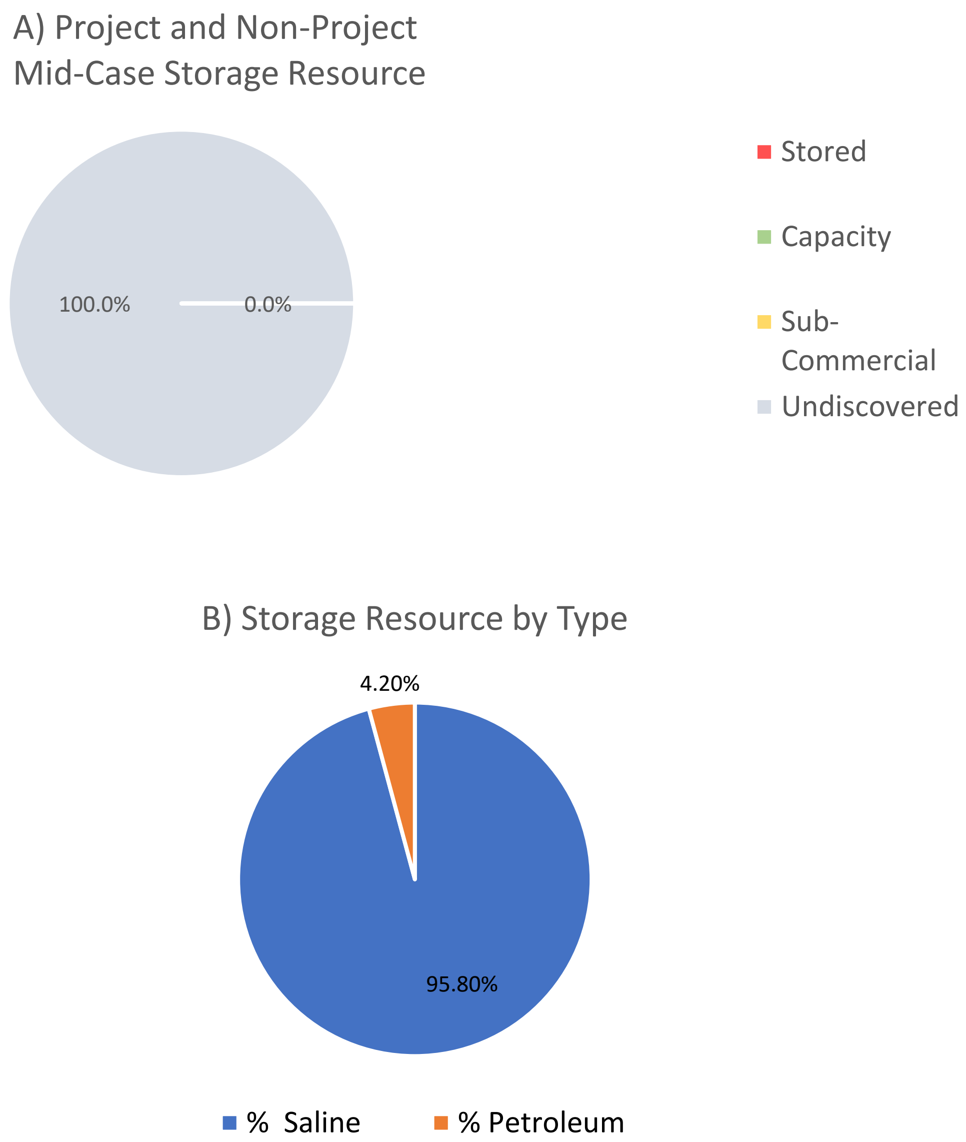


Figure 5-1: Czechia Spread of Storage Sites

a) Spread of storage resources in Czechia sites across SRMS classifications; both project specified and not. b) Split of Czechia storage resource between saline aquifers and hydrocarbon fields, both project specified and not. Note: due to the large variance in size of values, numbers in pie plots do not add up to 100.

5.2 Resource Statement

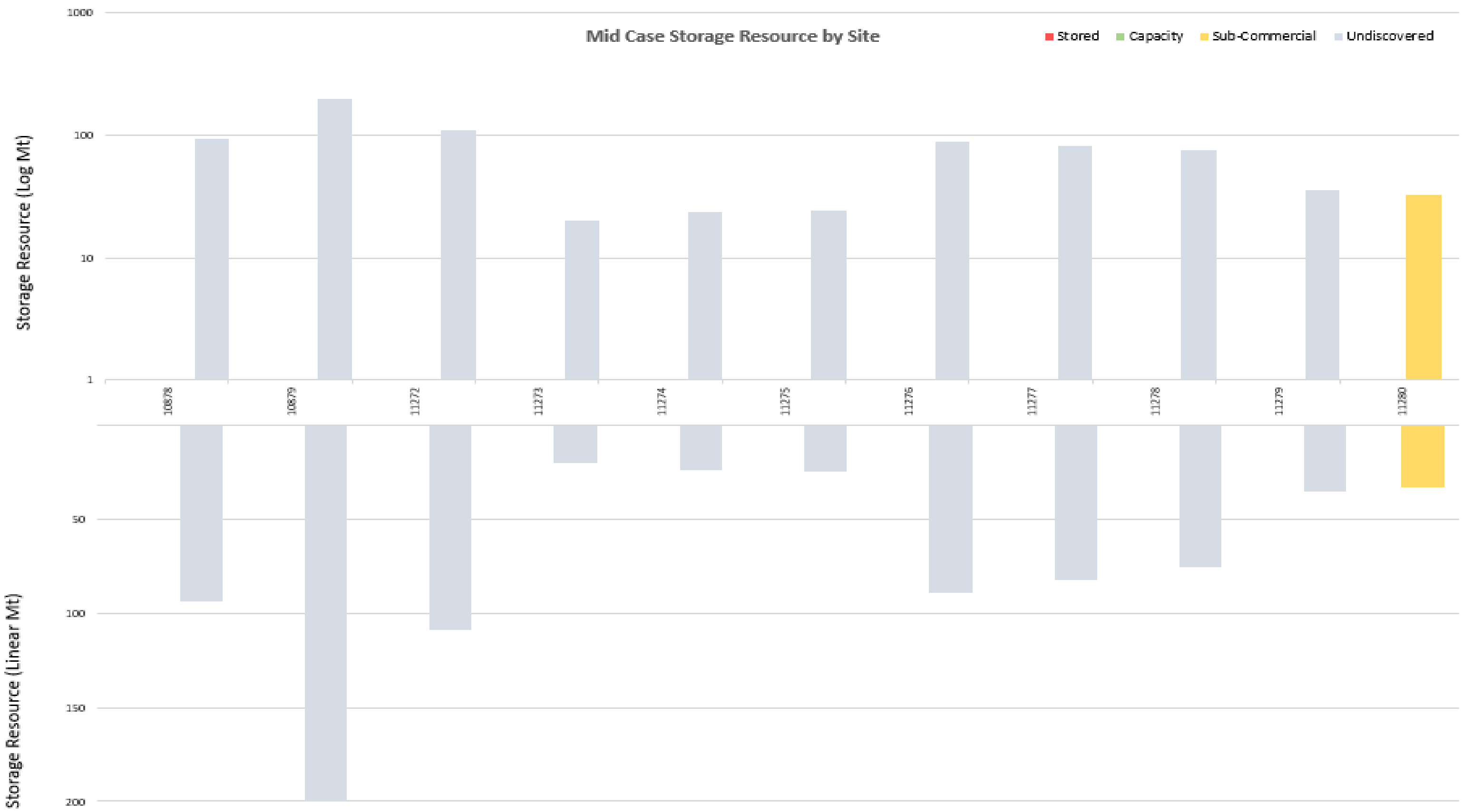


Figure 5-2: Storage resource summary for Czechia compiled in the CSRC. Graph above is log scale and graph below is linear.

5.3 Evaluation History

There are very limited studies for CO_2 resources in Czechia. The main estimates for CO_2 storage resources in Czechia originate from the GeoCapacity project (2006-2008 [8]. Czechia was also part of the CASTOR project (2004-2005) and CO_2Stop (2012-2013). CO_2Stop [7] provides estimates for several sites in saline aquifers. However, most reports prefer to use GeoCapacity estimates when reporting on storage resource potential. The recent CCS4CEE reports [1] include a summary of storage potential estimated from the Czech Geological Survey's work for GeoCapacity. The storage resource estimates are variable due to varying storage efficiency coefficients and a lack of data for saline aquifers. The highest storage resource estimate in saline aquifers is 2863 Mt CO_2, but more conservative estimates place this around 756 Mt CO_2. An additional geological project was the TOGEOS project (2009-2010). This project targeted saline aquifer storage sites and was coordinated by the Czech Geological Survey and the Norwegian partner IRIS – the International Research Institute of Stavanger.

5.4 Resource review

5.4.1 Major Projects

Although a number of geological studies and research have been done in Czechia over the last 15 years, there are no CCS pilot projects to date. The research projects have covered a wide range of CCS topics in the CCS value chain and include many studies on capture, storage, and transport [1]. Despite limited reporting on CCS sites, this demonstrates that Czechia is building up expertise and knowledge readiness on CCS technologies for future opportunities.

Recent projects of note for CO_2 storage over the last 10 years include the following:

The REPP-CO_2 project aimed to advance the technology readiness of CO_2 storage in Czechia and update resource estimates in the Carpathian region. The project also focused on the Vienna Basin and identified a site (LBr-1) that could be prepared for a future pilot project (mainly for EOR and as such is not entered in to the CRSC). The ENOS project (2016-2020) [2,4] aimed to deepen the knowledge of onshore CO_2 storage and EOR options. The Czech Geological Survey participated in this consortium, and the site LBr-1 (as identified in REPP_CO_2) was chosen as one of the project test sites for simulation studies.

The ENOS project also studied the development of a possible cluster in the Czech Vienna Basin sector on the borders with Slovakia and Austria. This project at LBr-1 assessed a small-scale pilot with limited storage, full-scale storage, and CO_2-EOR. It was also a key project to investigate and evaluate any transboundary issues that could arise from CO_2 storage in this field. Although this was a detailed study, only resource estimates of 70,000 tons were provided for a small-scale pilot. The main focus of this site is for EOR purposes.

The CO_2-Spicer Storage Pilot, which ran from 2020 to 2024, was operated by the Czech Geological Survey, MND, and the Norce Norwegian Research Center. The project worked on future steps toward realising the first CO_2 storage pilot project in Czechia. The Zarosice oil and gas field in SE Czechia was chosen. The naturally fractured Jurassic dolomite of the Vranovice Formation is considered a potential storage formation, sealed primarily with upper Jurassic marl (Mikulov Formation).

The COREu project and Project CCS Moravia are currently in the preparation stage. Project CCS Moravia is on a subsidy from the EU's Duty Program and part of the Green Deal commitment to reduce CO_2 emissions by 55% by 2030. The project partners are MND and Heidelberg Materials. The project aims to capture CO_2 from cement production and store it in saline aquifers in South Moravia. The project is planned to operate for 25 years. The total storage of the structure is 23.4 Mt, and injection is scheduled for 2034 [5]. This site may also be part of project COREu. This project's main objective is to develop CCS routes connecting emitters to storage sites and further support CO_2 capture, transport, and storage research. COREu links four potential routes together under the same project: Prinos/Kavala in Greece, South Moravia in Czechia, Baltic/Gdansk in Poland and Western Ukraine and plans to initiate an open-access, transnational network to connect emitters with European storage sites [5]. As there is no location the site is not entered in the CRSC, however it is hoped that future publications will provide more details on this project.

5.4.2 Depleted Oil and Gas Fields

In the south-eastern part of Czechia, a geological province of the Vienna Basin, there are several potential storage sites in oil and gas fields. According to EU GeoCapacity, the total storage resource of these fields was estimated at 33Mt CO_2. The location and volume of exact fields is sparsely reported in the literature and as such depleted fields are entered as one site in the CRSC. Some fields in this basin, LB-1, have already been investigated for storage options (LBr-1 EOR) [3].

5.4.3 Saline Basins

The Central Bohemian Basin has CO_2 storage potential in upper Carboniferous and lower Permian clastic sediment. CO_2Stop divided the basin into four subareas: the Zatec, Roudnice, Mnichovo-Hradiste, and Nova Paka. The combined storage resource for all these is 403 Mt. The entire basin is estimated at 471 Mt.

The Carpathian Foredeep contains storage potential in Neogene age formations. CO_2Stop identified four sites with a resource estimated at 281 Mt. The entire basin has a resource estimate of 295 (this is derived from a total estimate of 766 Mt for all of Czechia from GeoCapacity [1] minus 471 Mt as estimated by [3] for the Central Bohemian Basin. One site in the South Moravia area is part of the Project CCS Moravia (the project is detailed in the Major Projects section above). This site will store CO_2 captured from the Mokrá Cement plant near Brno. The actual site name and location for storage are not reported in any literature at the time of cycle 4.

5.4.4 Coal Fields

In addition to saline aquifers and depleted hydrocarbon fields, there is also theoretical methane storage in the Upper Silesian Coal Basin (NE Czechia in Ostrava province). A total storage of 54 Mt is estimated.

5.5 Regulatory Framework

The CCS Act prohibited the storage of CO_2 over 100,000 tons until 01/01/2020. Since then, commercial storage restrictions have ceased to exist. However, the Act still limits storage to 1Mt CO_2/yr. Czechia is not a party to the London Convention or London Protocol, so it must adopt similar standards and have bilateral agreements to export CO_2 for offshore storage. In addition, there may be issues with onshore transboundary and CO_2 storage is prohibited where leakage could occur [6].

The Czech National Energy and Climate Plan states that CCUS is on of its eight strategic priorities and that CCUS should be used for hard to abate industries such as cement manufacture.

Croatia scores 51.5 on the CCS readiness scale as defined by the GCCSI.

5.6 Issues for the Assessment

Storage resource estimates across Czechia are limited for saline aquifers and depleted oil and gas fields. This made site identification challenging to verify and report on.

5.7 Future Updates

5.7.1 Future evaluations

If more studies are conducted on site identification, this would benefit more realistic resource estimates. In addition, updates on any project advancement will be beneficial.

5.7.2 Future CSRC cycles

Any future submissions to the CSRC will improve the understanding of storage potential in Czechia.

6 Denmark

6.1 Summary

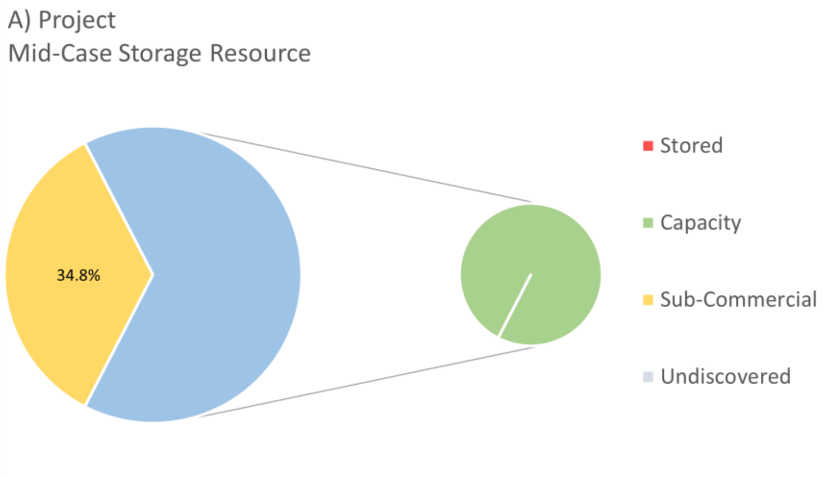
Denmark was previously assessed in Cycle 1 as part of the 'Baltic Countries'. In Cycle 4, Denmark was updated as an individual nation. A summary of the CO_2 storage resource is shown in Table 6-1.

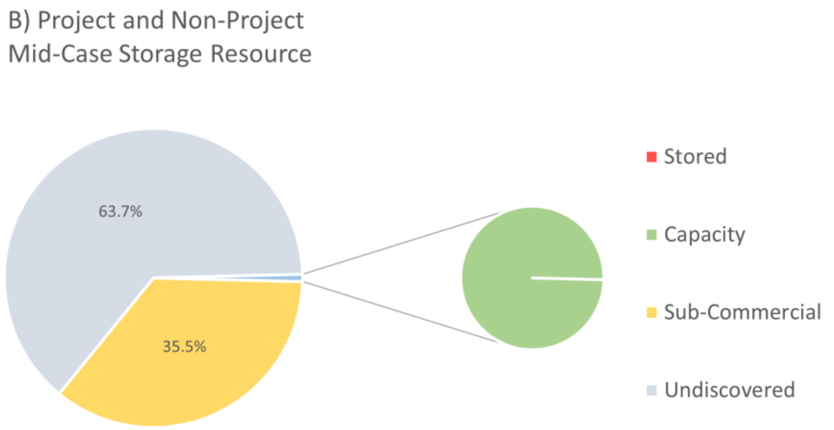
Classification	CO_2 storage resource (Gt) Project and no project	CO_2 storage resource (Gt) Project specified only
Stored	0.000	0.000
Capacity	0.125	0.125
Sub-Commercial	5.691	0.067
Undiscovered	10.212	0.000
Aggregated*	16.028	0.192

* 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 6-1: Storage resource classification summary for Denmark

- Denmark scored 66.5 within the 2023 CCS Chart of Legal and Regulatory Indicator system due to the country having specific CCS laws aligning with EU directives.
- Denmark has two pilot CCS projects at varying stages of development: Project Greensand and Project BiFrost. Both seek to use depleted hydrocarbon reservoirs at storage facilities. Testing of CO_2 injection took place in Project Greensand in 2023.
- Denmark's resources reside with both saline aquifers and depleted hydrocarbon reservoirs. Saline aquifers have been mainly reviewed at the formation level, and several onshore structures have been identified.
- There has been a significant effort at the national level to identify and characterise storage potential onshore and offshore.





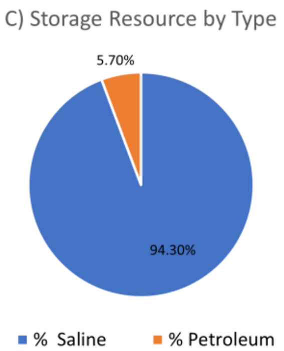


Figure 6-1: Denmark Spread of Storage Sites

a) Spread of storage resource in all Danish sites across SRMS classifications; both project specified and not. b) Split of Danish storage resource between saline aquifers and hydrocarbon fields, both project specified and not. Note: due to the large variance in the size of values, numbers in pie plots do not add up to 100.

6.2 Resource Statement

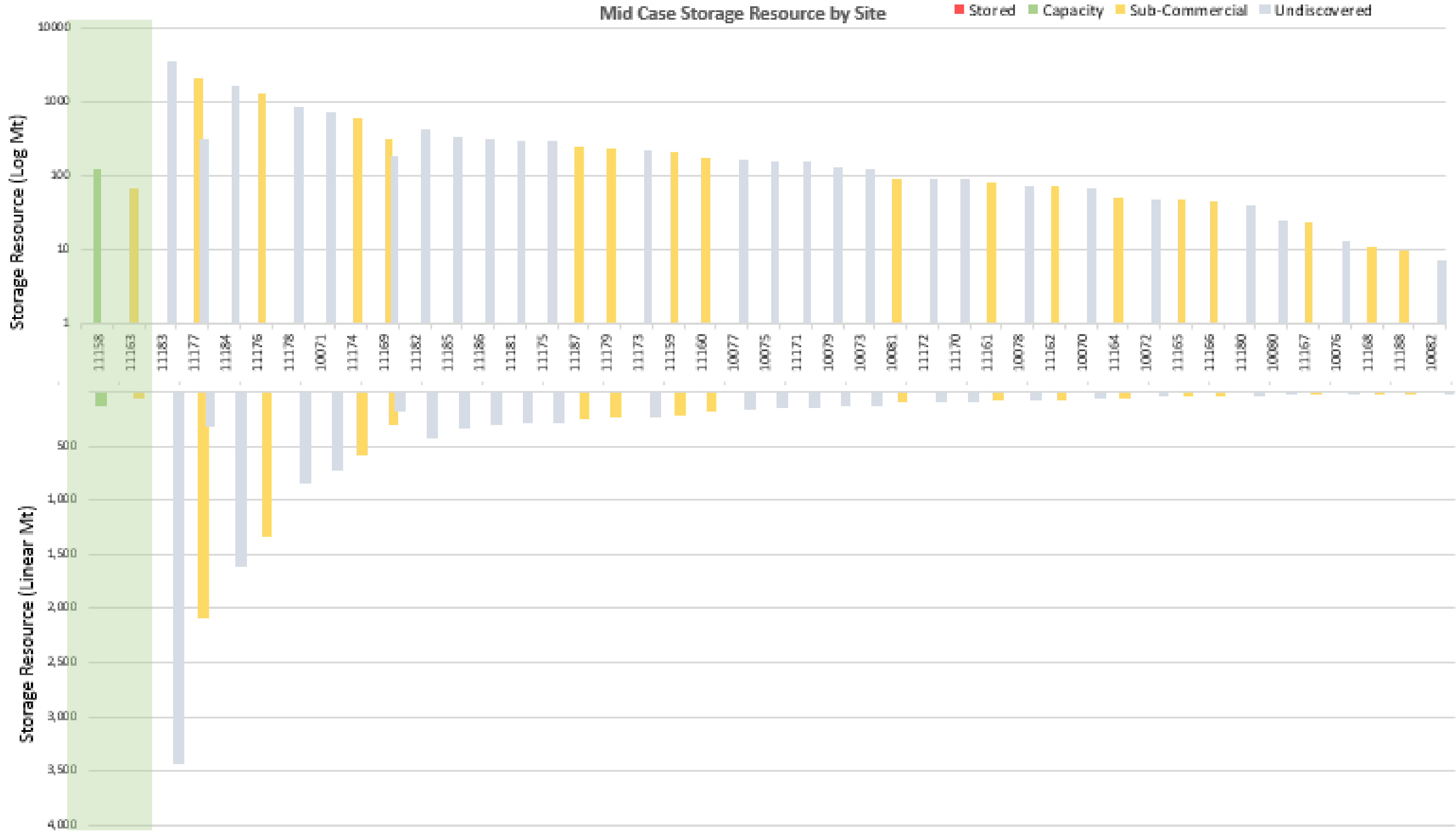


Figure 6-2: Storage resource summary for Denmark compiled in the CSRC.

Graph above is log scale and graph below is linear. Green box highlights sites where a project has been specified.

6.3 Evaluation History

CCS has been identified as a key technology that will help Denmark reach its climate targets. The industrial and energy sectors, where alternative fuel sources or energy efficiency cannot meet targets, are the primary targets for CCS.

The storage potential was first evaluated by the JOULE II project (5600 Mt onshore aquifers and 590 Mt in offshore depleted fields). Following this, the EU GeoCapacity (2009) published country-wide evaluations of storage potential (16,672 Mt in identified aquifer structures and 810 Mt in hydrocarbon fields). In 2014, The NORDICCS project [1] mapped a series of aquifer structures and more recently, the Danish Geological Survey (GEUS) has undertaken a series of studies to identify and rank potential storage sites across Denmark, both onshore and offshore [2].

6.4 Resource Review

Storage potential has been identified in depleted fields and saline aquifers, and commercial projects are being developed in both types of storage.

6.4.1 Major Projects

Denmark has two CCS pilot projects under development at the time of Cycle 4

Project Greensand is a joint venture between INEOS E&P and Wintershall Dea and is Denmark's first CCS project. Located 175 Km offshore, the project aims to utilise the depleted Nini-West field and re-purpose legacy infrastructure to develop the CO_2 storage facility. Ultimately, the plan is for CO_2 to be received by both pipelines and CO_2-transporting vessels.

Project Greensand commenced in 2020, with the first phase focused on appraisal to validate the technical aspects of the project. In late 2020, the appraisal phase was completed, and DNV GL approved the Nini West field as theoretically suitable for CO_2 injection and storage of 0.45 Mt per year over 10 years. The Paleocene marine sandstone storage reservoir is estimated to have a storage volume of 100 – 150 Mt and is located within a four-way dip trapping closure at approximately 1600 – 2200 MBSL. The project's build-out, including the Nini East, Cecilie, and Siri field reservoirs, is under consideration and will expand storage potential to up to 4 Mtpa [3]. In early 2023, the project entered phase 2 which saw the pilot injection operations start and continue through March and beyond. This CO_2 injection pilot (15,000t over four months) received the first storage permit from the Danish Energy Agency in December 2022. project is expected to enter phase 3 for the full-scale project following FID.

Project Bifrost is a joint venture pilot project under the Danish Underground Consortium (TotalEnergies, Nordsøfonden and Noreco) along with Ørsted and DTU (Delft University of Technology). Located 260 Km offshore, the project aims to utilise the depleted Harald West and East field in the Søgne basin as a CO_2 storage facility. The Harald field has two developed hydrocarbon reservoirs: the Harald East Cretaceous chalk reservoir with a porosity of 28-32% and permeability of 2.2 Darcys and the Middle Jurassic sandstone reservoirs of the Harald West. While the project will initially target the Harald West (and adjacent saline aquifer potential in the Oligocene Dagny permit area), the project aims to test storage in the Harald East carbonates reservoirs as a test of the potential of the Danish chalk reservoirs. The Bifrost project targets 5Mtpa injection by 2030 and potentially up to 15Mtpa from 2032 onwards. The consortium was awarded a CO_2 storage license in Q1 2023; however, no date has been set for project start-up.

6.4.2 Depleted Oil & Gas Fields

In addition to the Greensand and Bifrost, a small demonstration project named the "Stenlille Demo CO_2 storage" is being investigated by Gas Storage DK, who has published the aim to be operational by 2026 for a volume of 10 MT within the Gassum Sandstone formation.

Initially, the storage potential of Danish depleted fields was evaluated by the EU GeoCapacity project (810Mt) and the Nordic CCS Competence Centre (NORDICCS) [4]. A 2020 update [2] indicates a storage resource range 900-1300Mt within chalk fields. While the announced projects are focused on utilising clastic (sandstone) reservoirs, particularly within the Siri Canyon area (150-500Mt storage potential). Most Danish hydrocarbon fields sit within the chalk reservoirs (Cretaceous to Paleocene in age).

A study by Bonto et al. (2021) [5] focused on CO_2 storage in chalk formations. Using a reserves replacement approach, ten chalk fields were evaluated. The Tyra and Dan fields were the largest, with 211 and 174 Mt storage resources, respectively. Halfdan, Gorm, Harald East, and South Anne had estimated resources of 83 Mt, 73 Mt, 66 Mt and 52 Mt. Below 50 Mt, the Roar, Skjold and Valdemar fields were assessed to have storage of 48 Mt, 44 and 23 Mt, respectively. The Kraka field had a volume of 11 Mt.

6.4.3 Saline Aquifers

Several authors (for example, Larsen et al., (2007), Anthonsen et al., (2014) and Hjelm et al., (2022) [1,2,6] have studied the Danish subsurface independently assessing the same formations across the Danish basins, including the Norwegian-Danish basin and the northern rim of the North German basin. Screening and characterisation of saline aquifers across Denmark is challenged by low seismic density and generally poor-quality data [2]. However, it is suggested that a large storage opportunity sits within aquifers. Clastic (sandstone) formations are considered to carry the greatest storage potential, with the most prospective storage formations being the following:

- Bunter Sandstone and Skagerrak formations (Triassic)
- Gassum Formation (Upper Triassic – Lower Jurassic)

- Haldager Sand Formation (Middle Jurassic)
- Frederikshavn Formation (Upper Jurassic – Lower Cretaceous)

The most recent study [2] mapped 14 high-potential structures across onshore and offshore Denmark. These structures are estimated to hold a 12 Gt CO_2 storage resource, but the existing seismic database's sparse data may limit this.

Migration-assisted trapping in large, open aquifers of the Gassum formation in the Norwegian-Danish basin may contain up to 1Gt CO_2 storage resource. It should be noted that the published estimates are mostly derived from volumetric approaches, albeit using a Monte Carlo methodology to capture the considerable uncertainty associated with the estimates generated. The example provided in the Cycle 4 Global Summary report illustrates the issue whereby the difference between theoretical storage resources and pressure-limited storage resources from flow modelling reduced the named Hantsholm structure.

6.4.4 Sites not evaluated as volumes below 10 Mt OGCI threshold:

Bonto et al. (2021) published data for several sites that fall below the threshold for SRMS assessment. The Svend prospect was quoted as having a resource of 8.5 Mt. while the Siri prospect resource of 7.9 Mt, and Rolf is at 3.1 Mt. Lulita, Dagmar and Regnar all had a very small resource of 0.8 Mt.

6.5 Regulatory Framework

Denmark received a promising evaluation under the 2023 GCCSI CCS readiness index, scoring 66.5.

Denmark has recently passed several amendments to acts of law dating to June 2022. This includes Act no. 803, which authorises the Minister for Climate, Energy and Utilities to institute regulation regarding the geological storage of CO_2 under 100 kilotonnes undertaken for research, development, or testing of new products and processes. The amendment to Act no. 803 also warrants the participation of the Danish State or a company owned by the Danish State in CO_2 storage operations.

Executive Order No. 1165 was passed in August 2022, which pertains to the continuous granting of permits for the exploration and storage of carbon dioxide concerning the area on the Danish continental shelf west of 6° 15′ E and north of 56° 00′ N. This executive order warrants that applications for permits for exploration and storage of carbon dioxide can be submitted to the Danish Energy Agency (DEA) annually from the 15th of August to the 1st of October in the same year.

Act no. 1592 was passed in December 2022 and entered into force in January 2023. This act warrants the participation of Nordsøfonden (a company owned by the Danish state) in any CO_2

storage activities. As a result, Nordsøfonden will participate in every storage permit on behalf of the Danish state with a share of 20 percent [7].

In December 2022, the first CO_2 storage permit was awarded by the Danish Energy Agency to the Project Greensand Pilot phase for a 15,000 t, four-month test at the Nini West oilfield (developed by INEOS E&P and Wintershall Dea).

6.6 Issues for the Assessment

Volumetric storage approaches dominate published storage resource estimates. This is partly driven by the limited subsurface database available across the country, but recent studies are looking to improve the understanding of more practical storage potential.

6.7 Future Updates

6.7.1 Future CSRC cycles

As pilot and commercial scale projects progress towards advanced development, future cycles should request updates from developers and ensure the CSRC maintains an accurate project representation.

7 Finland

7.1 Summary

Finland was assessed during Cycle 4. The CSRC has identified that Finland has no published storage resource estimates, and so has zero sites to enter into the CSRC database:

Classification	CO_2 storage resource (Gt) Project and no project	CO_2 storage resource (Gt) Project specified only
Stored	0.00	0.00
Capacity	0.00	0.00
Sub-Commercial	0.00	0.00
Undiscovered	0.00	0.00
Aggregated*	0.00	0.00

* 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 7-1: Storage resource classification summary for Finland

7.2 Evaluation History

Finland was reviewed during Cycle 4. Finland is not a hydrocarbon-producing country. No CO_2 storage evaluations have been carried out at the federal level, nor are any available in the public domain. Finland's geology is unsuitable for conventional CO_2 storage and is dominated by pre-Cambrian shield igneous and metamorphic rocks. More recent sediments are restricted to thin, unconsolidated Quaternary glacial deposits.

7.3 Regulatory Framework

Finland has issued the Finnish Act on Carbon Capture and Storage (the "CCS Act"; 416/2012). According to this Act, geological storage of CO_2 is banned in Finland and its exclusive economic zone (EEZ). The driver for this was the unsuitable geology for CO_2 storage. However, new, temporary (2023-2026) legislation has been introduced, which gives permitting priority to green transition projects, which can include CCS but must adhere to a "do no significant harm" principle.

7.4 Future Updates

7.4.1 Future Updates for Evaluators

Given Finland's unsuitable geology, no future conventional CO_2 storage projects are anticipated, and therefore, no future updates should be required.

7.4.2 Future CRSC Cycles

Not applicable

8 France

8.1 Summary

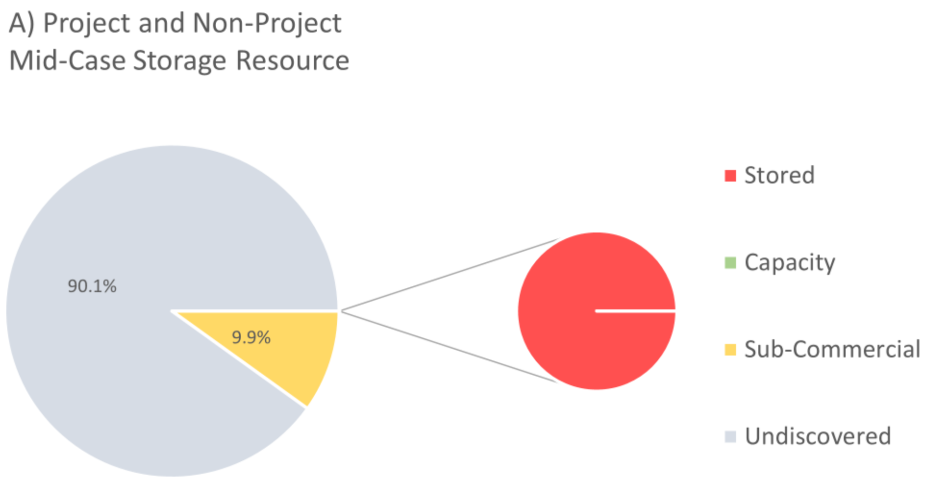
France was assessed in Cycle 4. A summary of the CO_2 storage resource is shown in the Table below.

Classification	CO_2 storage resource (Gt) Project and no project	CO_2 storage resource (Gt) Project specified only
Stored	0.000	0.000
Capacity	0.000	0.000
Sub-Commercial	1.007	0.000
Undiscovered	6.201	0.010
Aggregated*	7.208	0.010

* 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 8-1: Storage resource classification summary for France

- France has been an active player in CCUS, participating in and pioneering research in carbon capture, transport, and storage and many European and worldwide research projects.
- A total of 19 sites have been identified in France (10 saline aquifers and 9 depleted oil and gas fields)
- The majority of the sites are rarely able to be assessed beyond basin or sequence classification.
- There are some historical projects in France, and some are ongoing. Two historical research projects in Lacq-Rousse and one in Saint-Emillion are now terminated. The four ongoing projects relate to a more involved CCUS and energy transition supply chain: Dunkirk, Pycasso, H2020 STRATEGY CCUS and CO_2SERRE
- Volumes in saline aquifers are mainly reported at a basin level, with some smaller volumes at a prospect level.



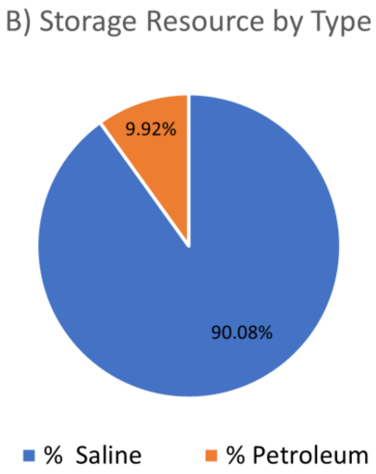


Figure 8-1: France Spread of Storage Sites

a) Spread of storage resource in all French sites across SRMS classifications; both project specified and not. b) Split of French storage resources between saline aquifers and hydrocarbon fields, both project specified and not. Note: due to the large variance in the size of values, numbers in pie plots do not add up to 100.

8.2 Resource Statement

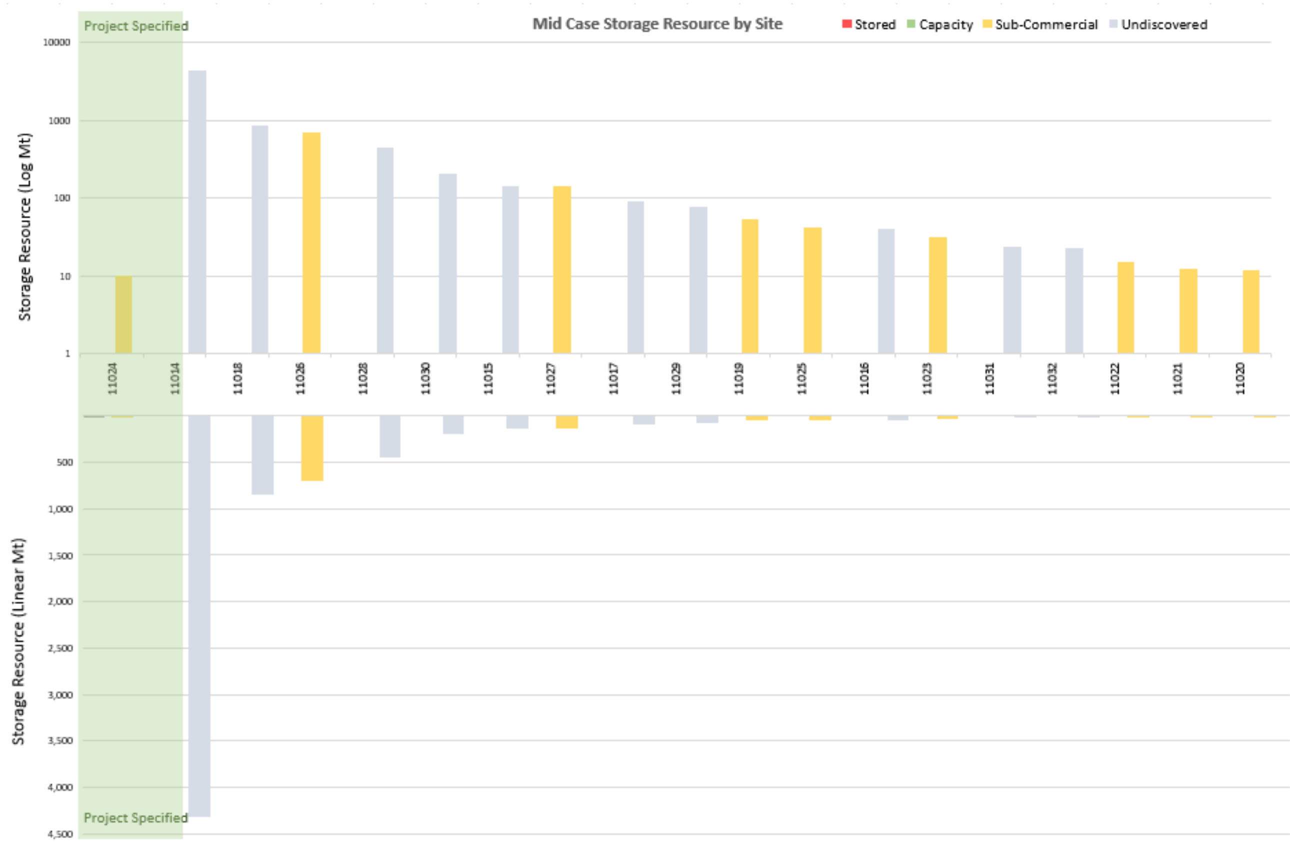


Figure 8-2: Storage resource summary for France compiled in the CSRC.

Graph above is log scale and graph below is linear. Green box highlights sites where a project has been specified.

8.3 Evaluation History

Since the 1990s, several European projects have estimated the CO_2 storage resource in France's saline aquifers and depleted hydrocarbon field. The first evaluation was performed during the Joule project in 1996, and a second was conducted during the GESTCO project in 2003. The latter was updated during the EU GeoCapacity in 2009. GeoCapacity estimates for saline aquifers ranged from 800Mt to 27Gt of CO_2 (a factor of 30 between the lowest and highest estimations). For hydrocarbon fields, they estimated in the range from 770Mt (low) to 1007.6Mt (high). France was also part of the CO_2StoP project in 2012-2013 [1]. Other research projects at the basin scale are the France Nord and ULCOS TGR-BF, which resulted in a more in-depth assessment of two potential storage resource areas in the Paris Basin and the Vasco project in the Marseille area.

The European project STRATEGY CCUS [2,3,4], which started in 2019 and was coordinated by BRGM (Bureau de Recherches Géologiques et Minières), gathered existing data in eight different regions. The aim of this research was to compile and develop a common methodology to evaluate CO_2 storage resources.

8.4 Resource Review

The potential for CO_2 storage in France lies in three onshore sedimentary basins: the Paris Basin, the Aquitaine Basin, and the Sud-East Basin. These basins have both aquifers and depleted hydrocarbon fields. Both the Aquitaine Basin and the South-East Basin extend offshore, where offshore possibilities are mentioned in [5]. However, limited publications have been found on offshore France's CO_2 storage potential.

8.4.1 Major Projects

Currently, there are no ongoing carbon geological storage operations in France.

Dunkirk

The Dunkirk project is a low-carbon hydrogen production in Port Jerome (Port Jerome CO_2 capture plant), a CCS-equipped steel-making plant in Dunkirk. The project is part of a study to develop a future European Dunkirk North Sea Capture and Storage Cluster [6].

Lacq-Rousse

The CCS pilot-scale project in Lacq-Rousse, a depleted field in the Aquitaine basin, was operated by Total (2006-2013) and injected more than 51 Kt of CO_2 from 2010 to 2013 [7,8].

Saint-Emilion

This experimental site in underground limestone in Saint-Emilion, in Nouvelle Aquitaine (France), was exploited by using "the rooms and pillars" method. It is currently terminated [9].

CO_2SERRE

A three-year study (2019-2022), led by BRGM (Bureau De Recherches Geologiques Et Minieres), which investigates the techno-economic and environmental feasibility of implementing a "BCCUS" (i.e. CCUS for CO_2 of biomass origin) pilot in France, in the Centre-Val de Loire Region. The Life Cycle Analysis (LCA) objective is to compare the environmental impacts of biomass transformation activities with and without CCUS [10].

Pycasso

The PYCASSO Project aims to capture, use and store CO_2 in the depleted fields of the Aquitaine Basin. At the beginning of 2021, 30 institutions, universities and industrial companies teamed up to form PYCASSO, a territories project and operational consortium focused on advancing CCUS development studies onshore SW France and NE Spain to reach the net zero emissions European objective in 2050 [11].PYCASSO aims to bring CCUS solutions to scale and implement a complete 1Mt (million tons)/year CO_2 abatement chain in 2030 to be further extended to 5 Mt/y in 2035.

H2020 STRATEGY CCUS

Scenarios for local CCUS development schemes in the Rhône Valley in the short, medium, and long term are being studied as part of the H2020 STRATEGY CCUS project (2019-2022), which is elaborating strategic plans from 2025 to 2050 for deploying CCUS in eight promising regions of Southern and Eastern Europe, including the Paris Basin and the Rhone Valley for France [3].

8.4.2 Depleted Oil & Gas Fields

A review of storage potential in France's depleted oil and gas fields is provided in the GeoCapacity project (2010). Many of the 32 identified fields in the Paris basin are too small in volume to be included in the CRSC. Four have volumes above 10 Mt (Coulommes, Donnemarie, Chailly, and Vilemer fields). The Aquitaine basin has a storage resource of just over 880 Mt. These include the only the pilot project at Lacq-Rousse. Other fields in this basin are the St. Marcet (41.10Mt), Laq Profond (691.90Mt) and Meillon (139.90Mt).

8.4.3 Saline Aquifers

Saline aquifers in France have a promising CO_2 storage potential. However, there is very limited research to delineate the sites beyond the formation level. The historic CO_2 storage resource projects provided an estimate for the CO_2 resource for the Paris Basin saline aquifers, where 4 formations have been identified. The Aquitaine basin has potential in the North Aquitanian in Triassic to Early Jurassic sediments, while the Jurassic-Cretaceous units of the South Aquitanian basin are also considered to carry some potential. The South-East basin has 8 CO_2 sites but there are limited assessment details to classify these sites; of those identified, only 2 make the volume cut off for the CRSC.

Offshore potential for CO_2 storage (offshore Aquitaine and offshore Mediterranean) has been cited, but these possibilities have not yet been studied.

8.5 Regulatory Framework

France established a regulatory framework for the storage of CO_2 as early as 2010. In addition, it has industrial competence covering the whole CCS chain, with all the necessary conditions and technical knowledge to start CCS projects.

According to the national low-carbon strategy, the legislative framework for CCS activities in France is ready. The CCS Directive was implemented into national law in 2011 (French national decree on the geological storage of CO_2 - Decree n°2011-1411). Further relevant legislation states from 2009 that any new coal-fired power plant must be CCS-ready and have a full-scale demonstration program.

8.6 Issues for the Assessment

Even though France has been a pioneer in the CCUS, just one pilot project (Le Lacq-Rousse) has been run, and the possible saline storage sites in the Aquitaine basin and the Southeast Basin haven't been assessed. Overall, data related to site assessment is very limited in the public domain. Large pan-European projects are still the only sources to define sites. This renders France's CO_2 storage resource highly uncertain.

8.7 Future Updates

8.7.1 Future evaluations

Future evaluations should check for updates on developing projects or new evaluations that can provide more insight into France's CO_2 storage potential.

8.7.2 Future CSRC cycles

A focus for future cycles should be on the current projects and their progression.

9 Germany

9.1 Summary

Germany was previously assessed by the CSRC in Cycle 1 as part of the Baltic Region (including Denmark). In Cycle 4 Germany was assessed as a single country.

A summary of the CO_2 storage resource is shown in the Table below.

Classification	CO_2 storage resource (Gt) Project and no project	CO_2 storage resource (Gt) Project specified only
Stored	0.000	0.000
Capacity	0.000	0.000
Sub-Commercial	2.000	0.000
Undiscovered	49.208	0.000
Aggregated*	51.208	0.000

* 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 9-1: Storage resource classification summary for Germany

- There have been limited and very varying assessments for Germany with respect to understanding CO_2 storage resources: JOULE 1996 (2-3 Gt), GESTCO 2003 (25-44 Gt), BGR 2005 (18-41 Gt), and GeoCapacity 2009 (17-29 Gt) projects. Research in the last decade has also been limited.

- Four additional sites have been identified in Cycle 4, adding to the offshore site reported in Cycle 1. These sites provide a cumulative total of just over 49Gt for saline aquifers (at basin scale) and 2Gt cumulative for hydrocarbon reservoirs.

- Germany has no major CO_2 storage projects underway, but it has several projects in the CCS value chain including capture and transport. It ran a pilot CO_2 injection and monitoring project from 2008 to 2013 at the Ketzin gas storage field.

- Germany's historical regulations restrict CO_2 storage projects. However, in early 2023, The Federal Ministry for Economic Affairs and Climate Action initiated stakeholder dialogue aimed at developing a strategy for CCS.

- Germany's most recent strategy, 'The German Carbon Management Strategy' hails a significant step towards its CCS deployment. The strategy will enable the legislative revisions needed to establish CO_2 pipeline networks and allow offshore storage of CO_2 under Germany's North Sea.

- If Germany's storage capacity remains restricted to permitting domestic storage, it will need to ratify Article 6 of the London Protocol to transport CO_2 to other countries to facilitate storage projects outside its jurisdiction.

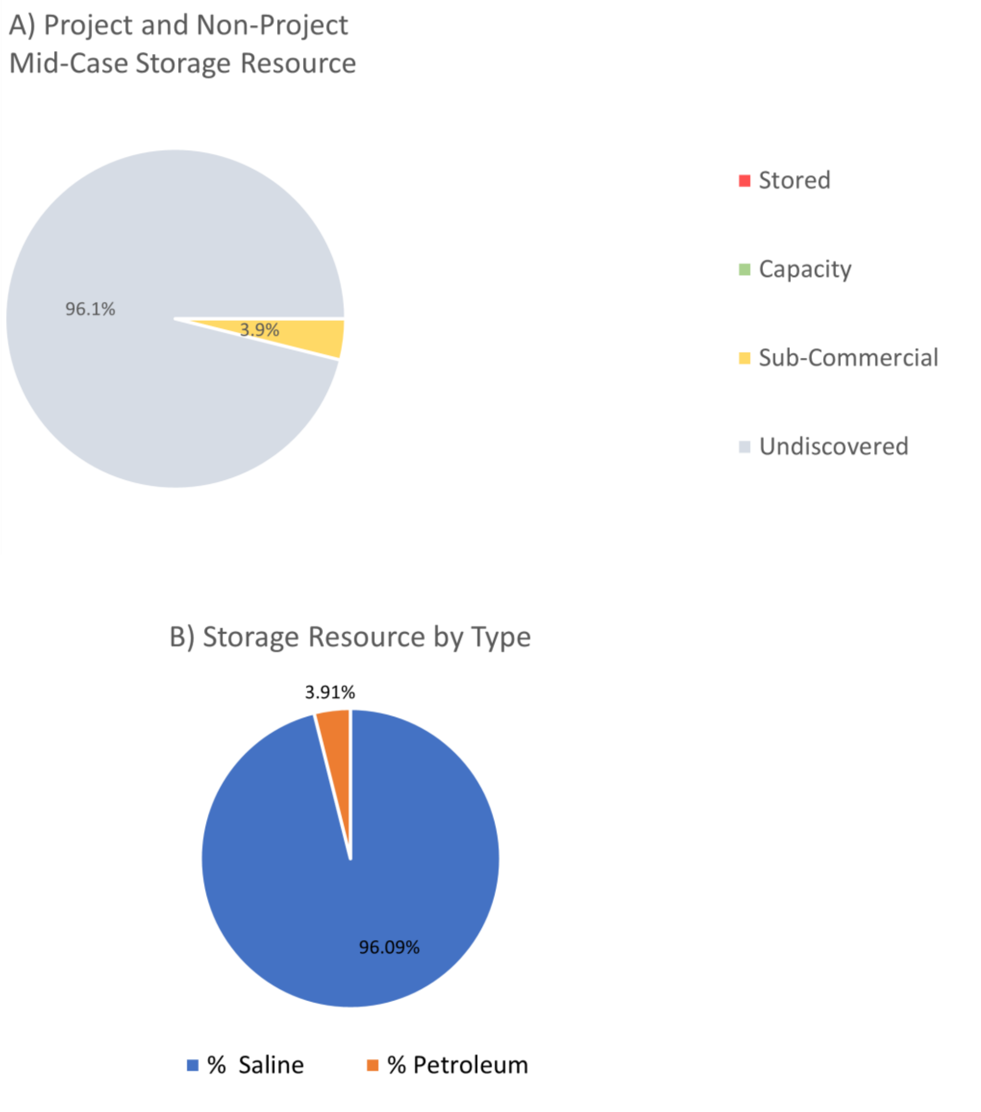


Figure 9-1: German Spread of Storage Sites

a) Spread of storage resource in all German sites across SRMS classifications; both project specified and not. b) Split of German storage resources between saline aquifers and hydrocarbon fields, both project specified and not. Note: due to the large variance in size of values, numbers in pie plots do not add up to 100.

9.2 Resource Statement

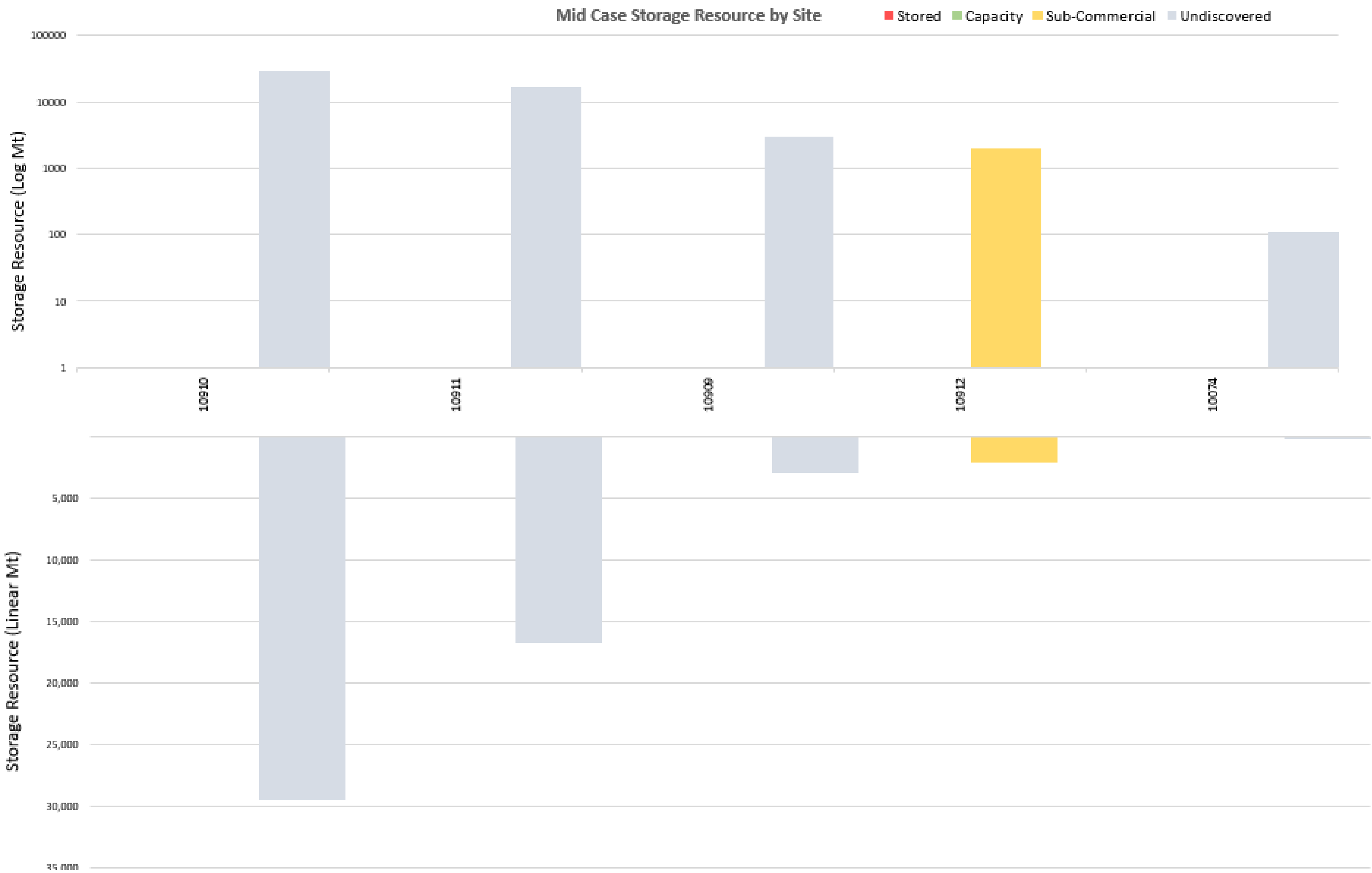


Figure 9-2: Storage resource summary for Germany compiled in the CSRC.

Graph above is log scale and graph below is linear. Green box highlights sites where a project has been specified.

9.3 Evaluation History

There have been several assessments to understand the CO_2 storage potential in Germany, which includes oil and gas fields and onshore and offshore saline aquifers. The earlier European reports JOULE II, GESTCO, BGR and GeoCapacity estimated storage resource (which included oil and gas fields and onshore and offshore saline aquifers) in the following ranges – JOULE 1996 (2-3Gt), GESTCO 2003 (25-44Gt), BGR 2005 (18-41Gt) and GeoCapcity 2009 (17-29Gt). These summaries are reported in Holler and Viebahn (2011) [2]. The authors provide their ranges for total German resources, with a minimum of 4 Gt, a mid estimate of 5 Gt, and a maximum estimate of 15 Gt. The much lower estimates are based on cautious efficiency factors that they apply to the volumetric calculations from the earlier studies. Germany was also reviewed for saline aquifer potential in the European CO_2Stop Project. However, no volumes were reported for the 25 formations identified; instead, an overall 1-3Gt range for saline aquifers and 2Gt for hydrocarbon fields were reported [3]. The saline formations were identified in the German North Sea, North German Plain, Central Uplands, South German Scarplands and Alpine Foreland. In addition, there are projects by the Storage Catalogue of Germany and GPDN; however, these are published in German and have not been reviewed. [6&7].

Bense and Jähne-Klingberg (2017) [4] performed a detailed geological review of the offshore potential in the German North Sea. No resource volumes were published, but the trapping and suitability of various stratigraphic intervals were investigated via a structural model.

The most recent and more involved study by Knopf and May (2017) [5] assessed aquifers using a ‘regional aquifer-based method’. This study was built on results [6&7] using a volumetric approach but considered distinct reservoir-barrier units with storage resources based on net thickness and porosity. Monte Carlo simulations were run with efficiency values between 0.9 and 4.6 to provide P10, P50 and P90 ranges. The study also compared the potential of structures within the units. This assessment has been favoured by the CRSC since it considers potential sites in Germany on a more containment basis (by considering both reservoir and barrier) and refines the resource estimates from previous studies. The estimates also provide higher storage volumes than earlier studies.

9.4 Resource Review

9.4.1 Major Projects

In Germany, there are currently no major storage projects. However, there are five projects in progress for various stages of the CCS value chain: H2Morrow is a project that aims to develop clusters and projects from industry and coalfields and then develop a CO_2 pipeline grid for export options at major ports. The LEILAC 2 Pilot aims to capture CO_2 from the Heidelberg Cement’s Hanover plant with a capture capacity of 25,000 tonnes per year. The WESTKÜSTE100 project is a real-world laboratory to develop a regional hydrogen economy on an industrial scale, with CO_2 being separated from cement production and then used in methanol synthesis. The CO_2 liquefaction and buffer storage in Wilhelmshaven project aims to capture 4.3Mt per annum from the European Energy logistics park and export it. The Downstream CO_2 pipeline Hastedt – Bremen aims to investigate a pilot CO_2 pipeline infrastructure connecting the industrial hub in Bremen to the Energy Park in Wilhemlshaven.

The Pilot CO_2 Injection project at Ketzin (called COMPLETE), which was injected from 2008 until 2013, saw 67,271 t of CO_2 injected through 5 wells. The project was extensively monitored and aimed to help a rigorous understanding of post-closure site behaviour and monitoring knowledge. Ketzin was a natural gas storage site [1].

9.4.2 Depleted Oil & Gas Fields

Very little information surrounds the potential for storage in Germany's oil and gas fields. CO_2Stop assessed the potential via reporting saline aquifer locations with hydrocarbon fields and reported an overall storage resource estimate of 2Gt. Due to a significant absence of reporting and literature on German potential in depleted hydrocarbon fields, an undifferentiated storage estimate is added to the CSRC of 2Gt. This is currently classified as Inaccessible due to regulations and Undiscovered due to absence of any further details relating to formation or basin locations.

9.4.3 Saline Aquifers

The largest potential is in the Mesozoic (Triassic) formations in North Germany in the German-Polish Lowland (or Middle European Plain) and the south of Germany. Triassic strata have the greatest CO_2 storage potential in the middle and lower Bunterstain and Volprehausen formations, with a 10-25% porosity and a 100-300 mD permeability range. The Alpine orogenic belt limits the extent of the aquifer from the South. Most assessments have a considerable lack of geological data; hence, there is a great deal of uncertainty surrounding saline aquifer storage estimates for CO_2 in Germany.

9.5 Regulatory Framework

The Carbon Capture and Storage Act (KSpG) 2012 came into force in August 2012 and was intended to test the first demonstration projects for the long-term storage of CO_2 in the ground in Germany. Specifically, it stipulated an annual storage of no more than 1.3m tons of CO_2, a maximum storage volume of 4m tons of CO_2 per year in Germany, and that permits could only be granted if an application for a CO_2 storage facility was made by 31 December 2016. By the end of the application, only one demonstration project had been applied for and built. Since then, no further applications have been made, and CCS is not considered possible in Germany. However, several actions may change the future of the CCS for Germany. Firstly, Germany is now considering CCS as a key component of climate action. The German Government have been pushing these discussions since 2021. In early 2023, The Federal Mistry for Economic Affairs and Climate Action initiated stakeholder dialogue to develop a CCS strategy (released in early 2024). Further to this, the Green House Gas (GHG) neutrality studies from 2021 evaluated a need to deploy CCS to meet climate targets and found that technologies for the full CCS value chain are mature enough. However, the legal framework in Germany currently prevents the deployment of any technology for CCS. Lastly, The Langfristszenarian Project (Long-term Scenarios for the Transformation of the Energy System in Germany) is being modelled on behalf of the German Federal Ministry for Economic Affairs and Climate Action. These scenarios model how the country's energy and climate policy goals can be achieved. A number of goals have proposed several scenarios that include CCS as a key component. Germany will need to ratify Article 6 of the London Protocol to transport CO_2 to other countries if storage in the country remains legally restricted and has been in discussion with other European countries for transboundary movement of CO_2.

The recent German Carbon Management Strategy (released in early 2024) will hopefully help Germany move towards more research in all aspects of the CCUS value chain and encourage the rest of Europe to advance in CCUS and CO_2 management strategies.

Germany scores 57.5 on the CCS readiness scale as defined by the GCCSI.

9.6 Issues for the Assessment

The most challenging issue with Germany is the lack of geological data and static or dynamic modelling to accurately define storage resource estimates. The country's regulations to date are likely to have hindered this. However, with a renewed interest from the government, further rigorous assessments may be conducted in the future.

9.7 Future Updates

9.7.1 Future evaluations

Future evaluations should seek to address any updates to sites or potential projects in light of the more progressive legislation for CO_2 storage.

9.7.2 Future CSRC cycles

Future cycles will need to focus on collating information from studies than provide a greater insight into the quality and resources of saline aquifers in Germany's jurisdiction.

10 Greece

10.1 Summary

Greece was been assessed by the CSRC in Cycle 4. A summary of the CO_2 Storage resource is shown in the Table below.

A summary of the CO_2 storage resource is shown in the Table below.

Classification	CO_2 storage resource (Gt) Project and no project	CO_2 storage resource (Gt) Project specified only
Stored	0.000	0.000
Capacity	0.000	0.000
Sub-Commercial	0.107	0.075
Undiscovered	3.877	0.000
Aggregated*	3.984	0.075

* 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 10-1: Storage resource classification summary for Greece

- Greece has seven sites that can be added to the CRSC, ranging from undiscovered to sub-commercial.
- Greece has an active and positive approach to CCS, and although early in its deployment, it has awarded a storage exploration license in the Prinos Basin.
- As a country, it is actively supporting European research projects, seeking out further storage sites within its borders, and funding CCS initiatives.
- Greece has been assessed by GESTCO and GeoCapcity in the past which identified several sites. Limited studies have been conducted since then but have helped to refine some resource estimates, namely those in the Messohelinic Trough.
- Greece has two hydrocarbon sites (Prinos and Kallirachi) and several saline basins suitable for CO_2, some of which are close to industrial centres like the Messohelinic Trough, where the Kozani and Ptolemaida industrial areas are. These include coal/lignite-fired power plants, waste incinerator, cement plants and biomass plants.
- Prinos is currently a storage project in the early stages of assessment with a license granted by HEREMA in 2022. Energean are the license holders.
- Further saline storage sites are in the Thessaloniki Basin and Ptolemais-Kozani Basin.

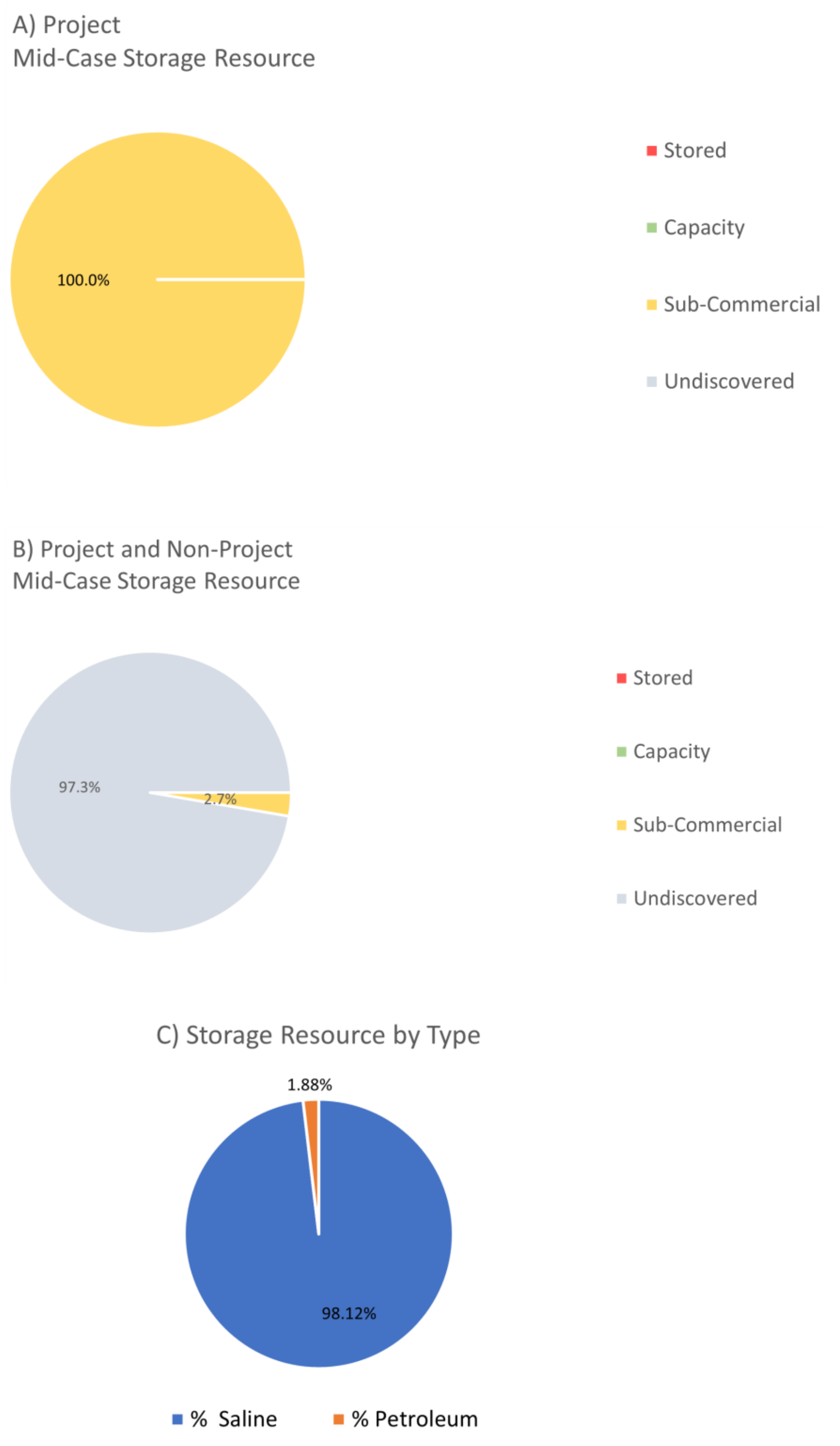


Figure 10-1: Greece Spread of Storage Sites

a) Spread of storage resources in Greece (9) across SRMS classifications, where a project has been specified. b) Spread of storage resources in all Greek sites across SRMS classifications; both project specified and not. c) Split of Greek storage resource between saline aquifers and hydrocarbon fields, both project specified and not. Note: due to the large variance in the size of values, numbers in pie plots do not add up to 100.

10.2 Resource Statement

Figure 10-2: Storage resource summary for Greece compiled in the CSRC.

Graph above is log scale and graph below is linear. Green box highlights sites where a project has been specified.

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10.3 Evaluation History

Greece participated in the GESTCO project (2000-2003) [1] and was evaluated for CO_2 storage potential for saline aquifers and oil and gas fields. Overall storage potential in saline aquifers was estimated at 2.2Gt and 17Mt in hydrocarbon fields. The Geocapacity Report of 2009 [2], in which Greece was also a participating country, estimated resources for the country's saline aquifers in the region of 184Mt and hydrocarbon fields of around 70Mt.

More recent studies by universities and research institutions have provided a greater understanding of some of the potential sites in Greece. These publications have provided a more concise view of individual storage site resources and have been used in this assessment. This research has been used to understand storage potential in the Ptlomais, Mesohellenic Trough, Thessaloniki Basin, Alexandria Anticline and the Loudias and Agriossykia Synclines and Volos region. These assessments still rely on a volumetric approach based on estimates provided by Geocapacity. All sites, except for Prinos, are classified as Undiscovered at a basin or sequence level (depending on the assessment resolution) due to an absence of data to determine well locations in the saline aquifers.

10.4 Resource Review

10.4.1 Major Projects

The first exploration license for the Prinos field was awarded by the Hellenic Hydrocarbons and Energy Resources Management (HEREMA) to Energean in late September 2022. The project is a key part of the Mediterranean CCS Strategic Plan. This plan was developed by France, Italy, and Greece and aims to create the first CO_2 storage hub in the Southeast Mediterranean. CO_2 is planned to be transported by both ship and pipeline. The first phase of the project aims to inject 1Mt CO_2 /yr as a compressed form and then later accommodate liquid CO_2 by 2027. The second phase aims to increase injection rates to 3Mt CO_2/yr for 25 years. Greece is also part of the European Horizon 2020 STRATEGY CCUS project, which aims to support the development of low-carbon energy and industry in Southern and Eastern Europe. The West Macedonia Region was selected due to high industrialisation, lignite production and a CO_2 capture plant developed by the Centre for Research and Technology-Hellas (CERTH). The Mesohellenic Trough has been identified as a storage site in this area.

10.4.2 Depleted Oil & Gas Fields

The Prinos Basin in the North Aegean Sea is the only area in Greece active in hydrocarbon production and is now licensed for exploration for CO_2 Storage. It is a rift basin with a thick sedimentary fill of clastics and evaporites. The pre-evaporitic sequence provides a suitable storage formation and overlays a thick sequence of evaporitic and clastics (Messinian-Quaternary), providing an excellent seal. Both structural and stratigraphic traps exist throughout the basin. In contrast to other areas of Greece, this site is tectonically stable and poses a much-reduced risk to containment issues. Recent studies to the license award have resulted in much refined estimates of storage potential. The resource estimate is taken from a recent white paper published by HEREMA and whilst this cites an upper value of 100 Mt, a value of 75Mt is included in the CRSC (based on injection of 3Mt/yr for 25 years from the development plan).

The Kallirachi oil field is another potential site for CO_2 storage when hydrocarbon production has ceased. It has a thick sandstone reservoir and, like Prinos, a very thick seal of salt. No storage values are available for this field yet.

10.4.3 Saline Aquifers

Greece has some saline aquifer sites that hold CO_2 storage potential. They are generally sparse in data availability, which impacts storage estimates. The Mesohellenic Trough in Western Macedonia, which was studied by Tasianas and Koukouzas (2016) [3], estimates significant storage potential in two formations: the Pentolofos and Eptachori. They used a geological model to understand potential resources built from 2D and 3D data and estimated over 700Gt of storage. This was re-evaluated by Koukouvis et al. (2021) [4] and provided P90, P50 & P10 estimates for the storage resource of the main formations using a methodology (US-DOE-NETL) as adopted in the STRATEGY CCUS project [5 in 4]. This approach gave P10 for both formations in the region of 3400Mt resource. In North-Eastern Greece, the Thessaloniki Basin has a few onshore Eocene age storage opportunities in saline sandstone aquifers and structures such as the Alexandria Anticline and the Loudias and Agriossykia Synclines. Total storage resources are reported at ~640Mt. The Bellona Foundation [6] summarises storage potential in these areas based on the GETSCO report. The Ptolemais-Kozani Basin, situated between the Messohelinic Trough and Thessaloniki Basin, holds a storage resource estimate reported by The Bellona Foundation of 1343 Mt. Lastly, Arvanitis et al. (2020) [7] reported potential in basalts of the Volos region with a resource of ~43,200 tons (not included in the CRSC database). Smaller volumes are also cited as having potential in the Klepa-Nafpaktia sandstones in Western Greece, with a storage resource of 18 x10^5 tons.

10.5 Regulatory Framework

Greece is positive in its approach to promoting solutions for CCS through initiatives, partnerships, and collaboration and is at an early stage in CCS deployment. In April 2022, HEREMA was appointed as the licensing authority for the geological storage of CO_2 in Greece. This also covered the overall management of the rights of the Hellenic state for the storage of CO_2 and other gases and liquids, such as natural gas and hydrogen (Law 4920/2022, Government Gazette A '74/ 15.04.2022). Greece has transposed The EU CCS Directive 2009/31/EC into Greek law. A recent implementation report on the Directive 2009/31/EC indicates that in addition to licensing authority changes, Greece plans to determine additional storage sites for CO_2, has programs in place to support the deployment of CCS financially and is actively involved in European research projects. Greece scores 57.5 on the CCS readiness scale as defined by the GCCSI [8].

10.6 Issues for the Assessment

Low research and a very limited amount of data for most of the CO_2 storage resources in Greece will affect the accuracy of storage estimates. Prinos is now a well-studied area; however, due to the proprietary nature of the studies, the storage volume estimates are reliant on published press release data by Energean.

10.7 Future Updates

10.7.1 Future evaluations

Future evaluations should seek updates to the Prinos project and any updates to the Messohelinic Trough area based on any outcomes of the STRATEGY CCUS project.

10.7.2 Future CSRC cycles

An update for all sites is recommended for future updates to the CRSC. Many sites that are currently at the formation level may have increased studies to be able to evaluate the lead and prospect levels.

11 Hungary

11.1 Summary

Hungary was assessed by the CSRC in Cycle 4. A summary of the CO_2 storage resource is shown in the Table below.

Classification	CO_2 storage resource (Gt) Project and no project	CO_2 storage resource (Gt) Project specified only
Stored	0.000	0.000
Capacity	0.000	0.000
Sub-Commercial	3.520	0.000
Undiscovered	7.308	0.000
Aggregated*	10.828	0.000

* 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 11-1: Storage resource classification summary for Hungary

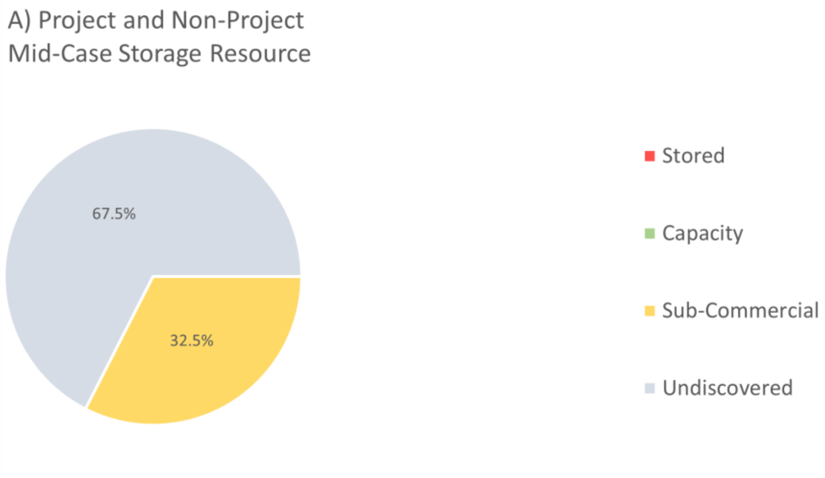
- Hungary's national oil company, Mol Group, has a long history of experience with CO_2-EOR with potential with the country itself having very sizeable potential for CCS/CO_2 storage within deep saline aquifers and depleted oil and gas fields.

- In 2010, the MOL group collaborated with ELGI (Hungarian National Research Institute) to conduct a screening study to evaluate 180 hydrocarbon reservoirs for CCUS productivity. Despite this, no evidence in the public domain demonstrates that the country has any active or firm future plans for CCS storage projects. Additionally, Hungary has yet to establish a CCUS pilot project.

- Although storage resource is reported as being present in both saline aquifers and oil and gas fields, the greatest potential by a sizeable margin exists within deep saline aquifers.

- According to the literature, the most prospective areas for CCUS storage are within the Jászság Sub-basin of the wider Pannonian Basin in the southwest of the country. The primary prospect across this region is the prolific Szolnok formation. Various authors have quoted volumes ranging from 97Mt to 2000Mt for this formation.

- MOL has expressed an intention to apply EOR in depleted hydrocarbon reservoirs in the region, potentially paving the way for a Hungarian CCS project to become financially feasible.



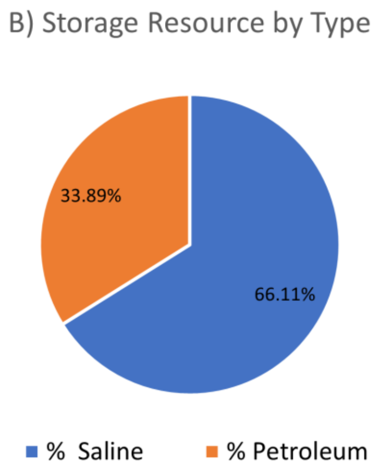


Figure 11-1: Hungary Spread of Storage Sites

a) Spread of storage resource in all Hungarian sites across SRMS classifications; both project specified and not. b) Split of Hungarian storage resource between saline aquifers and hydrocarbon fields, both project specified and not. Note: due to the large variance in size of values, numbers in pie plots do not add up to 100.

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11.2 Resource Statement

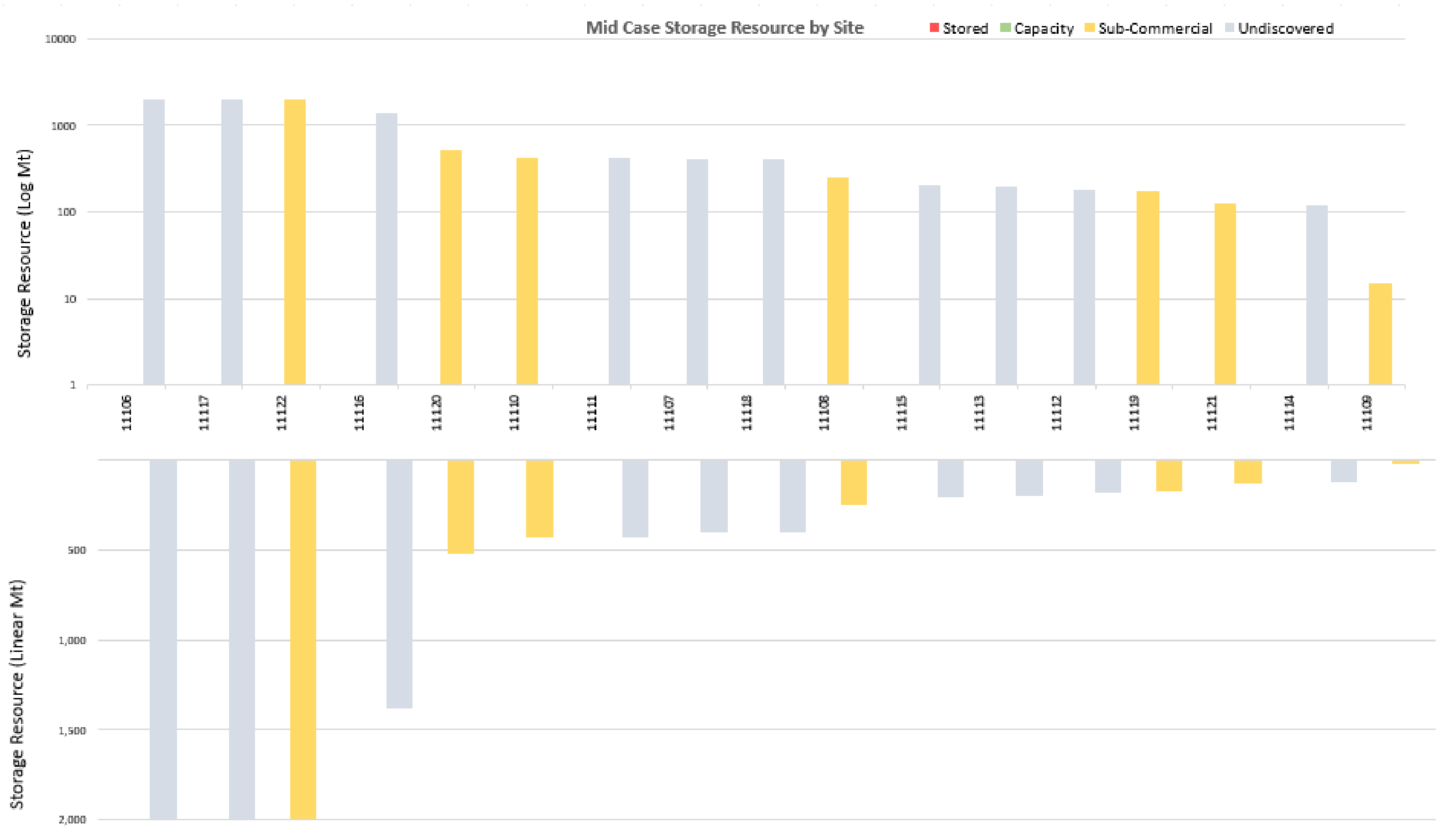


Figure 11-2: Storage resource summary for Hungary compiled in the CSRC.

Graph above is log scale and graph below is linear. Green box highlights sites where a project has been specified.

11.3 Evaluation History

The first country-wide review paper was published in 2010 (P. Kubus, SPE, MOL Hungarian Oil and Gas) [1] which evaluated 180 hydrocarbon reservoirs for CCUS prospectivity. It highlighted a cumulative resource of 430 Mt, of which 155 Mt would be available within the following 10 years, with a further 16 Mt in the next 25 years. A key finding from this study was that, on average, a depleted hydrocarbon reservoir could store a maximum of 10 – 15 Mt of CO_2 and thus concluded that the MOL CCS task force couldn't see a viable EOR project in storing CO_2 within Hungarian depleted hydrocarbon reservoirs. Despite this, the paper does allude to significant potential prospective resources. The paper also references coal fields located across the North of the country and in the Southwest to have an estimated cumulative storage resource of 300 Mt. The paper studied deep saline aquifers, noting that the storage resource was an order of magnitude greater than hydrocarbon reservoirs, however, due to sparse data could not reliably produce volumetric estimates to support this. The paper reported that the Újfalu formation has a resource of 424 Mt, the Szolnok formation has a theoretical cumulative resource of 2090 Mt (183 Mt for Jászság Basin, 197 Mt for Makó Trough, 120 Mt for Pusztaföldvár Horst, 204 Mt for Békés Basin and 1380 Mt for Transdanubian area).

It is worth noting that the method used to calculate volumes in this study involved utilising an equation developed by Professor Dr József Pápay. This equation is based on the formation's compressibility and the highest applicable overpressure. The author highlights that this method is conservative among the available estimation methods.

The 2010 Kubus [1] paper cited a "Flagship" CCS project as a case study that sought to investigate the feasibility of utilising the Mátra Power Plant as a site for capturing CO_2 and transporting it to the potential storage sites located south of the power plant. Proposed sites utilised depleted hydrocarbon fields or deep saline aquifers (Szolnok Fm). Ultimately, the project appears to have concluded that depleted hydrocarbon reservoirs were not economically viable at this stage and that significant investment would be required to fund an exploration programme to quantify better the true volumetric potential of deep saline aquifers.

11.4 Resource Review

Hungary has no active or firm plans for CCS storage projects and has yet to establish a CCUS pilot project.

The majority of prospective formations within Hungary have been assessed as Undiscovered at either the Basin or Sequence level according to SRMS guidelines.

11.4.1 Major Projects

Hungary did have a single historic proposed project that utilised the saline and hydrocarbon aquifers (namely the Szolnok & Algyo Formations) located close to the Matra power plant [1]. The saline constituent of the CCS site was suggested to have a storage potential of 250 Mt, while the Hydrocarbon equivalent had a resource of 15 Mt.

Cycle 4 has evaluated this prospect as 'Discovered, not viable' because the authors published a technical plan for the full CCS lifecycle from capture to storage, including a pipeline linking the plant with the storage site. To the present day, no further research or information in the public domain has surfaced, suggesting that this project has been abandoned.

Though not necessarily definable as a single major project, Kubus et al. (2010) referenced and expanded on the work completed by the Hungarian National Oil Company (Mol Group), which stated volumes at a country level for hydrocarbon (not defined) reservoirs. The work volumetrically calculated a CCS storage resource of 430 Mt for 180 fields at the time of writing (2010). It went on to state that 155 Mt of this resource was available from 2010 through to 2020, and beyond that date, a further 16 Mt would be available in 2035.

11.4.2 Depleted Oil & Gas Fields

Azbek et al. (2011) [2] published a study on several oil and gas prospects in various Hungary basins, featuring the Szolnok and Eszak-Afold formations.

Their findings conclude that for the Northern Great Plains basin, the Eszak-Afold formations with the Eszak Afold field has a storage resource ranging from 150 – 200 Mt. Accordingly, the Szolnok formation with the Del-Afold field was assessed to have a resource ranging from 500 – 550 Mt within the South Great Plains basin, while in the Transdanubian basin, this same formation had a storage resource ranging from 1000 – 1500 Mt. Finally, within the Pannonian basin, the Szolnok formation was assessed for a resource of 1500 – 2500 Mt. This Cycle 4 has evaluated these prospects as being 'Discovered, Not viable' as storage is located within depleted fields. However, no evidence in the public domain suggests that any plans exist to appraise or evaluate these prospects for furthering a CCS project.

Berta et al. (2011) [3] evaluated the Szolnok and Algyo formations cumulatively within the Northern Great Plains basin as having a storage resource of 400 Mt. Due to the maturity of the information available and the regional nature of the assessment, this Cycle evaluated the Berta (2011) assessment as being 'Undiscovered at a Sequence play level'.

Fazekas et al. (2022) [4] have produced the most recent CCS publication involving Hungary, in which the authors stated a resource of 97 Mt for hydrocarbon reservoirs within the Pannonian basin. However, due to the scarcity of detail in Fazekas' (2022) publication on the location and origin of the reported resources, this Cycle preferred to use other more detailed sources to identity depleted oil and gas fields.

11.4.3 Saline Aquifers

Kubus et al. (2010) evaluated the Szolnok formation as it applies to the sub-basins of Hungary. These were classified at the 'Undiscovered, Sequence play' level and yielded storage estimates as per the following:

Berta et al. (2011) [3] assessed the Szolnok & Algyo formations cumulatively within the Northern Great Plains basin to have a resource of 2000 Mt, which has been evaluated in this study as being 'Undiscovered at a Sequence play' level due to scarce information provided beyond formation name and regional location.

Kubus et al. (2010) [1] studied the Ujfalu formation within the Pannonian, stating a storage volume of 424 Mt. This assessment has been evaluated as meeting the threshold for Undiscovered, Sequence play level status according to SRMS.

Azbej et al. (2011) [2] produced a study evaluating the Upper and Lower Pannonian formations at a country level, producing a storage estimate of 400 and 2000 Mt depending on the formation's physical parameters. Due to the lack of information, the authors of this cycle deemed this evaluation immature and, therefore, evaluated it as 'Undiscovered, at basin play' level. The research also stated volumes of between 24 and 87 Mt for an unconventional prospect (coal seam).

11.5 Regulatory Framework

Hungary received a moderate definition when evaluated under the 2023 GCCSI CCS readiness index, with a score of 49.5.

The Mining Inspectorate and SZTFH (Supervisory Authority for Regulated Activities of Hungary) define and regulate detailed rules for geological structures suitable for storing carbon dioxide of energy and industrial origin to which decree no. 145/2012 and. 29/2022 are aligned toward.

The first known regulatory framework published by Hungary was under the Geological Storage Directive (May 2012) and states, "The potential sites should have adequate depth and should be sealed by impermeable strata. They should have porosity and permeability suitable for CO_2 injection".

Accordingly, in 2013, an assessment of the geological structures potentially suitable for the geological storage of carbon dioxide and their resource amounts was carried out, but it has not been updated since then. Under national legislation, storage capacities must be reassessed every five years [5].

11.6 Issues for the Assessment

The lack of public domain data and publications detailing methods for calculating storage volumes have limited the accuracy of the assessment for Hungary.

The most notable issue for storage resource assessment in Hungary is the large range of uncertainty in storage volume estimates for saline aquifers due to the lack of exploration work carried out in the country.

Because of the issues raised, this catalogue is therefore unable to accurately represent the true volume of storage potential Hungary's geological resources can offer.

11.7 Future Updates

11.7.1 Future CSRC cycles

Should Hungary's storage systems develop further, this should be reviewed annually to ensure the Global Storage Catalogue is up to date.

12 Ireland

12.1 Summary

Ireland was assessed for the first time in Cycle 4 of the CRSC. The CSRC has identified the CO_2 storage resource for Ireland in the table below.

Classification	CO_2 storage resource (Gt) Project and no project	CO_2 storage resource (Gt) Project specified only
Stored	0.000	0.000
Capacity	0.000	0.000
Sub-Commercial	1.100	0.000
Undiscovered	89.534	0.000
Aggregated*	90.634	0.000

* 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.

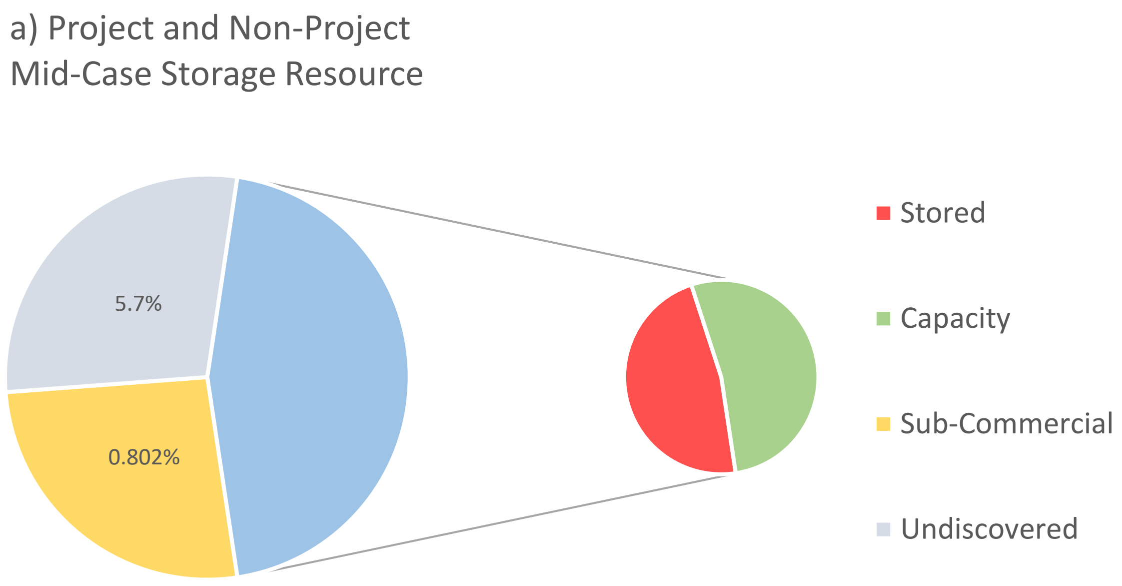
Table 12-1: Storage resource classification summary for Ireland

- Ireland has respectable potential for CO_2 storage offshore, with the most prospective opportunities located within the Peel Basin, Slyne Basin and East Irish Sea basins. The largest storage resource (at the sequence play level) is situated in the Sherwood Sandstone Group in the Peel basin at 68,000 Mt.

- Ireland's onshore prospectivity may be lower. However, it has one sizeable prospect located in the Northwest Carboniferous basin with a resource of 730 Mt.

- Irish law does not currently support CO_2 storage.

- Ireland has a relatively low score of 25 within the 2023 CCS Chart of Legal and Regulatory Indicator system.



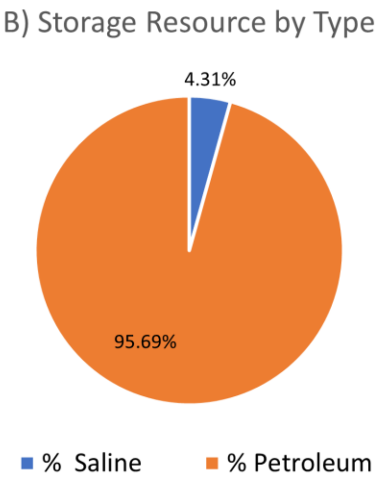


Figure 12-1: Ireland Spread of Storage Sites

a) Spread of storage resource in all Irish sites across SRMS classifications; both project specified and not. b) Split of Irish storage resource between saline aquifers and hydrocarbon fields, both project specified and not. Note: due to the large variance in size of values, numbers in pie plots do not add up to 100.

12.2 Resource Statement

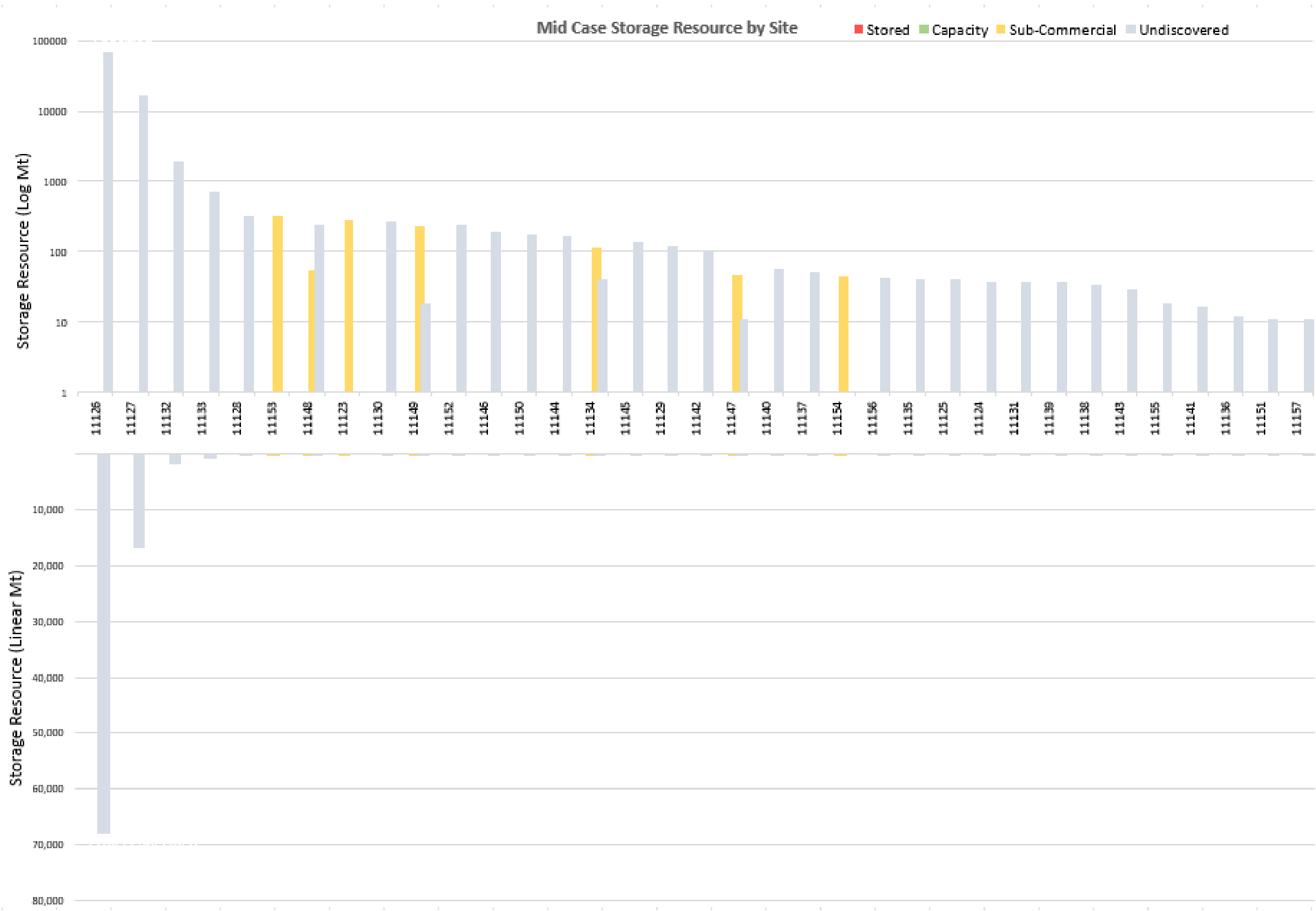


Figure 12-2: Storage resource summary for Ireland compiled in the CSRC.

Graph above is log scale and graph below is linear. Green box highlights sites where a project has been specified.

12.3 Evaluation History

The first authors to study Ireland's CO_2 storage prospectivity were Bentham et al. (2008) [1], who took a "basin by basin" approach to produce this initial country-wide review. Bentham et al.'s study produced theoretical and effective volumetric estimates for some fields by supplementing oil and gas data wherever possible to support effective volumes. This is possibly the most complete assessment of Ireland's CO_2 storage resource, including many of the country's depleted hydrocarbon prospects.

Lewis et al. (2009) [2] followed on from this review, providing another independent set of volumes for much of the same fields, with both author's outputs in agreement.

In 2011, Farrelly et al. studied the onshore prospects within the onshore Clare basin.

The most recent studies were published in 2022 (English et al.) [3] and 2023 (O'Sullivan et al.) [4].

These former studies focused only on two assets, providing a reduced estimate for the Kinsale head field and a new appraisal of the Corrib gas field. The latter focused on underexplored assets, including the Corrib, Inishmore, and Inishbeg gas fields.

12.4 Resource Review

12.4.1 Major Projects

Ireland has been producing hydrocarbons from its offshore Atlantic basins since the early 1970s. However, despite having a number of prospective targets, both onshore and offshore, it has yet to establish a CCS pilot project due to the current ban on CO_2 storage by Irish law.

12.4.2 Depleted Oil & Gas Fields

There are 15 potential depleted oil and gas fields in Irelands offshore waters. Quite significant resources could be found in the North Celtic Sea Bentham et al. (2008) documented the earliest and possibly the complete assessment of Ireland's CCS resources, studying many of the country's depleted hydrocarbon prospects. They stated that the Kinsale Head Field, Southwest Kinsale and Spanish Point Field have storage estimates of 330 Mt, 5 Mt and 120 Mt, respectively.

Lewis et al. (2009) published a study on the same fields, concluding similar volumes. In 2023, O'Sullivan et al. published a study assessing the Corrib (East Irish Sea), Inishmore (North Celtic Sea) and Inishbeg fields (Donegal Basin). For Corrib, a range of 62 – 119 Mt was quoted for the full closure and a smaller volume of 15 – 199 Mt for the gas cap. English et al., (2022) also assessed the Corrib field arriving at a volume of 44 Mt. Inishmore had been assessed by O'Sullivan et al. to have a volume of 92-310 Mt within the Triassic formations and up to 29 Mt for the Carboniferous formations. Inishbeg was quoted to hold a volume of 60 – 566 Mt.

12.4.3 Saline Aquifers

In addition to studying depleted hydrocarbon prospects, Bentham et al (2008) also documented prospective resources within saline aquifers. The largest resource they defined was the Sherwood Sandstone Group within the Peel Basin which had a stated storage resource of 68,000 Mt. The next largest opportunity is the Sherwood Sandstone group, in the Central Irish Sea Basin with an assessed volume of stated 17,300 Mt. Significantly smaller in size, is the Sherwood Sandstone group within the Larne Portpatrick Basin which stated as having a storage resource of 2700 Mt. When considering closed structures, Bentham et al. highlighted a far smaller volume of 37 Mt per structure on average for this basin. These volumes for the Larne Portpatrick Basin are agreeable when compared with the assessment published in the Lewis et al. (2009) paper.

The final assessment completed by Bentham for the Sherwood Sandstone group was for the Central Irish Sea Basin, which was stated as 630 Mt.

Within the North Celtic Sea, Bentham et al. referred to prospective resources disclosed as "Greensand A", publishing a volume of 101 Mt and 40 Mt determined by assuming 100% porosity and 40% porosity, respectively.

In addition, Bentham et al. stated volumes for several closures. Five closures containing the Sherwood Sandstone are identified within the Central Irish Sea Basin, with volumes ranging from 28 – 190 Mt, while 7 closures also containing the Sherwood Sandstone were highlighted as having volumes ranging from 11 – 57 Mt within the Kish Bank basin. A singular site was identified within the Portpatrick Basin containing the Sherwood Sandstone, with a volume of 23 Mt.

For onshore resources, Bentham et al. published volumes of 1940 Mt and 730 Mt for the Enler Group within the Lough Neagh basin and Dowra Sandstone within the Northwest Carboniferous basin.

Farrelly et al., (2011) [5] completed an independent assessment of the onshore Clare basin concluding that for the Ross Sandstone. The entire aquifer had a volume of 18 Mt with a trap resource of just 4 Mt, while the Dinantian Limestone had a volume of 42 Mt with a trap volume of 11 Mt.

Several authors referenced in this report have published data on sites that fall below the threshold for SRMS assessment. However, they are listed below for completeness.

- Bentham et al. (2008) published data on the Bains field within the East Irish Sea. Details are sparse, but the volume was quoted as 5 Mt.
- Lewis et al (2009) published data on the Southwest Kinsale Head prospect within the Celtic Sea. This prospect has its reservoir within the Upper Wealden with the Gault

formation as a seal and was speculated to have a storage volume of 5 Mt.

- Farrelly et al. (2011) studied a trap within the onshore Clare basin, which has a reservoir within the Ross sandstone. The authors quoted the trap as having a storage volume of 4 Mt.

- O'Sullivan et al (2023) published data on two small sites. Corrib North is a prospect within the East Irish Sea with a reservoir in the Corrib sandstone of the Triassic age, which is then sealed by the Uilleann Halite Member. The authors stated a volumetric resource of between 2 – 14 Mt. The second was the Carboniferous aged Inishmore Carboniferous 1 prospect within the North Celtic Sea, which was quoted to have a resource of between 2 – 16 Mt.

12.5 Regulatory Framework

Ireland has received a poor result following evaluation under the 2023 GCCSI CCS readiness index, scoring 25.

Irish law does not currently permit the storage of CO_2. Progress for future CCS projects will need regulatory and policy advancement to permit CO_2 storage.

Ireland has a semi-state multi-utility company (Ervia) that manages Ireland's energy network and is vested in decarbonising Ireland. Ervia has conducted studies surrounding CCS feasibility; however, from a regulation standpoint, these primarily focus on the export of CO_2.

12.6 Issues for the Assessment

Ireland currently lacks dynamic and project-specific assessments. Hence, all assessments are mostly theoretical. Should Irish law permit CO_2 storage, then future research may refine many of the theoretical storage estimates and reveal the true volume of storage potential Ireland's geological resources can offer.

12.7 Future Updates

12.7.1 Future CSRC cycles

Should any further development in the Irish storage systems occur, this should be reviewed annually to ensure the Global Storage Catalogue is up to date.

13 Italy

13.1 Summary

Italy was assessed by the CSRC in Cycle 4. A summary of the CO_2 Storage resource is shown in the Table below.

Classification	CO_2 storage resource (Gt) Project and no project	CO_2 storage resource (Gt) Project specified only
Stored	0.000	0.000
Capacity	0.000	0.000
Sub-Commercial	2.580	0.122
Undiscovered	5.623	0.000
Aggregated*	8.203	0.122

* 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 13-1: Storage resource classification summary for Italy

Italy has a significant estimated CO_2 storage resource in saline aquifers and depleted hydrocarbon fields. Despite this, Italy's only CO_2 storage project plan is an Eni project utilising the Ravenna depleted hydrocarbon field. This might be explained by the low public acceptance of CO_2 storage and the fact that many depleted fields are converted to gas storage.

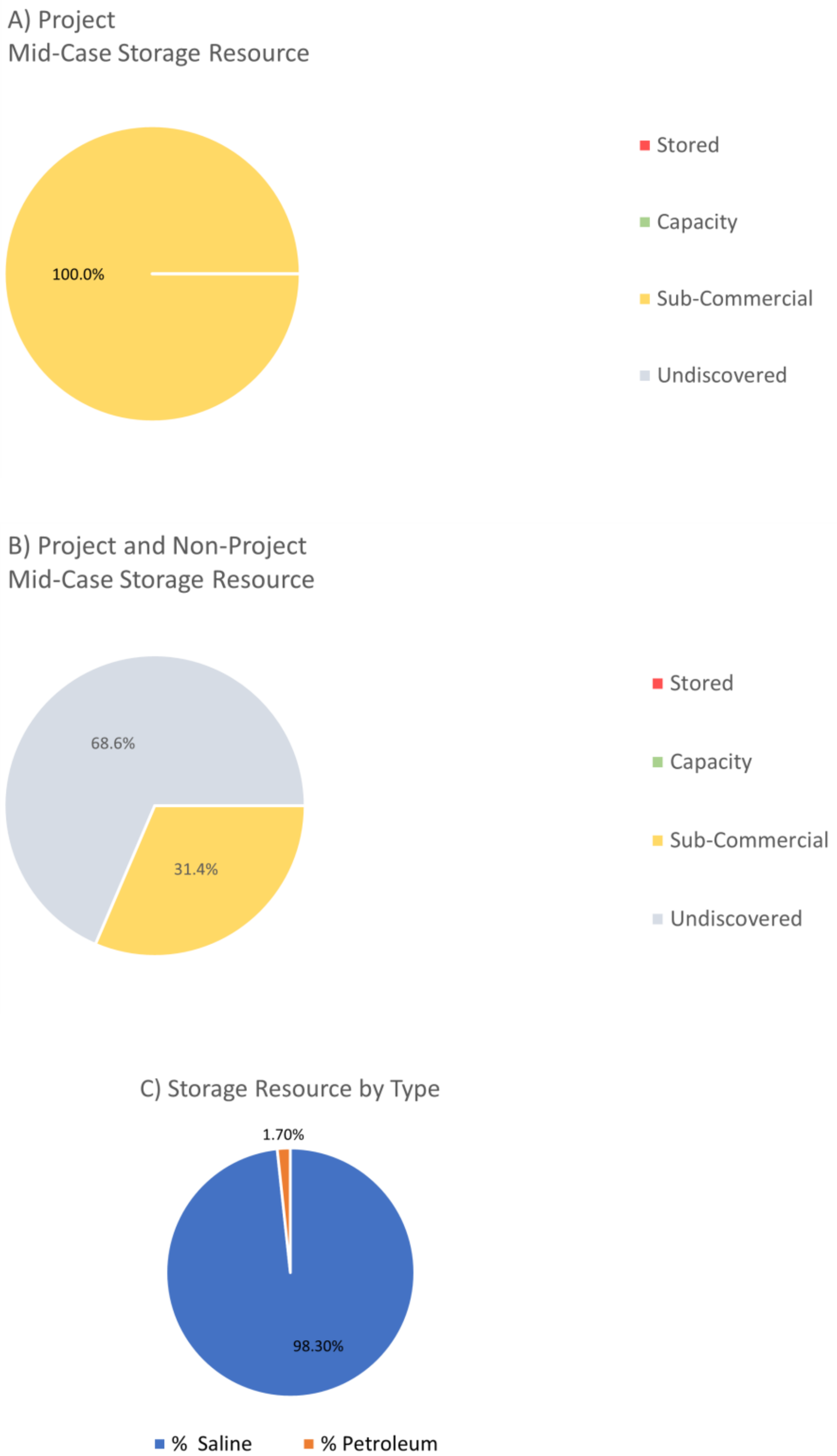


Figure 13-1: Italy Spread of Storage Sites

a) Spread of storage resources in Italy sites across SRMS classifications; both project specified and not. b) Split of Italy storage resource between saline aquifers and hydrocarbon fields, both project specified and not. Note: due to the large variance in size of values, numbers in pie plots do not add up to 100.

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13.2 Resource Statement

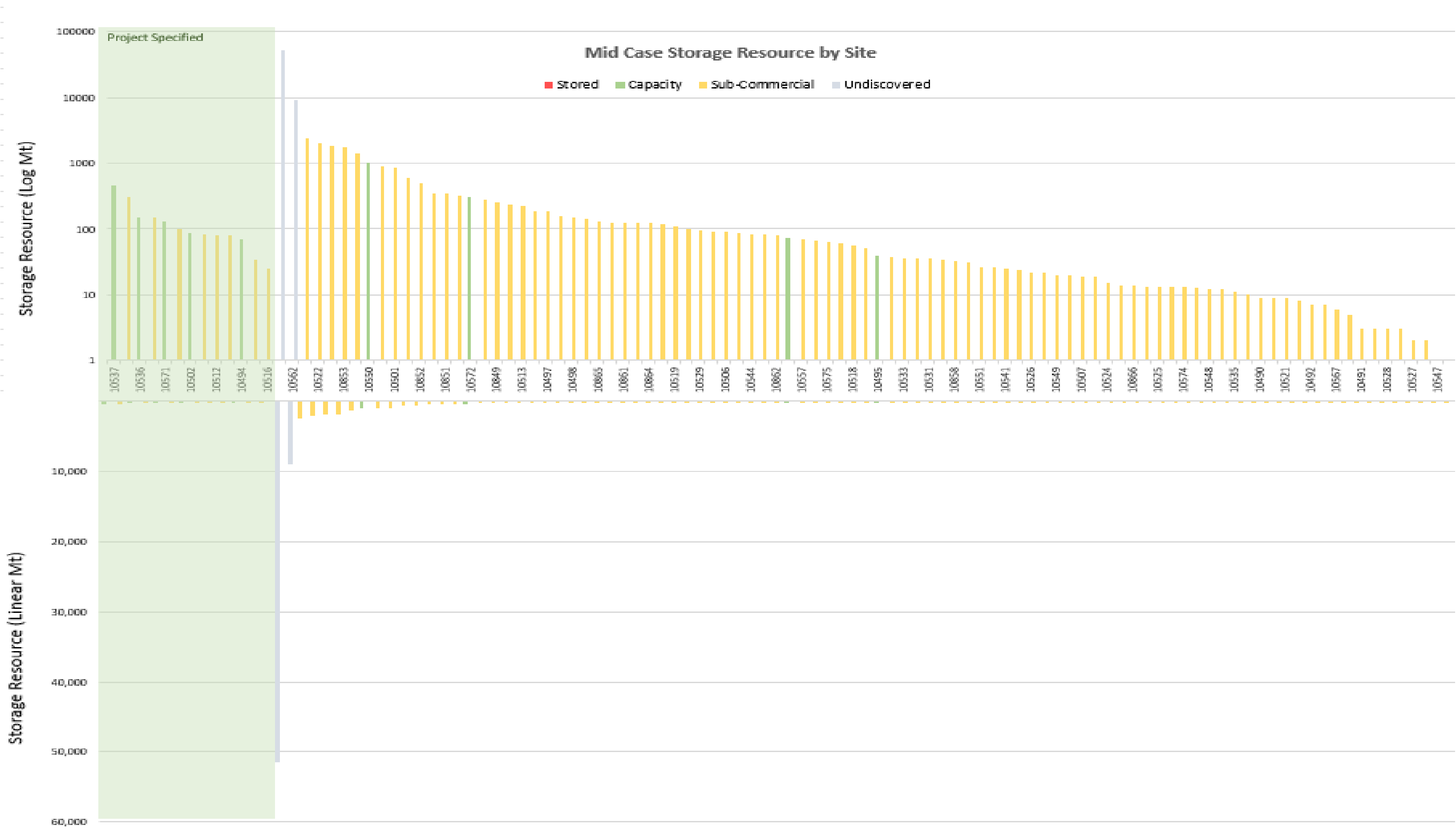


Figure 13-2: Storage resource summary for Italy compiled in the CSRC.

Graph above is log scale and graph below is linear. Green box highlights sites where a project has been specified.

13.3 Evaluation History

In Italy, the evaluation of storage resources has been performed only in the context of research projects, as the role of CCS in the Italian energy strategy is still relatively marginal (CO_2GeoNet-2021) [16]. Italy has the potential for CO_2 geological storage (CGS) in saline aquifers, both onshore and offshore, within both siliciclastic [1] and carbonate rocks [2]. These are supported by additional studies [3,4,5,6]. Italy's storage resources were evaluated by the GeoCapacity project (2009) [12] and CLEANKER (2022). All the results are based mainly on public data from the Ministry of Economic Development via the "Visibility of Petroleum Exploration Data in Italy (ViDEPI)" project and from additional published databases. The ViDEPI dataset includes data from approximately 1650 wells and 55,000 km of 2D multichannel seismic profiles acquired since 1957 by several oil companies for hydrocarbon exploration. An ArcGis project is available at: (ArcGIS - WebGIS UNMIG).

13.4 Resource Review

The geology of Italy is quite complex. It is characterised by a thrust belt area with the Alpine and Apennine chain in a compressional tectonic regime, foredeep and foreland areas in the East and south, and a back-arc basin in the west. The main Italian sedimentary basins, the Apennine foredeep and the Adriatic foreland, are characterised by thick siliciclastic sediments and carbonate accumulations and host the best potential storage sites. The potential reservoirs comprise deep saline aquifers hosted in both carbonate and sandstone formations. A theoretical storage resource ranging from 30 to more than 1,300 Mt CO_2 in the clastic formations has been estimated [1]. Additional potentially suitable areas have been identified by Civile et al. (2013) [2] in carbonate aquifer formations. Depleted oil and gas fields in the Malossa–San Bartolomeo area are considered to carry storage potential in the CO_2.

Altogether, 34 saline aquifers are mapped with a total resource of just over 8 Gt. Information about specific storage reservoirs is limited, but the storage resource in hydrocarbon fields is estimated to be 139 Mt. Published detailed descriptions of the storage sites are limited. The most researched area is the Adriatic Sea by Proietti, G. et al. (2021) [7] and Proietti, G. et al. (2023) [8].

13.4.1 Major Projects

Sulcis site (Sardinia): National funding has been allocated for the construction of a 350 MWe coal-fired power plant / CCS demonstration plant in the Sulcis area of SW Sardinia. The recently approved EC-funded ENOS project (Enabling Onshore CO_2 Storage in Europe) will use the Sulcis site as one of its main field research laboratories. Site characterisation is ongoing, and work has begun to design gas injection experiments at 100-200 m depth in a fault [9,10].

In 2011, ENEL launched an innovative CO_2 capture plant at the Federico II coal power plant in Cerano, Municipality of Brindisi. It consisted of four units with a resource of 660 MWe each (a total resource of 2640 MWe). However, the capture plant was closed after two years due to investment issues.

Within the CLEANKER project, supported by the EC H2020 program, several cement industries, in collaboration with research centres in Italy and other European countries, are developing a calcium-looping technology to capture CO_2 in the cement production process. The study will also consider how to develop a full chain CCS project in Northern Italy. The Zero Emission Porto Tolle (ZEPT) Project covered the design, procurement, and construction of a demonstration CO_2 capture plant and the detailed site characterisation to verify the feasibility of the injection and storage of CO_2 safely and verifiable. The ZEPT Project (Porto Tolle) was suspended [11].

There was also an Eni feasibility study and pilot project of injection into a depleted hydrocarbon field in cooperation with Enel, which tested various chemical solutions to capture CO_2 at the Brindisi power plant. A CO_2 pipeline to the Stogit field for storage was planned to be in operation from 2012. After an initial testing period in March 2011, the project was expected to be operational by 2012. However, the project did not proceed to the operational phase.

Eni recently announced the new CCS "Ravenna hub". Depleted offshore gas fields in the middle Adriatic will be used for CO_2 storage utilising existing operational infrastructure. CO_2 will be supplied from new CO_2 capture systems at onshore Eni power plants and other nearby industrial plants. Ravenna CCS aims to become the pioneer hub for Italy and the Mediterranean. Led by Eni, the hub is in development. The plan was to launch Phase 1 in 2023, testing technologies in a full capture, transport and storage chain handling up to 100,000 tonnes per year [13].

13.4.2 Depleted Oil & Gas Fields

Hydrocarbon production in Italy is associated with the three main tectono-stratigraphic systems: 1. biogenic gas in the terrigenous Pliocene-Quaternary foredeep wedges; 2. thermogenic gas in the thrusted terrigenous Tertiary foredeep wedges; and 3. oil and thermogenic gas in the carbonate Mesozoic substratum. The potential storage resource of 14 depleted fields, which represent only a small proportion of the total number of Italian hydrocarbon fields, has been estimated as gas reservoirs: 1.6 Gt - 3.2 Gt; oil reservoirs: 210 Mt - 226.5 Mt [12, 11]. The studied fields are, however, small; just three have estimated CO_2 storage resources above the CSRC threshold of 10Mt. Additional storage potential may exist in other depleted fields evaluated for natural gas storage and/or hydrogen storage, but not CO_2.

13.4.3 Saline Aquifers

Most of the potential saline aquifer sites lie in the major Italian sedimentary basins, i.e., the Apennine foredeep and the Adriatic foreland, characterised by thick sediment accumulations. The potential reservoirs are represented mainly by permeable, terrigenous deep saline formations, whose resources range from 30 to more than 1300 Mt [12,1]. Offshore saline aquifers were estimated by Beretta (2012) [15], although very little information is found in the public domain. Additional storage potential may exist but has not yet been evaluated or published in the public domain. For example, Barison et al. (2023) [15] present a list of deep saline aquifer sites, onshore and offshore, with hydrogen storage potential, but these have not been considered for use by CO_2 storage.

13.5 Regulatory Framework

EU Directive no. 31 of 23 April 2009 was issued and implemented in Italy with Legislative Decree no. 162 of 14 September 2011. Another amendment stating that CO_2 storage is not permitted in seismically active areas was also implemented.

13.6 Issues for the Assessment

The saline aquifers in Italy have been widely studied. They have been considered for gas storage, hydrogen storage and CO_2 storage. CO_2 storage in saline aquifers and depleted fields has not been a priority in Italy, although many depleted fields are used for gas storage. There has been limited maturation of CO_2 storage resource calculations since the 2009 GeoCapacity project, with the exception of the Adriatic Sea area. Further assessment of individual sites will be required to fully evaluate the country's storage potential.

13.6.1 Future evaluations

Any new evaluations of storage potential should provide site or project-specific, pressure-limited storage resource estimates to allow the identification of high-potential resources.

13.6.2 Future CSRC cycles

Any new storage resource estimates should be submitted by the author for assessment and inclusion in future updates of the CSRC.

14 Netherlands

14.1 Summary

The Netherlands was assessed for the CSRC in Cycle 4. A summary of the CO_2 storage resource is shown in the Table below.

Classification	CO_2 storage resource (Gt) Project and no project	CO_2 storage resource (Gt) Project specified only
Stored	0.000	0.000
Capacity	0.400	0.400
Sub-Commercial	1.325	0.513
Undiscovered	1.485	0.000
Aggregated*	3.210	0.913

* 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 14-1: Storage resource classification summary for The Netherlands

- The Netherlands was an early adopter of CO_2 injection and storage, establishing a pilot project that injected 100,000t into the K-12B depleting gas field in 2014.

- Although there are currently no active CO_2 storage projects in the Netherlands, two CCS projects, Aramis and Porthos, are in the development phase.

- The Independent CO_2 Storage Assessment (ISA) project, commissioned in 2010, reviewed and evaluated the Dutch Continental Shelf's offshore storage potential.

- The Netherlands scored 58 in the 2023 CCS Chart of Legal and Regulatory Indicator system due to the country having specific CCS laws aligning with EU directives.

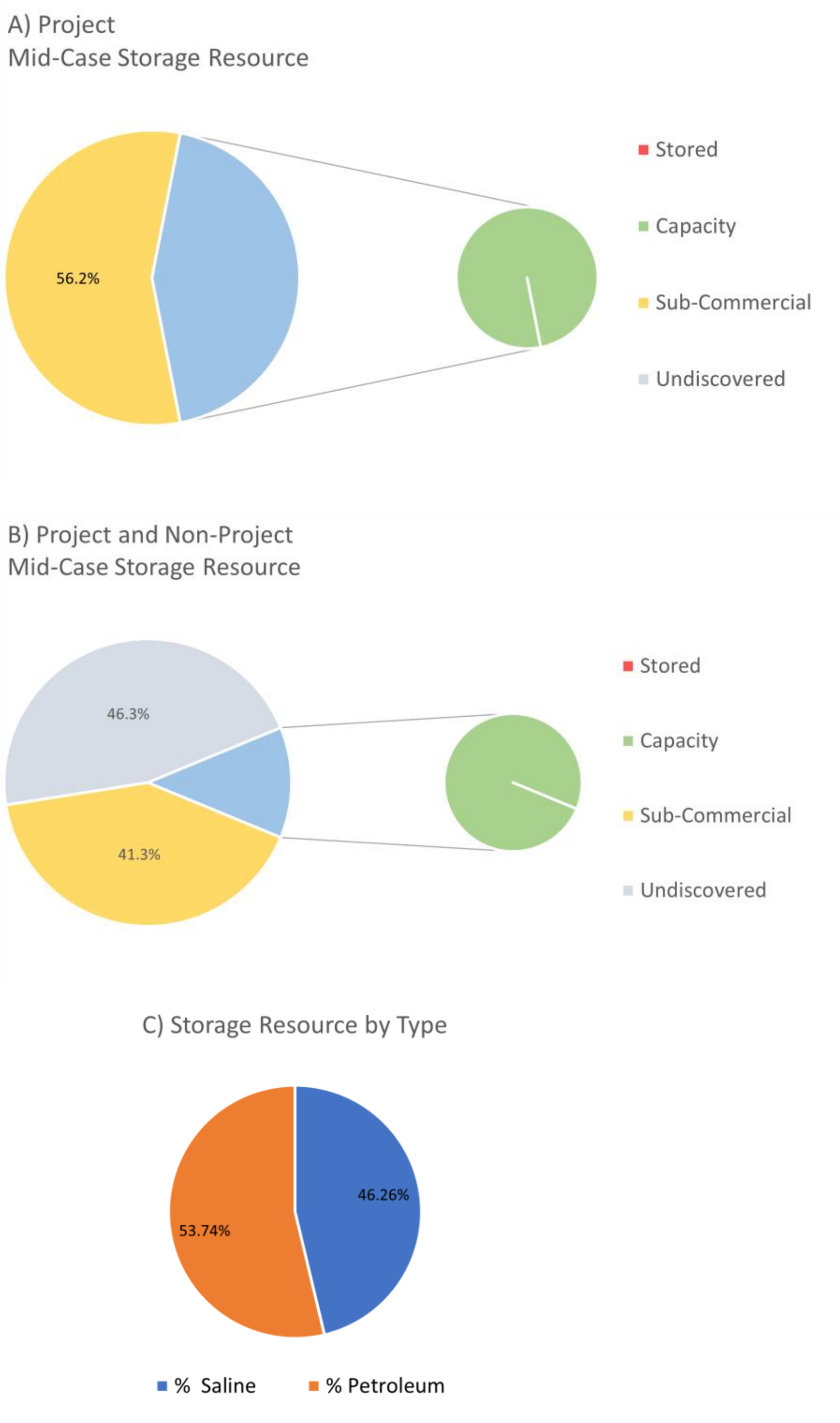


Figure 14-1: Netherlands Spread of Storage Sites

a) Spread of storage resource in all the Netherlands sites across SRMS classifications; both project specified and not. b) Split of the Netherlands storage resource between saline aquifers and hydrocarbon fields, both project specified and not. Note: due to the large variance in size of values, numbers in pie plots do not add up to 100.

14.2 Resource Statement

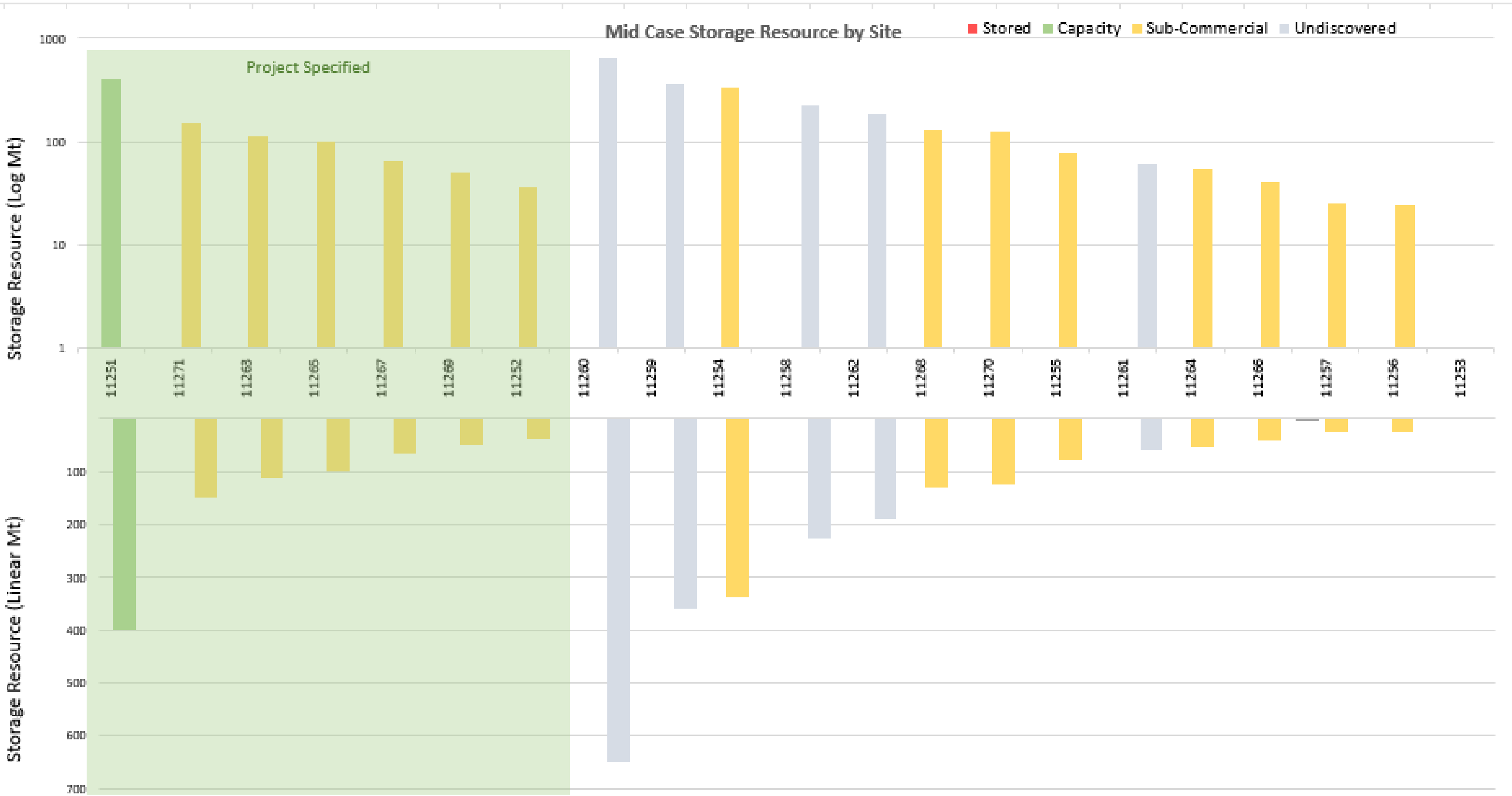


Figure 14-2: Storage resource summary for the Netherlands compiled in the CSRC.

Graph above is log scale and graph below is linear. Green box highlights sites where a project has been specified.

14.3 Evaluation History

While storage potential exists in both saline aquifers and depleted hydrocarbon fields, the evaluation history of the Netherlands has predominantly focused on depleted fields to utilise the offshore active hydrocarbon province in the Dutch sector of the Southern North Sea. A three-phase study – the Independent CO_2 Storage Assessment (ISA), was commissioned by the Rotterdam Climate Initiative in 2010 to evaluate the offshore storage potential of the Dutch North Sea. Phases 1 and 2 focused on near-shore (proximal to Rotterdam) opportunities and detailed characterisation of the highest ranked sites, including the P18 field which has been the focus of both the cancelled ROAD project and the current Porthos project. Phase 3 took a broader look at all potential geological structures in both saline aquifers and depleting hydrocarbon fields across the Dutch Continental Shelf. This study provides the widest review of the storage potential for offshore Netherlands.

14.4 Resource Review

14.4.1 Major Projects

The Netherlands has two CCS projects under development. Aramis has an estimated storage potential of 400Mt and is in joint development with Shell, Total Energies, EBN and Gasuine. The much smaller Porthos CCS project is estimated to have a storage resource of 37 Mt and is in joint development between Gasuine and EBN, which will seek to inject 2.5 Mt per annum for up to 15 years.

The Aramis project is spread across multiple offshore fields and will target storage within multiple geological intervals, namely the pre-salt Permian Rotliegendes, post-salt Triassic Buntsandstein and Cretaceous Holland Greensand. This project is an anchor project for other developments, including the Neptune Energy-led L10 CCS project, a carbon storage infrastructure project aiming to store up to 5 Mtpa, which entered FEED at the end of 2023. The Aramis project has progressed over a marked timeline. The initial phase of 2019 – 2021 saw the feasibility study and partnership formalisation signed off. Currently, the partners are progressing in phase 2, scheduled for 2022 – 2024, and will consider the design concept and CCS value chain parties' agreement. Phase 3, scheduled for 2025 – 2026, will be concerned with the FID across the value chain prior to project startup in Phase 4, which is targeted for 2028 – 2029. Beyond project start-up, the partners will then progress into phase 5, increasing resources from 7 Mtpa to 22 Mtpa. [1,2,3.4]

The Porthos project will target multiple depleted gas fields located approximately 20 Km offshore within the Dutch North Sea. The P18-2, P18-4 and P18-6 concessions are the fields of choice, with the P18-2 platform planned for CO_2 injection utilisation. The Porthos project has been underway since 2018, when the feasibility study was completed in April, after which the concept phase was signed off in January 2019. Early 2019 saw the FEED phase and technical development for transport and storage infrastructure being considered. Simultaneously, from

February and leading into March 2019, the expression interest companies were being negotiated and signed off. In June 2019, a memorandum on scope and detail was executed before July 2019 when the EU Commission awarded the project a 6.5 million Euros CEF subsidy for preparatory studies. From autumn 2019 to autumn 2020, joint development agreements were signed, and the EIA was completed. In February 2021, the project was awarded a 102 million Euros CEF subsidy by the EU Commission for construction works. Then, in autumn 2021, the transport and storage contracts were signed [5,6].

More recently, in September 2022, the CO_2 Storage permits for P18-2 and P18-4 fields were officially ratified, becoming irrevocable and thus enabling the FID to be completed in October 2023. Looking ahead, the Porthos project is scheduled to begin construction in the winter of 2023 and into 2024, with the ambition of the system going operational in 2026.

The ROAD CCS project [7] was a large integrated demonstration project to capture 1.1Mtpa CO_2 from a new coal-fired power station near Rotterdam. The CO_2 will be stored in offshore depleted gas fields attached to a single platform. Significant work was undertaken between 2009 and 2017 when the project was cancelled, including a FEED study and preparation for a final investment decision. The initial storage site was planned to be the P18-4 gas reservoir (total storage potential 8.1 Mt), and Europe's first storage permit was awarded (to TAQA) in 2013. To reduce project costs, the storage site was switched to the smaller Q16-Maas field (operated by ONE at the time; storage potential estimated at 1.9-2.3 Mt)

14.4.2 Depleted Oil & Gas Fields

Gas field storage potential (offshore sector) sits at approximately 1725 Mt. The ISA Phase 3 study [8] identified several gas field clusters as having the greatest storage potential in the offshore sector: K14/15 (165 Mt), K04/05 (140 Mt), K07/08/10 (195 Mt) and L10/K12 (175 Mt), and provided high-level indications of project risk associated with development, well integrity, and pore space availability, and an estimate of injection rates and project duration. The high potential P18 cluster of reservoirs was studied in Phase 1 but also has build-out storage potential in neighbouring fields, e.g., the P15 field at 40 Mt.

14.4.3 Saline Aquifers

Van der Meer et al. (2009) [9] studied three aquifers across the onshore and offshore Dutch North Sea. The study mapped out 41 aquifer traps (isolated or stacked with other formations) in the onshore sector and 32 traps in the offshore. A total of 438 Mt storage resource was estimated (not including gas fields in the onshore Roer Valley Graben within the Vlieland sandstone). This volume was broken down between individual aquifers as the Permian Slochteren Sandstone (337 Mt), the Triassic Bunter Sandstone (77 Mt) and the Jurassic/Lower Cretaceous Schieland Sandstone and Vlieland Sandstones (24 Mt).

Neele et al (2013) [1] also published evaluations of five sequences identified in Phase 3 of the ISA study as holding significant offshore storage potential at a combined ~1.5 Gt. The storage resource estimates include the "Q1 - Lower Cretaceous" (110 – 225 Mt), PQ - Lower Cretaceous (360 Mt), F15 and F18 – Triassic (650 Mt), L10 and L13 – Upper Rotliegend (60 Mt), and the Step graben – Triassic (190 Mt). These values are favoured for the CRSC.

Data coverage and availability for saline aquifers are acknowledged as limiting factors for the maturation of this site type within the Netherlands. Vandeweijera et al. (2020) [10] published data on the K-12B demonstration project, where 0.09 Mt was injected and stored into the Upper Permian Slochteren Sandstone between 2004 and 2017.

14.5 Regulatory Framework

The Netherlands has received a moderate evaluation under the 2023 GCCSI CCS readiness index, scoring 58.

The Ministry of Economic Affairs and Climate Policy is responsible for issuing storage permits for CO_2. In 2011, the Dutch government announced it would not be engaged in any onshore storage of CO_2, citing a lack of public support and instead suggesting it would target depleted gas fields offshore. This position was restated later in 2018.

The permit process for CCS storage within the Netherlands aligns with the EU strategy from which applicants can engage with the competent permitting authority. These Member States invite potential applicants to contact and engage with the authorities for information and advice. The requirements for a CO_2 storage permit application are set out in the Dutch Mining Act, amended in 2011 to include a transposition of the EU Storage Directive (EU Directive 2009/31/EC).

The Netherlands has issued storage permits (2021 and 2022) for the Porthos project. The Netherlands has also notified the European Commission of three storage applications for offshore areas: K14-FA from Shell International Exploration and Production B.V. and Shell Gas & Power Developments B.V., P18-6 from TAQA Offshore B.V. and EBN CCS B.V., and L04-A from TotalEnergies EP Nederland B.V.

The Netherlands is one of the only reporting countries (the other being Romania) where certain areas do not necessarily require an exploration permit to generate the information necessary for selecting storage sites. CO_2 storage in depleted oil or gas fields does not require new exploration activities because the existing data is considered sufficient.

14.6 Issues for the Assessment

Given the generally limited static and dynamic data available for the sequences identified, storage values for saline aquifers should be considered preliminary resource estimates.

14.7 Future Updates

14.7.1 Future evaluations

Any updates or refinement of the ISA study should be used to improve the CSC content.

14.7.2 Future CSRC cycles

As the projects are in the advanced stages of development and those recently awarded licenses publish additional data, the CSRC should be updated accordingly.

15 Norway

15.1 Summary

Norway was assessed during Cycle 1 and was updated in Cycle 2, 3 and 4 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	0.028	0.028
Capacity	0.084	0.084
Sub-Commercial	58.809	1.739
Undiscovered	45.487	3.490
Aggregated*	104.408	5.341

* 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 15-1: Storage resource classification summary for Norway

- There are currently a total of 51 sites at both local and regional scales 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 14 project-specified sites, the majority (13) of which also contain a simulation model.
- As of 2023, a total of 27 Mt of CO_2 has been injected into deep geological storage at Sleipner (19 Mt) and Snøhvit (8 Mt).
- Aside from Sleipner and Snovit, there are five current projects in the development stage, this being Havstjerne CCS (Wintershall DEA and Altera), the Northern Lights CCS project (Equinor, Shell, and Total Energies). Polaris CCS (Horisont, Equinor, Var Energi), Smeaheia CCS (Equinor), Trudvang CCS (Sval, Storegga and Neptune), Luna (Wintersall DEA, Total Energies and CapeOmega) and finally Poseidon (Aker BP and OMV).
- The Norwegian government has created solid foundations for a CCS market in Norway by introducing a high carbon tax for fossil fuel extraction and the GHG Emission Trading Scheme. However, gaps remain in CCS-specific legislation, according to the GCCSI Legal and Regulatory Indicator Report. Norway has a score of 61.5 within the 2023 GCCSI Chart of Legal and Regulatory Indicator [GCCSI 2023)

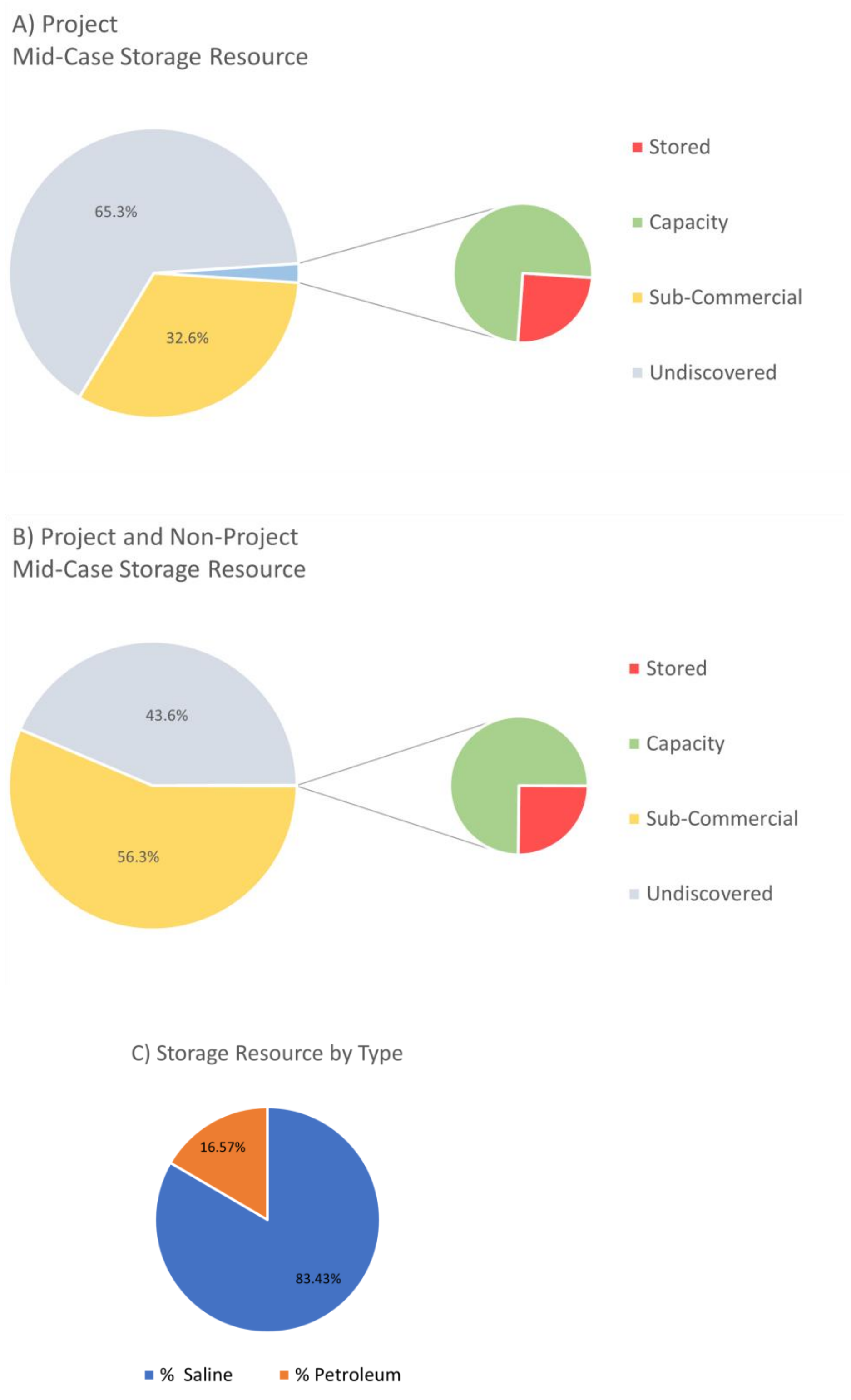


Figure 15-1: Norway Spread of Storage Sites

a) Spread of storage resources in Norway sites across SRMS classifications; both project specified and not. b) Split of Norway storage resource between saline aquifers and hydrocarbon fields, both project specified and not. Note: due to the large variance in size of values, numbers in pie plots do not add up to 100.

15.2 Resource Statement

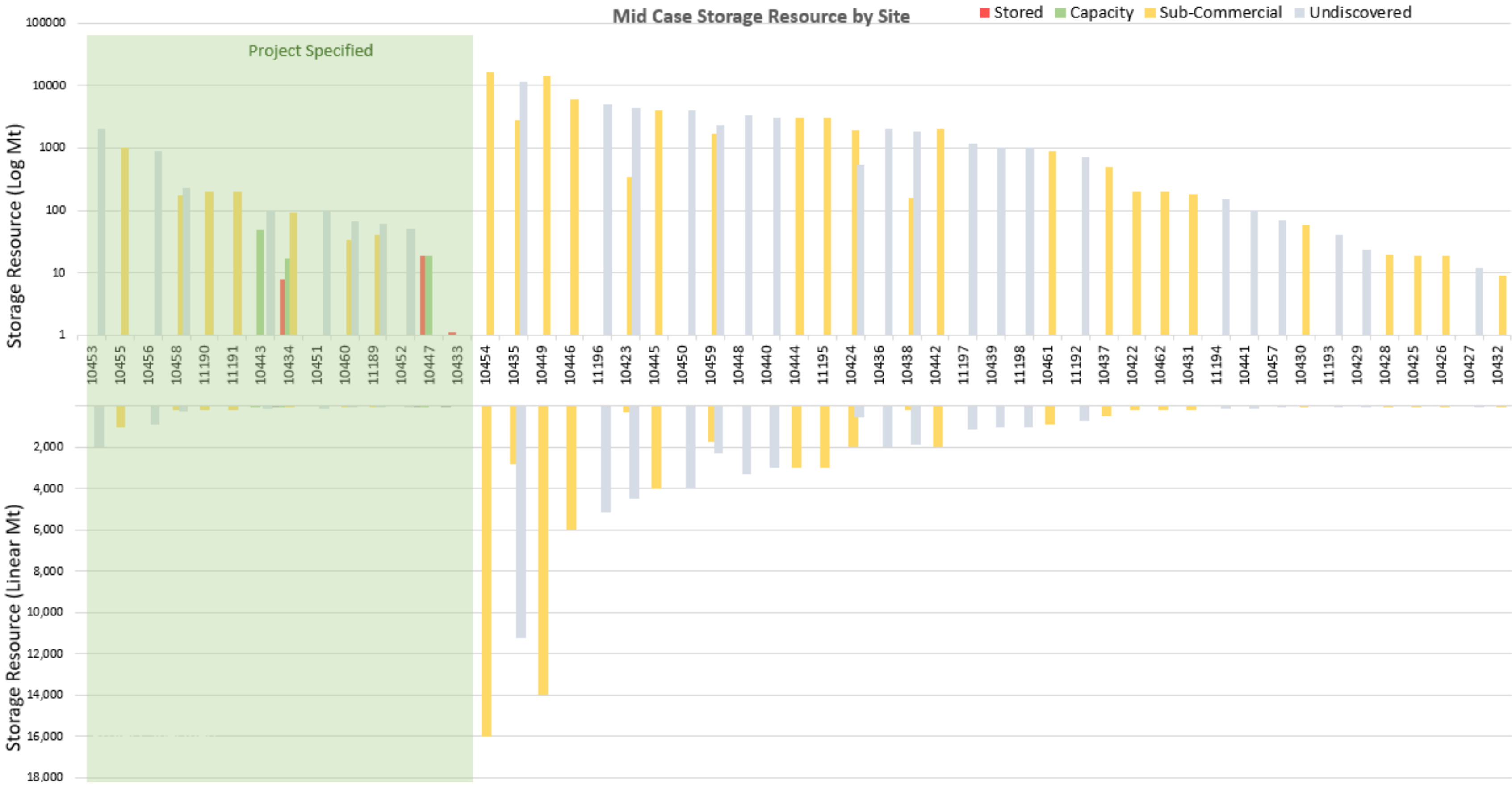


Figure 15-2: Storage resource summary for Italy compiled in the CSRC.

Graph above is log scale and graph below is linear. Green box highlights sites where a project has been specified.

15.3 Evaluation History

The Norwegian CO_2 Storage Atlas is a key document for the 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 formed the data source for the majority of the Norwegian sites within this assessment up to Cycle 4. The Atlas is compiled from both site-specific evaluations in published literature and regional evaluations by the NPD. It comprises 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.

Some additional sites were added to the database in 2024 as a result of the license rounds to award Polaris (2022), Trudvang (2023), and Smeaheia's consideration in the Northern Lights project. Additional sites are included as a result of more refined analysis from published papers by Lothe et al., 2019, and Anthonsen, 2014.

Norway has a similar overall resource character to the UK but enjoys larger areas of undrilled potential and storage resource prospectivity. It also has operational and developing CO_2 injection projects, which creates a spread of resources across the SPE SRMS classifications. Significant storage resources are 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. This is still the case in 2024 (Cycle 4).

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

Data availability dictates a site's maturity and the subsequent methodology to evaluate its storage potential in the Norwegian Atlas. 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. When the site reaches a different maturity level, a different methodology will be deployed to estimate the site's storage resources.

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 the potential to find "accessible pore volume being suited to containment", as described in the SRMS. As a result, 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.

15.4 Resource Review

15.4.1 Major Projects

In Norway, two commercial-scale CCS projects injecting CO_2 are 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 18.6 Mt (end-2019; P Ringrose, pers. comm; [4]) [5].

Snøhvit is an LNG facility 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 primarily 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 and should allow sufficient pressure dissipation.

Since Cycle 3, Norway has increased its major project list, namely due to the award of 7 licenses. Sites are added to the CRSC if injection rate and plan is published to allow calculation of anticipated full injection amount. If sites have only published injection rates then they are not included in the database since a full calculation of expected storage resource cannot be made:

1. The Aurora site (Johansen Formation) (EL001) is the storage site for the Northern Lights project. The project has been approved for Phase 1 with an injection of 1.5 Mt per year and is on target to start receiving CO_2 in 2024. Phase 2 anticipates expansion to 6-7 Mt/yr (https://northernlightsccs.com).

2. Trudvang CCS (EXL007) is in the pre-FEED stage and scheduled to start in 2029. It is anticipated to have storage of around 8-10 Mtpa and a total resource of around 200-300 Mt. The Trudvang project involves capturing CO_2 from several industrial emission sources in Europe and transporting it, either via ships or pipelines to the storage site (https://trudvang-ccs.com/).

3. The Polaris Project (EXL003) is a component of the planned Barents Blue Ammonia plant and will also provide a resource for third-party storage. German Energy Company E. ON intends to store 1 Mt of CO_2 from European customers. Storage resource is currently projected at >3 Mtpa (https://horisontenergi.no/projects/polaris/).

4. The Smeaheia Project (EXL002) plans to provide storage for CO_2 transported from Northern Europe via pipelines and ships in the North Sea. Estimates project there is a resource for 30-50 Mt of storage and ~ 20Mtpa injection capacity. The license is 100% operated by Equinor.

5. Wintershall Dea has been awarded operatorship of the 'Havstjerne' CO_2 storage license (EXL006) and has a projected annual storage potential of up to 7 million tonnes of CO_2. Transport is planned by ship from a cluster of emitters in the Baltics, Netherlands, Portugal and Spain.

6. The Luna site (EXL004) is the second license awarded to Wintershall Dea with participating interests from Total and CapeOmega Carbon Storage. Luna is estimated to have an injection capacity of 5 Mtpa. The partners plan to build a hub on the German North Sea for collection and transport up to Luna (https://www.ogj.com/energy-transition/article/14298015/totalenergies-acquires-interest-in-luna-ccs-project).

7. The final project to add to cycle 4 is the Poseidon Project (EXL005), awarded to Aker BP and OMV. The license is projected to potentially provide 5 Mtpa CO_2 storage. CO_2 is expected to be transported from Europe. The license holders collaborate with Hoegh LNG to transport CO_2 through marine CCS solutions. (https://akerbp.com/en/borsmelding/aker-bp-and-omv-awarded-licence-for-CO_2-storage-2/).

15.4.2 Depleted Oil & Gas Fields

The aggregated storage resource within hydrocarbon fields in the Norwegian sector is 17.3 Gt (1.1 Gt in the Norwegian Sea and 16 Gt in the North Sea. A smaller 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 the Norwegian Sea are either abandoned or are due to be abandoned by 2050. However, no sites in the published literature are reportedly undergoing active appraisal for CO_2 storage. 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.

15.4.3 Saline Aquifers

The storage resource for saline aquifers in Norway is spread across a range of the SRMS classifications, with aggregated storage resources: ~45.5 Gt Undiscovered, 41.5 Gt Sub-commercial, 0.083 Gt resource and 0.028 Gt Stored. The Undiscovered portion is primarily 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 resources are 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 aquifers since the Atlas was published. Recent work has focussed on the Utsira Formation and Garn Formation, where simulation modelling has identified optimal CO_2 injection locations across the regional aquifers. The additional sites entered in cycle 4 are from research that has better described and delineated specific structures in the Smeaheia area (Lothe et al. 2019). Some additional formation sites are added based on research that appears not to have been included in the NDP Atlas. These add around an extra 8000 Mt storage for saline aquifers. [1,6,7].

15.5 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 the 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]. The Norwegian government has also funded several R&D projects and facilities, including initiating Gassnova, a state-owned CCS enterprise, and the Technology Centre Møngstad, an R&D facility to test CCS technologies.

Norway is working to establish bilateral agreements to enable cross-border CO_2 transport, which it approved in 2010, to comply with the London Protocol (and amendment to Article 6 of the Protocol).

Norway scores 61.5 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."

15.6 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 considering injection into optimal structures within the aquifer [6]. In accordance with the SRMS guidelines on aggregation of resources, double counting cannot be avoided due to the different maturity of the sites against the SRMS classification system [10]. In addition, it is difficult to establish the formations and structures in previous cycles that have become projects. There is limited information about the geology of sites in the literature and reports on projects. Future cycles must focus on sourcing more details to help define and clarify project formations and avoid double counting.

15.7 Future Updates

15.7.1 Future CSRC cycles

It is recommended that future publications should focus on revisions and more detailed research on individual sites. If available, then dynamic simulations will make significant refinement to any theoretical estimates.

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 ongoing CCS projects. Following the successful drilling of the Northern Lights injection well, updates on the storage resource of the site in the published literature would be welcome. Future updates to project progress should be included for Luna, Poseidon, Smeaheia, Polaris, Trudvang and Havstjerne.

16 Poland

16.1 Summary

Poland assessed for the CSRC in Cycle 4. A summary of the CO_2 storage resource is shown in the Table below.

Classification	CO_2 storage resource (Gt) Project and no project	CO_2 storage resource (Gt) Project specified only
Stored	0.000	0.000
Capacity	0.000	0.000
Sub-Commercial	3.696	0.000
Undiscovered	79.175	0.000
Aggregated*	82.870	0.000

* 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 16-1: Storage resource classification summary for Poland

- Poland has undertaken an evaluation of prospective sites for carbon storage. Most of this work has been conducted by the Polish Geological Institute and the Polish Academy of Sciences.

- The country was assessed as part of the CCS4CEE project funded by EEA and Norway grants. Poland was identified as being a potential cluster for CCS. This project ultimately led to a CCS roadmap for building momentum for long-term CCS deployment in Poland.

- CCS in Poland is limited by regulatory barriers. The key barrier is that onshore CO_2 Storage is not yet permitted.

- Poland has developed small-scale pilot projects and is in the process of developing larger scale projects.

- Storage potential exists in depleted oil and gas fields, saline aquifers, and coal seams. By far, the most significant storage resource is found in aquifer structures.

- The CCs4CEE project identified Poland as a potential storage hub for adjacent countries. If regulations are developed to allow onshore CCS development, Poland has significant aquifer storage potential, a strong research and development knowledge base, and few industrial and natural barriers to both storage and transportation network development.

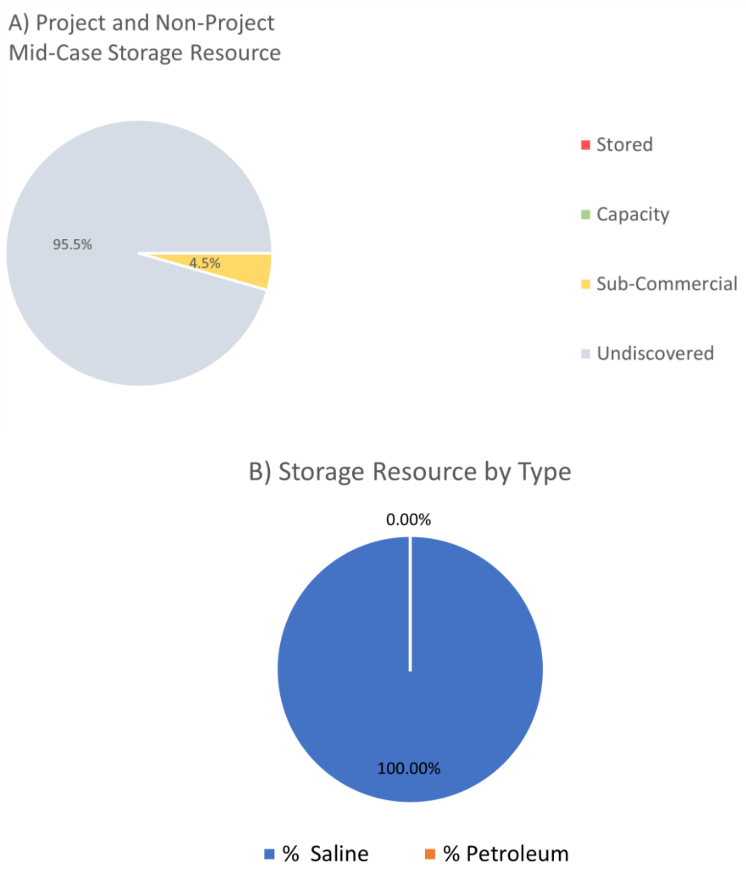


Figure 16-1: Poland Spread of Storage Sites

a) Spread of storage resource in all Polish sites across SRMS classifications; both project specified and not. b) Split of Polish storage resource between saline aquifers and hydrocarbon fields, both project specified and not. Note: due to the large variance in size of values, numbers in pie plots do not add up to 100.

16.2 Resource Statement

Figure 16-2: Storage resource summary for Poland compiled in the CSRC.

Graph above is log scale and graph below is linear. Green box highlights sites where a project has been specified.

16.3 Evaluation History

Polish Geological Society

From 2008 to 2012, the Ministry of the Environment launched a national program, "Identification of Formations and Structures for Safe Geological Storage of CO_2, together with their Monitoring Program", conducted by the Polish Geological Institute [1]. The aim was to identify storage opportunities that meet the feasibility, safety and environmental impact requirements specified in the draft "EU Directive on the geological storage of carbon dioxide". This detailed and comprehensive project covered detailed geological characterisation of potential sites, simulation modelling for CO_2 injections, risk assessment and development of monitoring programs. The study's outcome was the creation of an interactive atlas and database for potential CO_2 storage sites. A total of 45 aquifer structures with storage potential were identified across 8 regions. Four detailed case studies were also performed on selected aquifers. Numerous wells penetrate the formations where the aquifers reside and were used to provide insight into aquifer quality in the study. Both volumetric and dissolved storage potential were reported in the study. The study also identified 38 oil and gas fields for potential storage, although only 14 exceed the CSRC minimum threshold of 10Mt of storage resource. Unfortunately, permission to use this data in the CSRC was not provided during Cycle 4. Therefore, the values reported in the CRSC are from other sources in the public domain. The report is, however, accessible in the public domain, and references are provided so interested parties can access the additional information.

CCS4CEE

Poland was part of the CCS4CEE [2] project funded by the EEA and Norway grants. The project aimed to renew the discussions on the long-term deployment of CCS in the CEE (Central and Eastern Europe) countries and assess the potential for CCS in terms of transport, geological storage, regulations, knowledge, and government support. Poland was identified as a potential CO_2 Storage hub for neighbouring countries due to its significant storage potential, estimated between 10.1 and 15.5Gt and comparatively much lower annual emission levels, which allows it to have spare resources.

Poland was also part of CO_2StoP [3], GeoCapacity [4], and GESTCO. GeoCapacity provided resource estimates in Mesozoic aquifers at the regional scale (Lower Cretaceous – 7,647 Mt, Lower Jurassic – 43,826 Mt, Lower Triassic – 26,494 Mt) and for selected 18 geological structures (3,522Mt). Storage resources were calculated for Polish hydrocarbon fields using a 1:1 volumetric replacement of hydrocarbons with supercritical CO_2, estimated at 764.32 Mt.

16.4 Resource Review

16.4.1 Major Projects

No major storage projects exist in Poland. However, despite regulatory challenges, Poland has continued to conduct research and develop projects along the full CCS value chain, thereby developing technological expertise. Finished projects include research and development projects by Polish research institutes, two much larger scale CCS projects that were abandoned in 2011 and 2013, and a pilot project conducted for carbon capture from coal-fired plants and CO_2 Methanation by Tauron Polska Energia S.A. Ongoing projects included a capture and storage project in the Borzecin gas reservoir managed by the Polish Oil Mining and Gas Extraction and a capture and utilisation project designed by IchPW for CIECH Soda Polska. Planned projects include CCS applied to the CHOP station in Przemyśl and the Poland EU CCS interconnector project [5].

16.4.2 Depleted Oil & Gas Fields

The Polish Geological Survey assessed 38 depleted hydrocarbon fields. Due to permissions restrictions on the use of the publications that these fields are reported in it has not been possible to include each individual field in the CRSC. There they are summarized below. These fields are situated in two major petroleum provinces: the Carpathian overthrust and the Carpathian Foredeep, with target storage formations in Neogene, Miocene, and Cretaceous formations, and Western Poland, where the predominant fields are Permian Zechstein—Rotliegend fields. Storage potential has been assessed to be in the range of 784-1021 Mt.

Storage resource was calculated using the approach of the FP5 GESTCO project, which was based on the assumption of 1:1 volumetric replacement of extracted hydrocarbons with supercritical CO_2. Such an approach refers to effective resources, albeit a very preliminary one.

In the southeastern part of the Carpathians and Carpathians Foredeep, 12 gas fields were considered, resulting in storage resources ranging from 4.1Mt (Uszkowce Field) to 244.57Mt (Przemyśl Field). The GeoCapacity project refers to the total storage in this region of 421Mt, which is mainly found in Paleocene and Miocene formations.

In Western Poland (in the basement of the Polish Lowland), 13 Permian gas fields were estimated to carry a total storage resource of 240Mt, ranging from 2.41Mt (Gorzyslaw) to 92Mt (Zuchlow).

The offshore region in the Baltic Depression has only minor potential.

16.4.3 Saline Aquifers

The Polish Geological Study applied methodology used by the FP6 EU GeoCapacity Project combined with the parameters outlined in the CO_2 STORE Project (Chadwick et al., 2008). They provide a volumetric and dissolved storage resource that can be accessed in the publication. Sites were assessed in Mesozoic, Miocene, Carboniferous, Permian saline aquifers, and the Carpathian Front (Basement). Four sites were selected for more detailed injection simulations: Budziszewice-Zaosie (Bełchatów), Skóczow-Czechowice (USB), Choszczno-Suliszewo (NW Poland), Poznań trough (Greater Poland).

The German-Polish Lowlands basin (Permo-Mesozoic European Platform) has the following saline aquifer sites:

- Lower Cretaceous Barremian-Albian sandstones and carbonate sandstones are intercalated with low permeable siltstone and mudstone. The formation outcrops at the surface and then descends to depths of over 2800 m in the basin centre. At the basin's centre, sediment thickness can reach 500m.
- Lower Jurassic resources include Toarcian and Upper Pleinesbachian aquifers. The upper Toarcian (Borucice beds of the lower Aalenian Sandstone present one of the better aquifers and are sealed by Upper Aalenian claystone-mudstone. The second, deeper aquifer is related to Upper Pliensbachian (Slawecin Serie) and is sealed by Lower Toarcian claystone-mudstone. This aquifer is found at the surface through to depths of 3900m at the basin centre.
- Lower Triassic resources are found in the middle Buntersandstein sediments, which are sealed by the Roethian clastic-carbonate-evaporatic sequences. Suitable units for storage are found at depths of 1500 - 5300m in the basin centre to several hundred meters at the basin margins.

Within the Polish Lowland area, several anticlines have been identified as sites for potential CO_2 storage. The largest structure (Bodzanov) has an estimated resource of 575.5Mt, while the smallest structure (Chabowo-T) has an estimated resource of 69.3Mt. These structures have Lower Cretaceous, Lower Jurassic, and Lower-Upper Triassic formations. Significant potential may be found in some of these structures.

To summarize, 25 structures have been identified in the Polish Lowlands and all have been drilled to some extent.

Coal Fields

Although the CSRC does not include non-conventional storage estimates, Poland does have significant potential in its coal beds. In addition to saline aquifers and depleted hydrocarbon fields, there is also theoretical storage of methane in the Upper Silesian Coal Basin. A total storage of 1254 Mt is estimated. A further 27 coal fields were selected for assessment, mainly in the southern part of the basin. These are 1-2 km deep and demonstrate a good seal in the overburden. For these fields, a total CO_2 storage resource of 414.6Mt is estimated.

16.5 Regulatory Framework

Poland has been identified as having a CCS readiness index of 45 by the GCCSI. As part of the EU, Poland has a committed NDC (Nationally Determined Contributions) to remove 3,278 Kt of CO_2 equivalent from 2026-2029 and reduce emissions by 17.7% by 2030. The most significant regulatory barrier for Poland's potential CCS industry is that onshore CO_2 storage is prohibited. There is hope that future amendments will address these issues. However, other limitations are high financial security, a state that does not provide any support scheme for CCS or having CCS and climate strategies high up the agenda. These factors will restrict the development of CO_2 storage sites to only the largest corporate organisations. Poland is considering export options for CO_2 to the North Sea and being part of the EU CC Interconnector project, ECO_2CEE, to transport CO_2 to Lithuania. The CCS4CEE project identified limited natural and infrastructure barriers to CO_2 storage and CCS technology development.

Several changes to CCS technology in Poland happened during 2021/2022, including law amendments, future project announcements, research, and the creation of the Minister of Climate and Environment. The reports from the CCS4CEE project detail these changes, comprehensive road maps, and recommendations for enabling future deployment of CCS projects in Poland [2].

16.6 Issues for the Assessment

Although the detailed Polish Geological Society report thoroughly evaluates the storage potential in saline aquifers and depleted hydrocarbon fields, only a few project-based flow models exist. Permission to include this data was requested during Cycle 4, but no response was received. The historic lack of government momentum for CCS has limited further research. Most sites are assessed at volumetric storage resources.

16.7 Future Updates

16.7.1 Future evaluations

Published evaluations for the sites currently active in Poland would be welcome for future updates to the CSRC. If Poland's regulations change, more projects may commence, allowing better insight into the potential future of the CCS industry in the country.

16.7.2 Future CSRC cycles

Future update cycles will need to focus on any projects being developed and the associated storage sites that include them. Any changes in CCS regulations will need to be reviewed to assess how they may change the face of Poland's CCS industry.

17 Romania

17.1 Summary

Romania was assessed for the CSRC in Cycle 4. A summary of the CO_2 storage resource is shown in the Table below.

Classification	CO_2 storage resource (Gt) Project and no project	CO_2 storage resource (Gt) Project specified only
Stored	0.000	0.000
Capacity	0.000	0.000
Sub-Commercial	0.425	0.000
Undiscovered	18.000	0.000
Aggregated*	18.425	0.000

* 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 17-1: Storage resource classification summary for Romania

- Published databases of CO_2 storage potential in Romania indicate significant storage resources are present in saline aquifers and depleted hydrocarbon fields.
- Storage in saline aquifers is predominantly in onshore formations, with limited storage identified in the offshore sector.
- Both depleted oil (seven fields) and gas (seven fields) fields have been identified as having storage potential. Some of these, for example, the Copsa Mica depleted gas field, are significant storage resources at 100Mt.
- The Getica CCS project, a demonstration project planned to decarbonise a lignite coal-fired power station with storage in local saline aquifers, was proposed in 2011 to capture and store 1.5Mtpa CO_2. The project was put on hold due to a lack of funding for capture FEED and storage appraisal studies and has not been re-started.
- CO_2 storage follows the EU approach to CO_2 storage, having transposed the EU CCS Directive; however, the national legislation for CCS in Romania remains somewhat fragmented.

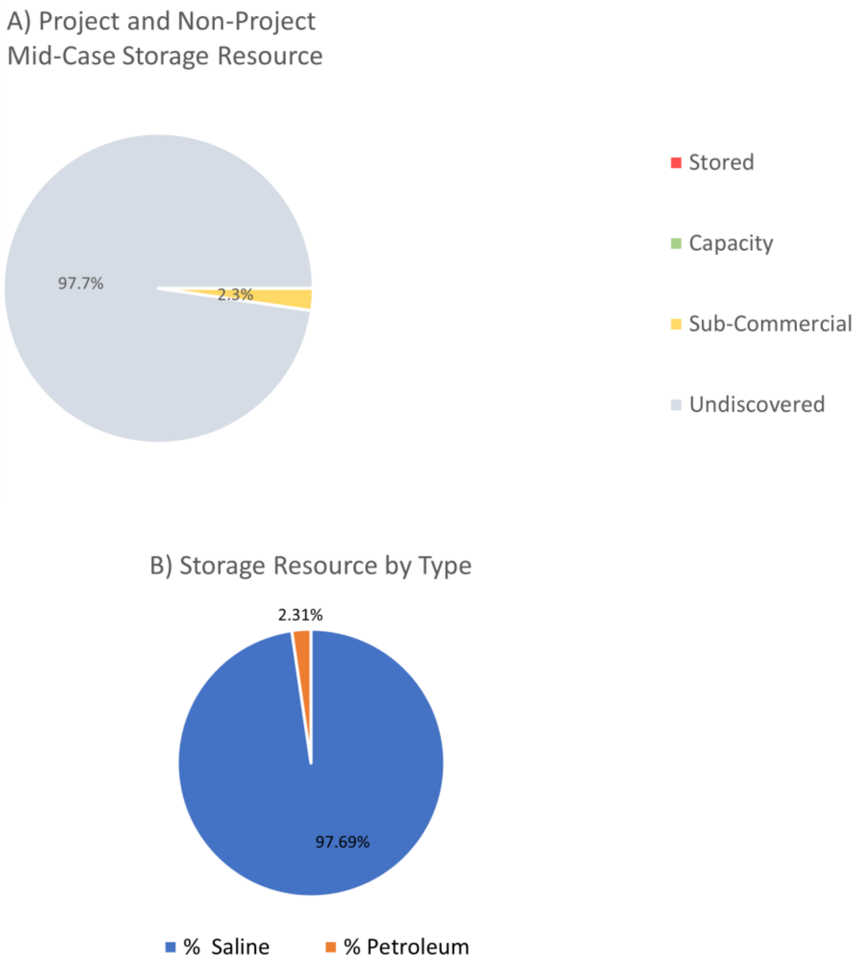


Figure 17-1: Romania Spread of Storage Sites

a) Spread of storage resource in all Romania sites across SRMS classifications; both project specified and not. b) Split of Polish storage resource between saline aquifers and hydrocarbon fields, both project specified and not. Note: due to the large variance in size of values, numbers in pie plots do not add up to 100.

17.2 Resource Statement

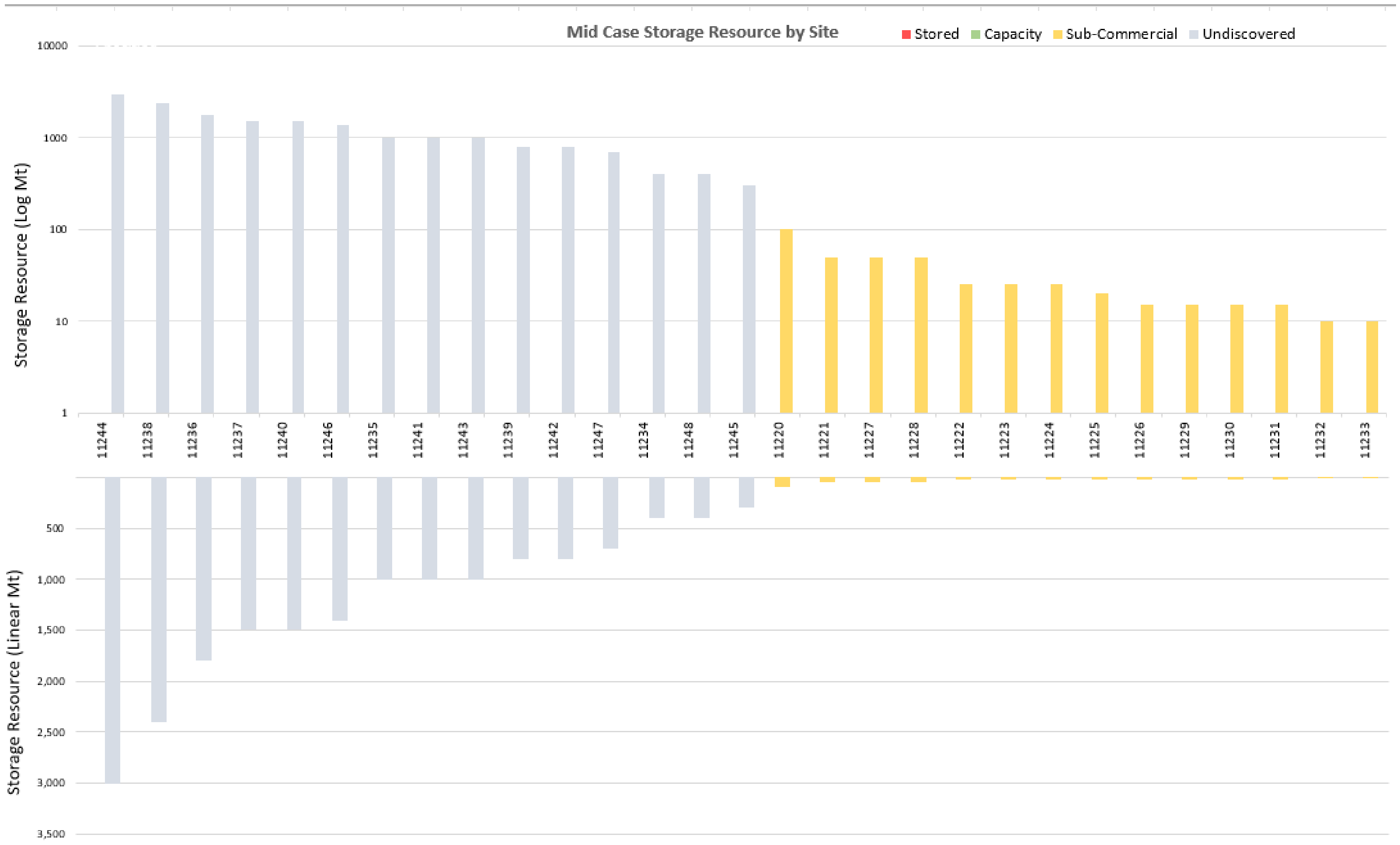


Figure 17-2: Storage resource summary for Romania compiled in the CSRC.

Graph above is log scale and graph below is linear. Green box highlights sites where a project has been specified.

17.3 Evaluation History

CO_2 storage potential in Romania was evaluated by the EU GeoCapacity project (2009) [1], and this remained the dominant source of storage estimates until a second EU Commission-funded project, 'Assessment of CO_2 storage potential in Europe' [2], was published. This project covered storage potential in 27 countries, including Romania. Project products include a detailed report and accompanying storage resource database. However, the data from EU GeoCapacity was re-used for sites in Romania in all but a single case due to a lack of available subsurface data to refine the storage estimates. The data presented by CO_2SToP have been utilised for the CSRC in preference to the EU GeoCapacity project reports as a more detailed report on the technical approach is provided and storage resource estimates for individual storage sites are reported.

The EU GeoCapacity project identified Romania as having high storage potential in saline aquifers (up to 1900 Gt) and high (up to 4 Gt) potential in depleted hydrocarbon fields. The CO_2SToP database downgraded these storage estimates, with the storage resource within hydrocarbon fields decreasing to 514 Mt, with an even split between depleted oil and gas fields.

Mapping of emitters and storage opportunities for the Federatia Patronala Petrol si Gaze (FFPG; 2022) identified six main areas of interest: Gorj, Dolj, Galati-Buzau, Prahova, Mures, and Valcea but also utilised EU GeoCapacity storage resource figures with no additional refinement.

The EU-funded 'Strategy CC(U)S' project (2019-2022) evaluated Romania as part of the effort to develop low-carbon energy and industry in Southern and Eastern Europe. The Galati region in eastern Romania was selected as a potential CCS cluster development, matching one of the largest industrial emitter clusters (emissions over 121.5Mtpa from 42 major industrial installations) with unnamed depleted hydrocarbon fields (offshore and onshore) and saline aquifers.

The Rex-CO_2 [3] consortium project also focused on the Salonta, Oltenia, depleted gas field as an example of a 'typical' depleted field in the region. No CCS project has been associated with the Salonta field, but it provides a case study for potential well re-use.

17.4 Resource Review

The reported storage resources are located within saline aquifers and depleted hydrocarbon fields.

The CO_2StoP project applied a methodology in which storage units were mapped at the reservoir formation level. To qualify as a storage unit, the formation had to be part of a formation present at depths >800m and have an effective caprock. At the sequence level, storage units are saline aquifers considered to have potential for CO_2 storage but may also contain one or more 'daughter units', which are defined as structural or stratigraphic traps or oil and gas fields.

Note: different volumetric storage estimation methods were used for each storage type (unit, daughter structural/stratigraphic unit, depleted field):

- Storage units: A pore volume-based approach using CO_2 density at anticipated reservoir conditions and a selected storage efficiency factor. The daughter unit pore volume is subtracted before the mass of CO_2 is calculated.
- Structural and stratigraphic traps: A probabilistic estimate of storage in all daughter units was calculated using either the volumetric (with storage efficiency) approach or a pressure capacity approach (where data are available), whereby the maximum allowable pressure increase and rock/fluid compressibility are applied.
- Depleted fields: storage potential is based on a reserves replacement approach using the Ultimately Recoverable Reserves (URR). The URR is divided by either the oil or gas formation factor and translated to CO_2 mass using the anticipated CO_2 density at reservoir conditions.

17.4.1 Major Projects

Since the failure of the Getica CCS Demonstration project (see below), there have been no further developments in the country. As such, no publicly announced major projects are currently under development, but this should be reviewed in the future.

17.4.2 Depleted Oil & Gas Fields

Romania has had an active hydrocarbon industry for over a century (FPPG, 2022), resulting in existing infrastructure (pipelines, wells) and expertise in developing large-scale surface-subsurface projects. The total storage resource in depleted fields is estimated to be 514 Mt, with an even split of 246.78 Mt in oil fields and 267.56 Mt in gas fields (EU CO_2 Storage Potential database) [2]. However, not all fields included in this estimate meet the 10Mt threshold for the CRSC.

The CSRC database's data are derived from the original EU GeoCapacity study, as no follow-up studies (e.g., CO_2StoP) were able to access sufficient data to update the storage resource estimates.

Seven gas fields (out of nine named fields) have been identified as carrying greater or equal to the threshold 10 Mt storage resource estimate, the largest being the Copsa Mica field (100 Mt), the Ghergheasa field (50 Mt) and the Targu Mures Dome, Sangeorgiu de Padure, the Stramba-Rogojelu fields (all at 25 Mt).

Seven (7) oilfields (out of 22 named fields) also qualify for inclusion in the CSRS, although these are slightly smaller. The largest are the Baeni and Bibesti-Bulbuceni oil fields, with a 50 Mt estimated storage resource.

17.4.3 Saline Aquifers

Most of Romania's storage resources are in onshore saline aquifers, with Gigatonne-scale storage predicted. Published figures for offshore resources suggest limited opportunity, with three Albian-age clastic aquifers identified (Strategy CCUS, 2020) estimated to hold a combined 17Mt storage resource, but individually, none exceed 7Mt.

At the time of Cycle 4, only data at the sequence level (utilising the CO_2StoP storage unit resources) were available for saline aquifers. No individual structural or stratigraphic traps (daughter units) were identified.

17.4.4 Demonstration and Pilot Projects

The Getica CCS Demonstration project, decarbonising a lignite coal-fired power station with storage in local saline aquifers, was proposed in 2011 and was able to align public and private support while also encouraging the development of a legislative framework for CCS in Romania. This was due to be the first integrated CCS project in the country. The project was due to be operational by 2015/16 with a project lifespan of 14 years. Up to 1.5Mtpa CO_2 was to be captured from the Turceni plant Unit 6 through retrofit of a capture unit. The project was eventually put on hold due to a lack of funding for capture FEED and storage appraisal studies and, to date, has not been re-started.

17.5 Regulatory Framework

Romania has transposed the EU CCS Directive via Government Emergency Ordinance (GEO) 64/2011, Art.22. This gave CCS Regulation implementation authority to the National Regulatory Authority for Energy (ANRE) and the National Agency for Mineral Resources (ANRAM). However, according to a recent study for FFPG by PwC and EPG Consulting in 2022 (FFPG, 2022) [4], the national legislation for CCS in Romania remains rather fragmented.

17.6 Issues for the Assessment

A key issue for the assessment of storage potential in Romania was the limited information in the public domain. While the potential resources have been reviewed over the past 15 years, the published estimates have not been updated since 2009. Given the basin and sequence level scale and volumetric storage resource methodology, they are almost certainly an overestimation.

17.7 Future Updates

17.7.1 Future evaluations

Future storage evaluations should focus on accessing and utilising subsurface data to enable identification and delineation of storage sites. Storage resource estimates must be based on site-specific geo-models and flow modelling using a pressure-limited approach to derive a more realistic range of values.

17.7.2 Future CSRC cycles

If additional site evaluations are performed, these should be submitted to the OGCI CSRC for inclusion in the database. All future submissions should provide storage estimates derived from appropriate dynamic approaches.

18 Slovakia

18.1 Summary

Slovakia was assessed for the CSRC in Cycle 4. A summary of the CO_2 storage resource is shown in the Table below.

Classification	CO_2 storage resource (Gt) Project and no project	CO_2 storage resource (Gt) Project specified only
Stored	0.000	0.000
Capacity	0.000	0.000
Sub-Commercial	0.100	0.000
Undiscovered	11.218	0.000
Aggregated*	11.318	0.000

* 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 18-1: Storage resource classification summary for Slovakia

- Storage resources are reported in saline aquifers and oil and gas fields. The greatest potential exists within deep saline aquifers.

- The Slovakian government passed acts into local Slovak law in 2009 so the country may align with the CCS European Parliament and Council Directives. Slovakian law, therefore, permits CO_2 storage, but federal financial support may be difficult.

- Data mapping and a country-wide assessment were available in the public domain in 2023. The Slovak State Geological Institute and the University of Košice have published findings from 2009 to 2016 in research databases. Slovakia was part of the CCS4CEE project (2021). CO_2

- The most prospective areas for CCUS storage are located within the onshore basins: the Danube Basin in the west and the Transcarpathian Basin in the east. However, the Slovak State Geological Institute has licensed areas for CCUS exploration outside of these basins in the country's central region.

- Ten individual sites with assessed storage potential have been identified in Cycle 4. However, these ten sites don't provide a comprehensive picture of the total storage potential within Slovakia, as some papers discuss storage potential at a country-wide level for saline aquifers or depleted oil and gas fields.

- Slovakia has a score of 48.5 within the 2023 CCS Chart of Legal and Regulatory Indicator system due to the country having specific CCS laws aligning with EU directives.

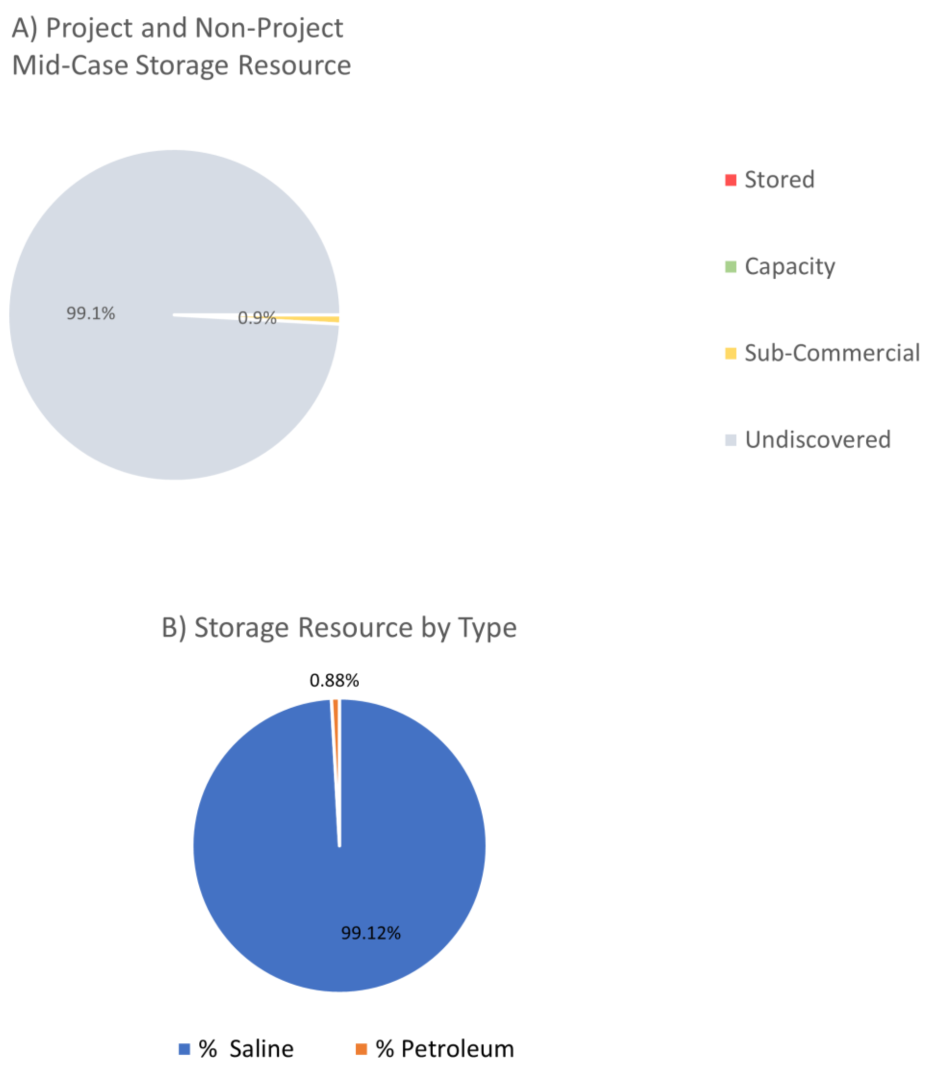


Figure 18-1: Slovakia Spread of Storage Sites

a) Spread of storage resource in all Slovakian sites across SRMS classifications; both project specified and not. b) Split of Slovakian storage resource between saline aquifers and hydrocarbon fields, both project specified and not. Note: due to the large variance in size of values, numbers in pie plots do not add up to 100.

18.2 Resource Statement

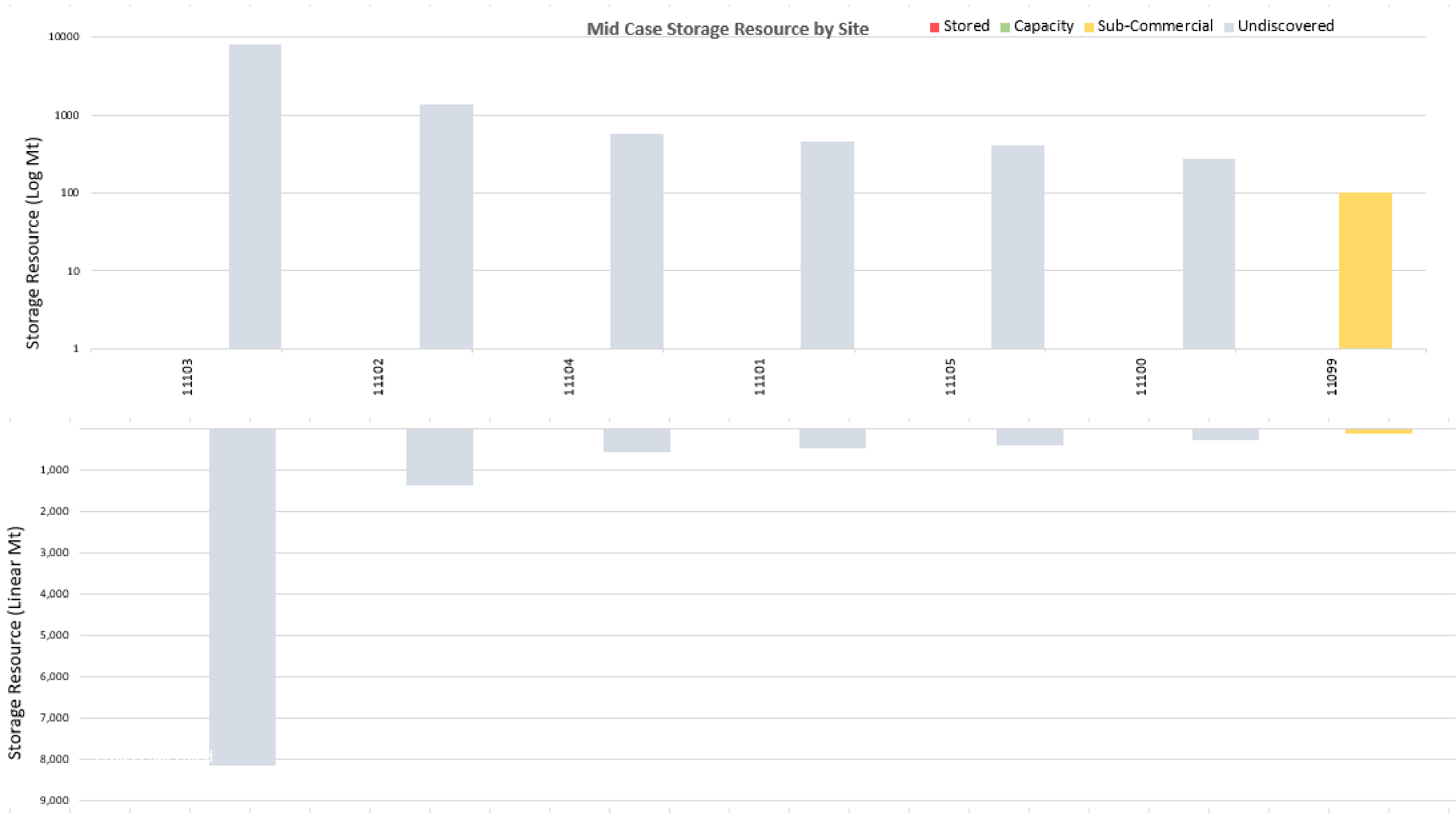


Figure 18-2: Storage resource summary for Slovakia compiled in the CSRC.

Graph above is log scale and graph below is linear. Green box highlights sites where a project has been specified.

18.3 Evaluation History

The first countrywide review for potential CCS storage sites within Slovakia was published in 2009 (Kucharič et al.) [1] as part of the EU Geocapacity Project. Within the East Slovak Basin, the Sarmatian Sandstone and Pannonian Sandstone are quoted as having volumes of 273 Mt and 446 Mt, respectively. Triassic Dolomites within the Bzovik Basin was quoted to have the potential for a volume of 567 Mt. Within the Danube basin; the Pannonian and Pontian aquifers represent potential storage volumes of 1361 Mt and 8165 Mt. 134 Mt were reported resource estimates for oil and gas fields.

In 2011, the preliminary results of a Slovakian national project undertaken by Kucharič et al [2] were published. The paper highlights a range of storage potential between 5 – 15 Mt for the Borovské complex, a conglomerate aquifer located in the Central Carpathians and 100 Mt for the Vysoká-Zwendorf Gas field located in the Vienna Basin and operated by OMV.

In 2016, Pinka et al. [3] published findings for volumes at a country-wide level that dwarf the earlier findings of Kotulová et al. (2009). This latest evaluation by Pinka et al. proposes volumes of 400 – 10,000 Gt for Saline Aquifers and 134 Mt Oil and Gas fields.

The most recent CCUS storage volumes for Slovakia were published in 2021 (Bartovic et al.) [4] by the CCS4CEE project. The paper discusses volumes at a country-wide level, highlighting the potential for 1716 – 13,708 Mt of storage volume in regional saline aquifers and 134 Mt in Oil and Gas fields.

18.4 Resource Review

Within Slovakia, the most identified storage potential is situated within saline aquifers, with only a small contribution from oil and gas fields.

All Cycle 4 entries to the CSRC are classified as undiscovered at the basin and sequence play levels.

18.4.1 Major Projects

At Cycle 4, Slovakia has yet to initiate a pilot CCUS project.

18.4.2 Depleted Oil & Gas Fields

Researchers have only published data specifying storage volumes in the Vysoká – Zwendorf gas field, which is quoted as having 100 Mt of potential storage resource. Beyond this, gross figures for storage volumes associated with oil and gas fields within Slovakia range from 100 Mt – 930 Gt.

18.4.3 Saline Aquifers

Within the East Slovakian basin, the Sarmantian and Pannonian sandstone formations were assessed to have storage estimates of 273 Mt and 446 Mt, respectively. In the Danube basin, published estimates of 1361 Mt and 8165 Mt are cited for the Pannonian and Pontian aquifers. The Bzovik prospect, in the South Slovakian basin, is reported at 567 Mt [1,5].

In 2011, Kucharic et al [3] published storage resource estimates for the Borovské complex located near Aaiun – Tarfaya, which ranged from 5 – 15 Mt. The authors also assessed a volume ranging from 30 – 60 Mt for the Zlata Bana stratovolcano, which is an unconventional prospect within the Trans Carpathian Basin.

18.5 Regulatory Framework

Slovakia has been evaluated as moderate under the 2023 GCCSI CCS with a score of 48.5, which relates to the country's specific CCS laws aligning with EU directives. However, supporting a pilot project will be economically challenging for Slovakia and could hinder future CO_2 storage development.

18.6 Issues for the Assessment

Public domain data and publications detailing methods for calculating storage volumes are limited. This impacts the accuracy of any storage estimates and evaluations underassessment for Slovakia. Due to these limitations, the assessed storage potential for Slovakia in Cycle 4 is considered an inaccurate representation of the available resources.

18.7 Future Updates

18.7.1 Future CSRC cycles

Should any further development in the Slovakia storage systems occur, this should be reviewed annually to ensure the Global Storage Catalogue is current.

19 Spain

19.1 Summary

Spain was assessed for the CSRC in Cycle 4. A summary of the CO_2 storage resource is shown in the Table below.

Classification	CO_2 storage resource (Gt) Project and no project	CO_2 storage resource (Gt) Project specified only
Stored	0.000	0.000
Capacity	0.000	0.000
Sub-Commercial	6.931	0.000
Undiscovered	13.840	0.000
Aggregated*	20.771	0.000

* 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 19-1: Storage resource classification summary for Spain

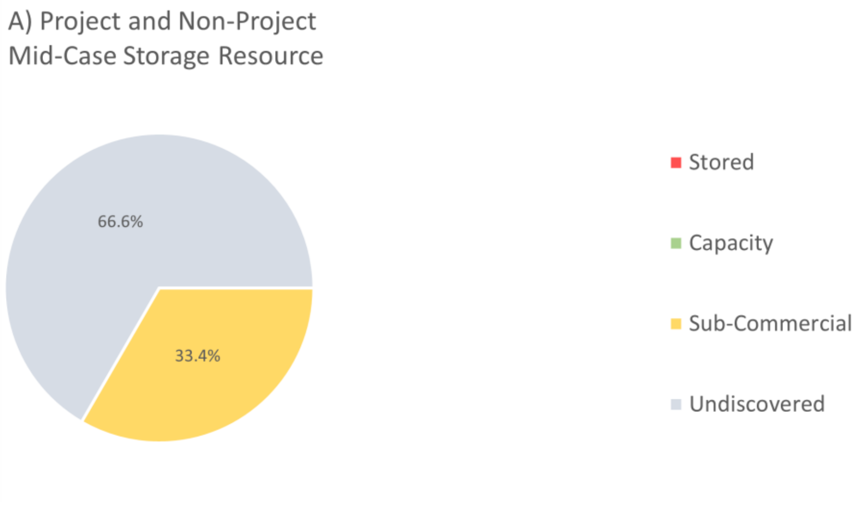
- Spain has been extensively reviewed in early pan-European CO_2 storage projects such as GeoCapacity, ALGECO$_2$ and COMET. Much of these results have been incorporated into a comprehensive CO_2 Atlas published in 2010 by IGME.

- Three pilot projects for CO_2 capture and one for CO_2 storage were developed between 2006 and 2014. However, this trend did not continue. The economic crisis and uncertainty about the role of CCS in the energy transition slowed that momentum and no commercial or demonstration projects are planned in Spain in the near future.

- A total of 91 sites in Spain have been added to the CRSC database In Cycle 4, with the majority located in aquifers. Only one onshore oil field has been considered. Most offshore fields have been designated for gas storage.

- The main aquifers are all onshore in Spain.

- CCS in Spain is currently challenged by its legislation. Although the EU Directive 2009/31/CE was transposed to Spanish legislation, it has not been accepted at a regional level, which prevents projects from being permitted.



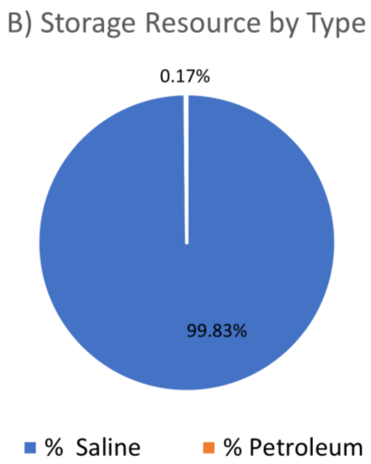


Figure 19-1: Spain Spread of Storage Sites

a) Spread of storage resources in Spain, all Spanish sites across SRMS classifications; both project specified and not. b) Split of Spanish storage resource between saline aquifers and hydrocarbon fields, both project specified and not. Note: due to the large variance in size of values, numbers in pie plots do not add up to 100.

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19.2 Resource Statement

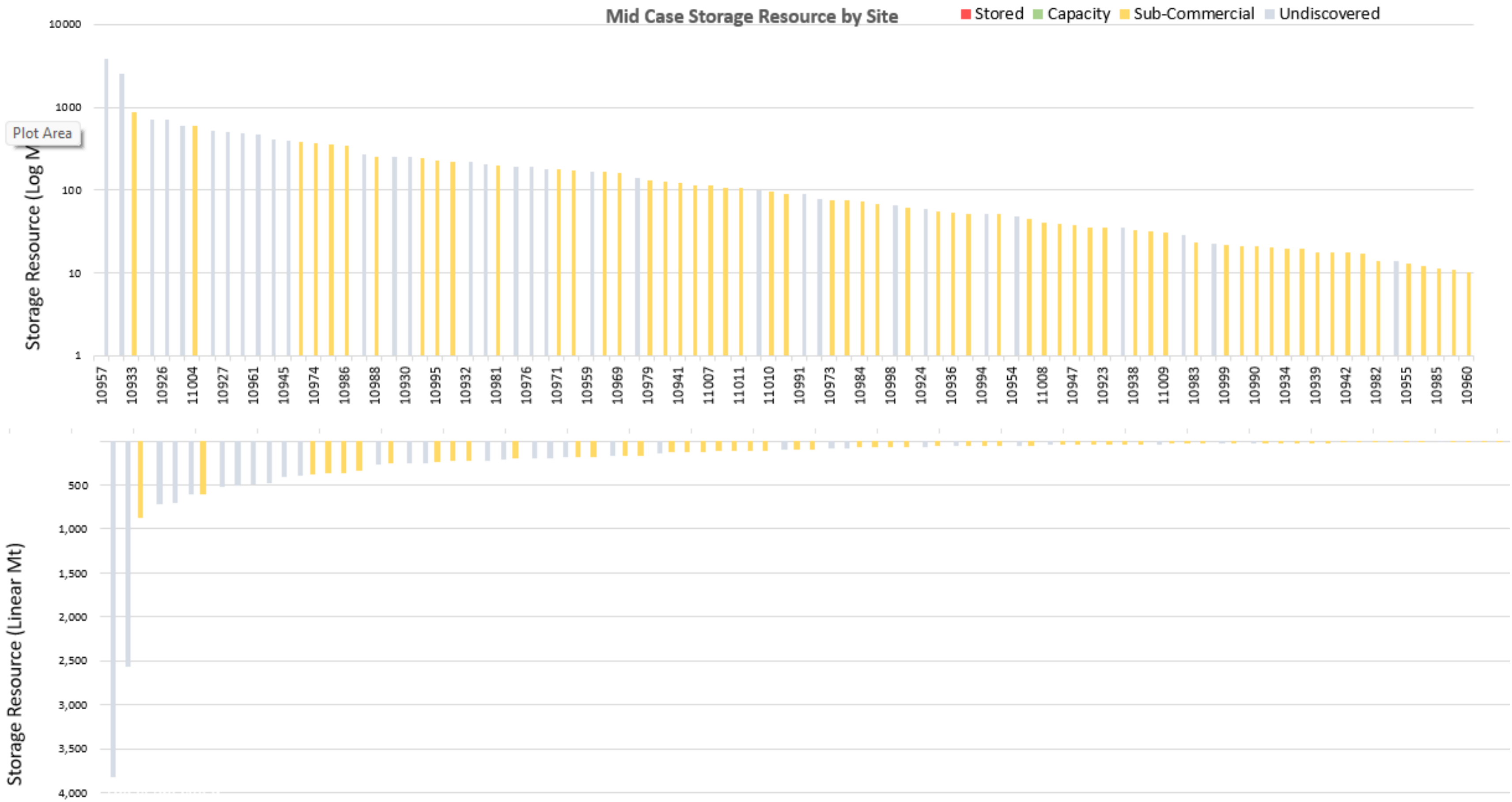


Figure 19-2: Storage resource summary for Spain compiled in the CSRC.

Graph above is log scale and graph below is linear. Green box highlights sites where a project has been specified.

19.3 Evaluation History

The evaluation of CCS potential in Spain started with the GeoCapacity project (2006-2009), which reviewed CO_2 storage in deep saline aquifers and hydrocarbon reservoirs. The assessment revealed a total storage resource of 14 Gt, almost entirely in deep saline aquifers.

Subsequently, the Spanish Geological and Mining Survey (IGME) conducted the ALGECO2 project (2009–2010) to mature the characterisation of potential storage structures in Spain and create a CO_2 storage atlas, IGME (2009). Martínez del Olmo (2019) [1] revisited the characteristics of these favourable structures and improved the results by complementing the inventory for all of Spain with the offshore saline aquifers. These have all been included in the CSRC catalogue.

From 2010 to 2013, the COMET project aimed to identify and assess the most cost-effective CO_2 transport and storage infrastructure available to serve the West Mediterranean area, including Portugal, Spain, and Morocco [2]. The overall strategy of COMET comprised four fundamental tasks, including the complete inventory of present and future CO_2 sources and sinks in the region, cost modelling of national and regional energy systems, the in-depth assessment of selected transport networks, and the dissemination of the information. Based on the results of the COMET project, a further study conducted an injection rate and cost assessment for CCS development in the West Mediterranean area. It concluded that about 11–15 clusters of 43 storage prospects defined in the study area are cost-effective, depending on the emission mitigation scenario [3].

A recent study presented a novel source-to-sink assessment methodology based on a hubs and clusters approach to identify favourable regions for CCS deployment and attract renewed public and political interest in viable deployment pathways [4].

All evaluations are based on a volumetric approach as defined by the EU GeoCapacity study. Many sites are classified as Discovered due to the presence of wells as detailed by the ALGECO2 project. However, whilst the EU Directive 2009/31/CE was transposed to Spanish Legislation, it has not been accepted at a regional level which prevent projects being permitted and as such all sites are classified as inaccessible.

19.4 Resource Review

Different subdivisions of the Spanish sedimentary basins for the CO_2 storage resource estimation have been applied in different studies. CO_2

The GeoCapacity project gave an overall resource estimation of 35Mt in depleted hydrocarbon fields and 14.3Gt (14,300 Mt) in regional aquifers. Spain also carries some storage potential in non-conventional storage with an estimated 200Mt held in coal beds. The storage resource was based on a volumetric approach using the methodology of Brook at al., 2003 and Bachu et al., 2007 [11]. All subsequent studies have also used and validated the storage resource values published by both this study and ALGECO2 projects.

Due to the current legislation status in Spain, CO_2 storage is not permitted; hence, all sites are classified as Inaccessible.

19.4.1 Major Projects

There are a total of four carbon capture projects in Spain, with only one being a pilot CO_2 storage project and another a research project. No CCUS projects are running or planned for the near future in Spain.

The Compostilla project [5] was a proposed circulating fluidized-bed (CFB) oxyfuel CCS demonstration project. Captured CO_2 was to be stored in nearby onshore saline formations in the Duero basin. The injection trial site of this project was at the Hontomin storage site. Phase I of the project received EU EEPR funding of up to EUR 180 million (Dec 2009), and partners Endesa, CIUDEN and Foster Wheeler signed contracts with the EU Commission in May 2010. Phase I delivered a 30MW pilot, transport and storage pilot trials and a FEED Study. The FEED Study was completed and published in 2013. FID was expected before the end of 2013, but the partners decided not to proceed with the demonstration project. The injection pilot project at Hontomín was put on hold in 2018 due to political and administrative reasons [6].

The Elcogas project, run by ELCOGAS S.A., developed a precombustion CO_2 capture and H2 production pilot plant with a 335 MW Integrated Gasification Combined Cycle (IGCC). It was built in Puertollano, an old industry centre for hydrocarbon refinery and processing in Central-SW Spain [7]. The power plant, along with the CO_2 capture and H2 production plant, was shut down in 2016 due to accumulated debt.

The La Pereda pilot, located in NW Spain on the site of the coal-fired La Pereda power plant, was developed by a consortium of national and international partners, including Endesa Generacion, Hunosa, Foster Wheeler, and CSIC (the Spanish National Research Council) and commenced in 2009. This project received EU funding through three projects: CaOling (2009–2013), ReCaL (2012–2015), and CaO2 (2014–2017). The operating company, Hunosa, is converting the La Pereda power plant to be biomass-fueled, but there is no update about the reuse of the capture pilot facility [4].

The CARBOLAB project was an RFCS 4-year project aimed at gathering and analysing the effects of CO_2 injection in coal at a panel scale in an existing underground coal mine in the north of Spain.

19.4.2 Depleted Oil & Gas Fields

In Spain, the possibility of storing CO_2 in depleted fields or in depleting oil and gas is of little relevance due to the scarcity of hydrocarbon resources. Added to this is that the few hydrocarbon fields exploited are being used for natural gas storage [8]. Hence, the estimated 35 Mt storage resource of CO_2 [1] is entered in the database as a single entry and not field-specific since CO_2 storage potential has been refined across individual fields.

19.4.3 Saline Aquifers

A total of 12 basins with 103 traps within saline aquifers are considered suitable for CO_2 storage. Most are located in the Mesozoic – Cenozoic basin onshore and 5 offshore. For the GeoCapacity project, Spain storage structures were divided into 4 geologic onshore domains:

1. Cadena Ibérica & Submeseta Meridional.
2. Cadenas Beticas & cuenca del Guadalquivir
3. Pyrenees and Ebro Basin
4. Cadena Cantabrica & Duero Basin

According to the IGME Atlas, most, if not all, designated saline resources were tested by mostly unsuccessful hydrocarbon exploration drilling campaigns between the 1950s and 1980s.

19.5 Regulatory Framework

The EU Directive 2009/31/CE was transposed to Spanish Legislation as Law 40/2010 on 29 December 2010 on the geological storage of carbon dioxide, but the development of specific regulations to tackle each project case has not been carried out to date [9]. Due to control of regional jurisdiction in Spain, whilst accepted on a national level, the directive was not incorporated into regional law. Hence the permitting of injection of CO_2 for storage is not yet possible at the regional level. In the case of Hontomín, this was passed for research purposes as the study was considered a pilot at under 10Mt and is regulated by Mining Law 22/1973 (Spanish Law 22/1973, 1973) [9]. The absolute laws relating to CO_2 storage in Spain are unclear and fluid; hence, prospective storage development would need clarity on the legal status, depending on the region in question. Spain scores 43.5 on the CCS readiness scale as defined by the GCCSI [10].

19.6 Issues for the Assessment

No offshore reservoir characteristics and CO_2 storage specific papers have been found. The papers of Martinez del Olmo (2019) and Sun et al. (2021) mention the potential for offshore hubs for CO_2 storage but provide only limited information. Most structures require new data acquisition since the data is limited to old seismic data and wells drilled for hydrocarbon exploration.

19.7 Future Updates

19.7.1 Future evaluations

Future evaluations should seek to address any updates to legislation and, if this has changed, to encourage any projects or research.

19.7.2 Future CSRC cycles

Should any further development in Spanish legislation occur, key onshore and offshore sites should be reviewed to establish if any have progressed to a project level.

20 Sweden

20.1 Summary

Sweden was assessed for the CRSC in Cycle 4. A summary of the CO_2 storage resource is shown in the Table below.

Classification	CO_2 storage resource (Gt) Project and no project	CO_2 storage resource (Gt) Project specified only
Stored	0.000	0.000
Capacity	0.000	0.000
Sub-Commercial	1.583	0.200
Undiscovered	1.786	0.700
Aggregated*	3.369	0.900

* 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 20-1: Storage Resource Classification Summary for Sweden

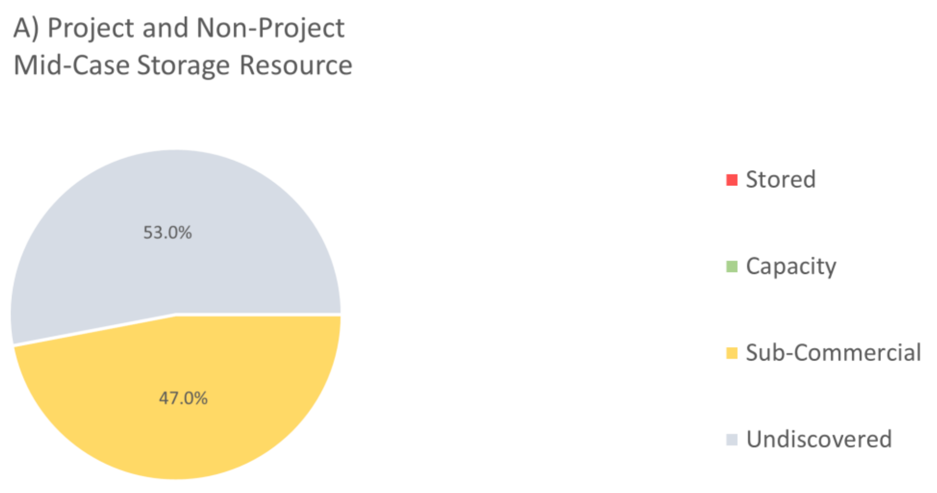
- A storage resource is reported to be present in saline aquifers. Sweden has a limited history of hydrocarbon exploration and production; however, no depleted fields have been identified as having storage potential.

- Evaluation of potential storage sites began in 2011 by the Swedish Geological Survey. SLR Consulting assessed Sweden as part of the BASTOR project in 2013 [1] and evaluated storage estimates based on the GeoCapacity method. Sweden was also part of the Mustang project (2009-2014) (EU, ID: 227286) [2] run by the EU grant project Coordinated by Uppala University and also SwedeSTORECO_2, [3], a pre-feasibility study to store CO_2 in Sweden (2012-2013). Further assessments in 2014 applying the EU GeoCapacity methods were used to compile the NORDICCS Nordic CO_2 Storage Atlas (2011-2015 [4]) (Anthonsen et al., 2014) [5]. Studies have also been undertaken to assess selected storage sites using probabilistic and dynamic modelling methods [1, 6].

- A total of 12 potential storage units have been identified in Sweden in the south-east Baltic Sea and south-west Scania. Both areas underwent drilling and seismic surveys in the 1970s-80s for hydrocarbon exploration. The Middle Cambrian Faludden aquifer (South East Baltic Sea) and the Early Albian-Cenomanian Arnager Greensand aquifer, and the Jurassic Höganäs-Rya aquifer (South West Scania) are the most promising units. Additional units in the Baltic include early Palaeozoic aquifers, and in the Scania area, aquifers in formations from the Triassic, Jurassic, and Early Cretaceous have been identified.

- Sweden has no active CCS projects within its borders. Sweden is involved in carbon capture projects through BECCS but favours storage options in adjacent Nordic countries with more CO_2

storage and hydrocarbon production expertise. Since March 2014, geological storage of CO_2 has been permitted in Sweden [7].



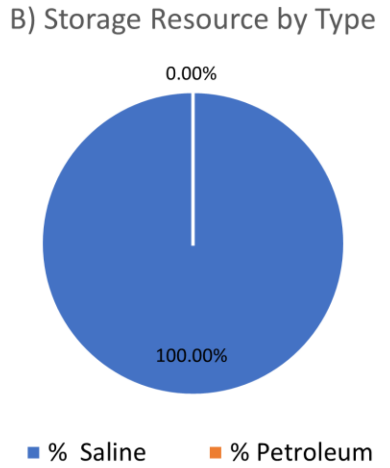


Figure 20-1: Spread of Swedish Storage Sites

a) Spread of storage resources in Sweden Sites across SRMS classifications; both project specified and not. b) Split of Swedish storage resources between saline aquifers and hydrocarbon fields, both project specified and not. Note: due to the large variance in size of values, numbers in pie plots do not add up to 100.

20.2 Resource State

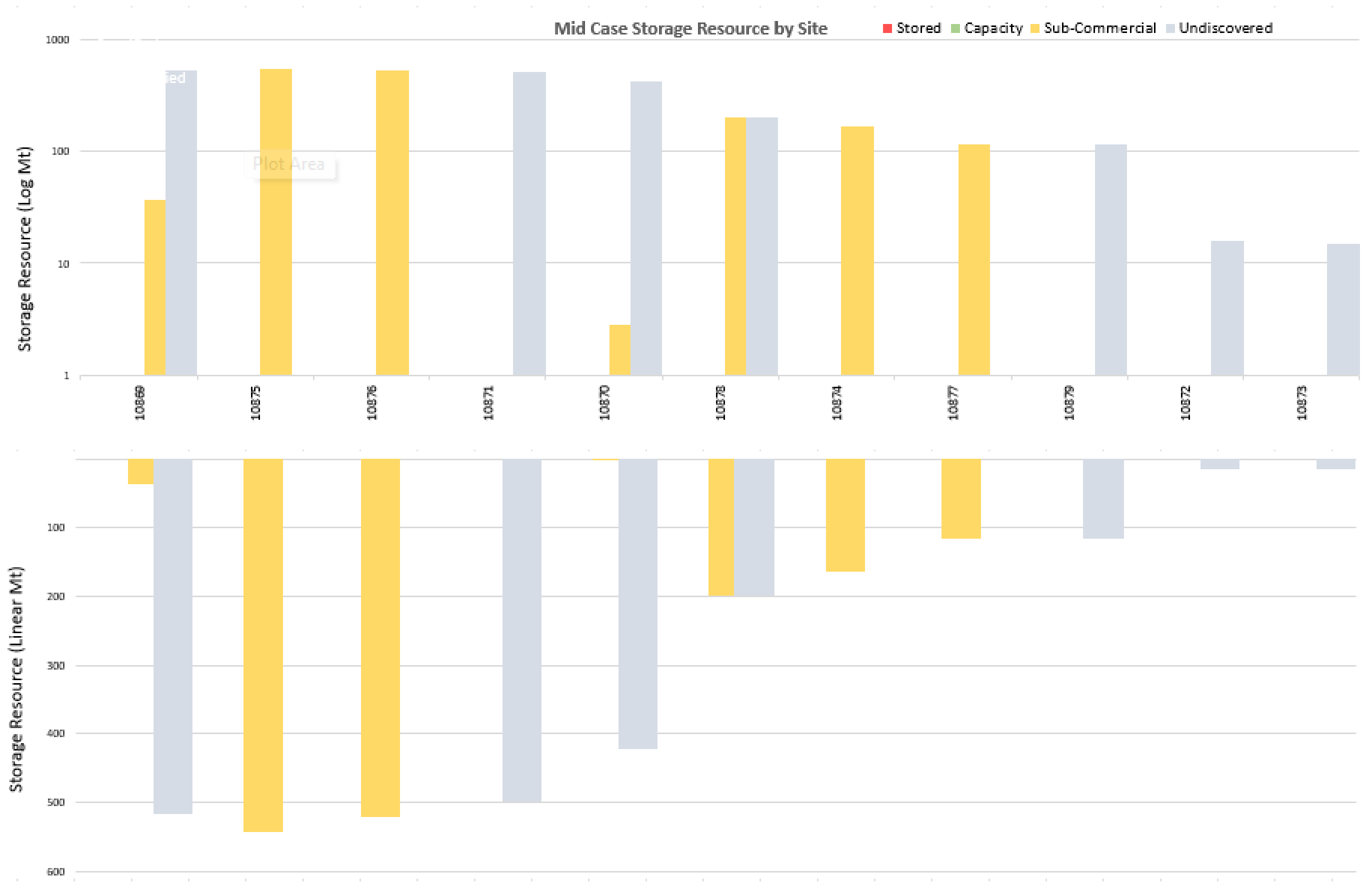


Figure 20-2: Storage resource summary for Sweden compiled in the CSRC.

Graph above is log scale and graph below is linear. Green box highlights sites where a project has been specified.

20.3 Evaluation History

The first evaluation of potential storage resources in Sweden began in 2011 and was performed by the Swedish Geological Survey (SGU), Anthonsen et al., (2013) [8]and Erlström et al. (2011) [9]). This research identified three suitable areas (deep saline aquifers), all situated in the offshore southernmost area of the Sweden Baltic Sea. They used the USDOE assessment methods to evaluate Cambrian aquifers, which included the Viklau, När and Faludden sandstones. The study estimated the effective CO_2 storage potential in structural closures to be approximately 100 Mt and the effective storage resource for the Faludden stratigraphic trap between 0.4 Gt and 4.5 Gt [1].

Further assessment in the offshore area of the Southwest Skåne revealed suitable aquifer seal pairs. No structural traps were identified; however, 3 potential aquifer units were identified: the Lower Triassic Bunter and Ljunghusen, the Uppermost Triassic to Hettangian Höganäs Formation and the Lower Cretaceous Arnager Greensand. The estimated CO_2 storage resource in the Triassic aquifer is 750Mt, the Jurassic sandstone 4.5Gt and the Cretaceous sandstone 5Gt. However, there was great uncertainty about these estimates. The last area identified was in the southeast part of the Kattegat Sea, with an estimated 80-150Mt [8].

A regional assessment of the CO_2 storage potential in the Baltic Basin was published as part of the BASTOR project in 2013. Similarly to the SGU project, this study assessed CO_2 storage resources across the Baltic Basin and identified favourable sites for CO_2 storage. However, the study authors (SLR) could use a considerable quantity of proprietary data such as interpretations, maps, seismic and well data. Using the GeoCapacity methodology, this data was used to calculate storage estimates. It identified that the combined storage resource of eight large structural closures in Cambrian saline aquifers was estimated at 761.37 Mt. The study also assessed the total effective storage resource in the Faludden stratigraphic trap to be 1923 Mt [1].

The NORDICCS CCS Competence Centre is a joint task force of the five Nordic countries. A significant project undertaken was the creation of a Nordic CO_2 Storage Atlas, published in 2015. The Swedish component was based on screening and analysing existing wells and seismic data in deep saline aquifers in the Swedish Baltic Sea and Southwest Scania area. The resulting CO_2 storage resource estimates were calculated using volumetric methods based on lithology, volume, net/gross, porosity, permeability, injectivity, reservoir type, salinity, CO_2 density at reservoir conditions, efficiency factor, and cap rocks [5]. The study outcome identified eight deep saline aquifers and one structural trap with a preliminary estimate of total storage resources in Sweden over 3400 Mt. Each formation aquifer was also assessed for its resource and storage efficiency based on the approaches published by the U.S. DOE. Future work from these studies anticipated dynamic modelling and ranking to refine resource estimates.

Mortensen et al., 2014 and 2016 [12,6] continued the NORDICCS review work to rank the most prospective formation and perform static and dynamic modelling on selected sites.

The 2014 study, which used a set of variables with defined optimal ranges for both reservoir (e.g., porosity, permeability, thickness, facies) and seal (e.g., lithology, lateral extent, fault intensity) and additional safety issues, found the Cretaceous Arnager Greensand, Cambrian Faludden and Jurassic Höganäs-Rya formations to be most prospective. Estimated storage resources from the NORDICCS study were used.

The dynamic and static modelling by [6] took the Faludden and Arnager formations into both a static basin modelling assessment and a dynamic simulation approach. Both gave quite differing results, with the static model approach presenting more unfavourable estimates due to the lack of structural trapping in the region. The dynamic approach accounted for more residual trapping. The outcome of these studies continued to support the viability of these storage units for CO_2. However, there are large differences between these studies and the earlier estimates from NORDICCS and SLR. The dependency of a modelling approach on spatial data is a contributing factor here – the areal extent in Mortensen 2016 is limited compared to the volumetric estimates from NORDICCS, SLR, etc.

Sopher et al., 2014 [1] reviewed the main storage units in Sweden – the Faludden, Nar and Viklau sandstones using methods given by the U.S. DOE and U.S. Geological Survey to calculate CO_2 storage resources probabilistically. The Dalders structure, in the southeastern part of the Swedish sector of the Basaltic Sea, has estimated low, mid and high storage resources of 85 Mt, 145 Mt and 224 Mt, respectively, however the majority of storage potential resides in the adjacent Estonian waters. The regional Faludden stratigraphic unit was estimated to have low, mid and high effective storage estimates of 4330 Mt, 5579 Mt and 6962 Mt, respectively.

20.4 Resource Review

20.4.1 Major Projects

There are no major storage projects in Sweden as defined by the CSRC. However, Sweden does have a BECCS project underway in Stockholm, which will export CO_2 to the North Sea for storage [13].

20.4.2 Depleted Oil & Gas Fields

No detailed reviews of storage potential in depleted oil and gas fields are available in the public domain, and no specific calculations have been made yet for the depleted oil and gas fields in Sweden.

20.4.3 Saline Aquifers

Work undertaken evaluating storage potential in Sweden has focused on saline aquifers.

Most of the storage resources for saline aquifers in Sweden are classified as discovered and undiscovered. There are a few wells present in some sites and three sites have simulation studies (Faludden and Arnager sands). Eleven sites with storage estimates exceeding 10 Mt were logged in the CSRC. These sites are located in the Swedish sector of the Baltic basin and the Swedish sector of the South West Scania area. The majority of these estimates are "sequence play". There are no resources onshore.

The Cambrian Faludden formation in the Baltic Sea and Jurassic Höganäs-Rya Cretaceous and Arnager formation in South West Scania are considered to have the greatest promise for storing CO_2. The Faludden is a large homogenous, gently dipping sand unit, an open/semi-closed aquifer covering around 33000km^2. The area of this formation in Sweden is at a suitable depth under 800 m and is 11000 km^2. This is mainly a stratigraphic trap except for Faludden sands in the Dalders Structure. It is capped by a thick multi-sequence set of seals comprising Ordovician – Silurian carbonates, shale, and marlstones [4&6].

The Albian-Cenomanian Arnager Greensands, which cover 5200 km^2, are gently dipping but fault bound northeast by the Romeleåsen Fault Zone and partly fault confined through the remaining distribution. The quality of the sands starts to diminish further North. The Arnager sands are capped by a thick seal of clayey limestone, chalk, and interbedded sands and silts. [4&6]. The quality of these seals is uncertain due to the lack of physical properties [8]. There are limited structural opportunities in this aquifer.

The Jurassic Höganäs-Rya aquifer includes a CO_2 storage potential of around 2100 km^2. It is a very gently dipping semi-closed aquifer, bound in the North by the Romeleåsen Fault Zone. Stratigraphic trap opportunities may exist in lens-shaped sand bodies. The Höganäs-Rya aquifer unit is capped by a regional dense shale layer and further capped with a thick sequence of clay-rich limestone and chalk. (Anthonsen et al., 2014). Regarding fault-related issues (compartmentalisation and reactivation), the southwest Scania area is tectonically more complex than the Baltic Basin.

The Dalders structure, partially located in the southwestern part of the Swedish sector of the Baltic Sea, is the only large structural trap. Despite being a large structural closer with an estimated mid-range resource of 145 Mt, it can only store 1-2 years of Swedish emissions [1]. Due to its location and size, it is unlikely to be feasible to develop CO_2 Storage.

20.5 Regulatory Framework

Sweden is not planning any injection of captured CO_2 into aquifers within its jurisdiction. However, to meet its commitment to carbon neutrality by 2045, Sweden is investing in bioenergy with carbon capture (BECCS) and considering the export of captured CO_2 to permanent storage in Norway. This is due to more favourable geology and greater expertise in CCS operations in Norway than in Sweden [9].

There are no regulatory barriers to exporting CO_2 after the IMO allowed for the application to the amendment of Article 6 of the London Protocol in 2019. Sweden has ratified the 2009 amendment and drawn up proposals with Norway. With respect to storing CO_2 in the future, some regulatory challenges for storing CO_2 in the Baltic Sea could occur, namely from The Baltic Marine Environment Protection Commission Helsinki Commission (HELCOM) and Natura 2000 [10]. Sweden scores 56 in the 2023 CCS Legal and Regulatory indicator (the highest being Australia at 70) [12].

20.6 Issues for the Assessment

Whilst there are several assessments in Sweden with increasing granularity for selected sites, the main issues with further assessment of CO_2 storage in Sweden are the lack of data and the age of the existing data. Most datasets are derived from oil and gas exploration in the 1970-80s, which limits the insight that can be gained through interpretation and modelling. There is also great uncertainty over the physical properties of the aquifers. In addition, Sweden does not view CO_2 storage as a solution to use within its country boundaries, at least for the foreseeable future; therefore, it is unlikely to gather new data.

20.7 Future Updates

20.7.1 Future Evaluations

If Sweden decides to investigate its country storage further or consider developing sites rather than pursuing the export strategy it currently has, then this should be reviewed to update the CSRC.

21 United Kingdom

21.1 Summary

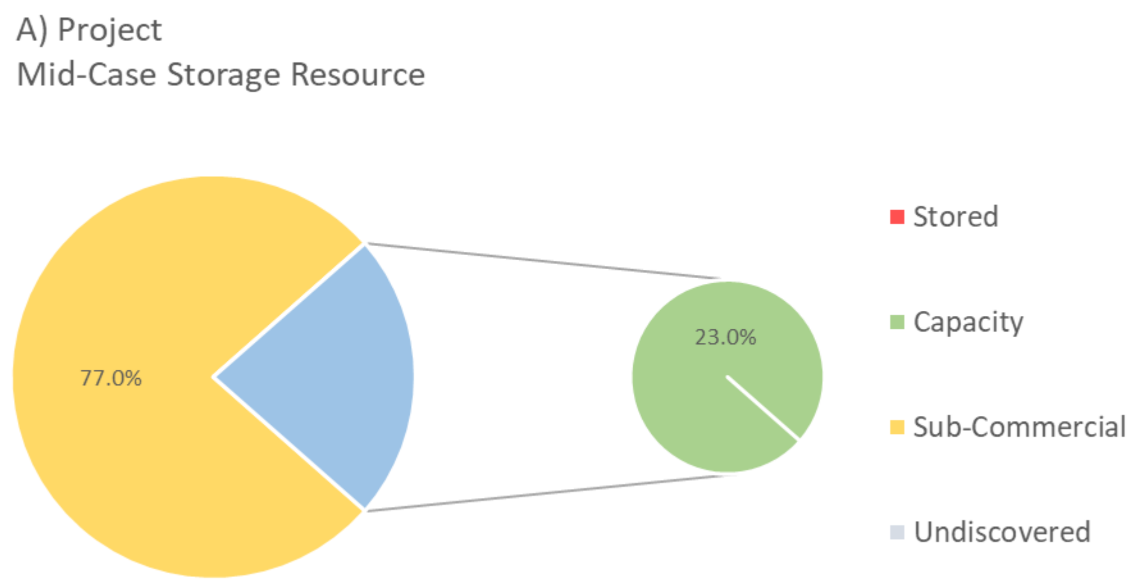
The United Kingdom was assessed during Cycle 1 and updated in Cycle 2 to reflect changes in licensing and UK Government funding announcements. The Cycle 4 updates reflect the recent license awards, progress with major storage and CCS value chain projects, revised storage estimates based on current research and the addition of several new sites to reflect site characterisation and identification in the literature. The CSRC has identified a CO_2 storage resource for the United Kingdom as follows:

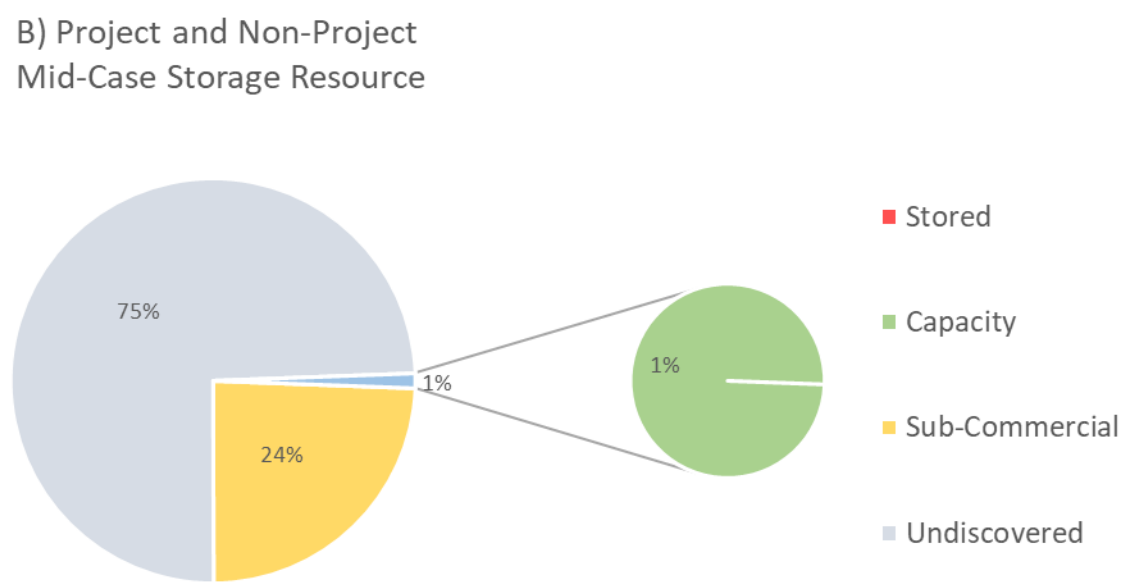
Classification	CO_2 storage resource (Gt) Project and no project	CO_2 storage resource (Gt) Project specified only
Stored	0.00000	0.00000
Capacity	0.960	0.539
Sub-Commercial	19.816	2.180
Undiscovered	60.565	0.000
Aggregated*	81.341	2.719

* 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 21-1: Storage Resource Classification Summary for the UK

- 110 sites are identified in the UK, although only 107 are entered in the database. Three fields, despite being in a CCS license block, do not have reported volumes yet (these are the Sean Fields). Twenty new sites have been added, and 86 sites have been updated from Cycles 1-3.
- 12 of the new sites are core storage units for major CO_2 storage projects in the UK, either as the primary storage site or as part of an expansion plan for the projects.
- Several CCS projects are under planning or development in the UK. Two have been approved for Track 1 funding from the UK Government – HyNet in the East Irish Sea and the East Coast Cluster (utilising the Northern Endurance storage site) in the southern North Sea. Track 2 approved funding includes the Acorn project in the Northern North Sea and the Viking CCS project in the Southern North Sea. Ten more projects relating to the CCS value chain (not storage focused) are also in operation in the UK today. Many of these are part of cluster projects associated with the major storage projects with Track 1 and Track 2 funding. Other projects associated with the first UK CO_2 Storage licensing round acquisitions are beginning to be publicised.
- The success of the NSTA CO_2 Storage licensing round in 2023 led to the award of 21 licenses. One is in the Eastern Irish Sea, 2 are in the Central North Sea, 4 in the Northern North Sea and 14 are in the Southern North Sea. This brings the total license awards for storage and appraisal to 27. More details can be accessed on the NSTA website.


A) Project
Mid-Case Storage Resource
77.0%
23.0%
Stored
Capacity
Sub-Commercial
Undiscovered


B) Project and Non-Project
Mid-Case Storage Resource
75%
1%
24%
1%
Stored
Capacity
Sub-Commercial
Undiscovered

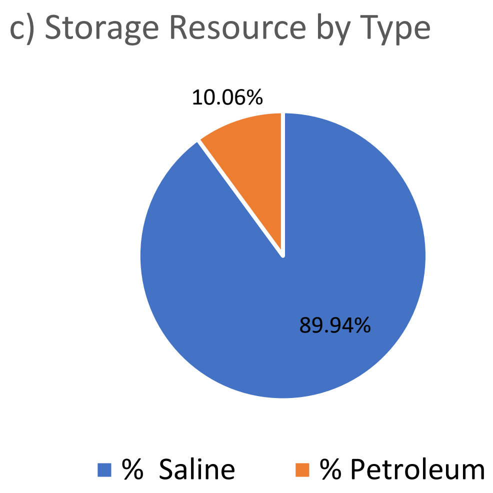


Figure 21-1: UK Spread of Storage Sites

a) Spread of storage resources in the UK (110) across SRMS classifications where a project has been specified. b) Spread of storage resources 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. Note: due to the large variance in size of values, numbers in pie plots do not add up to 100.

21.2 Resource Statement

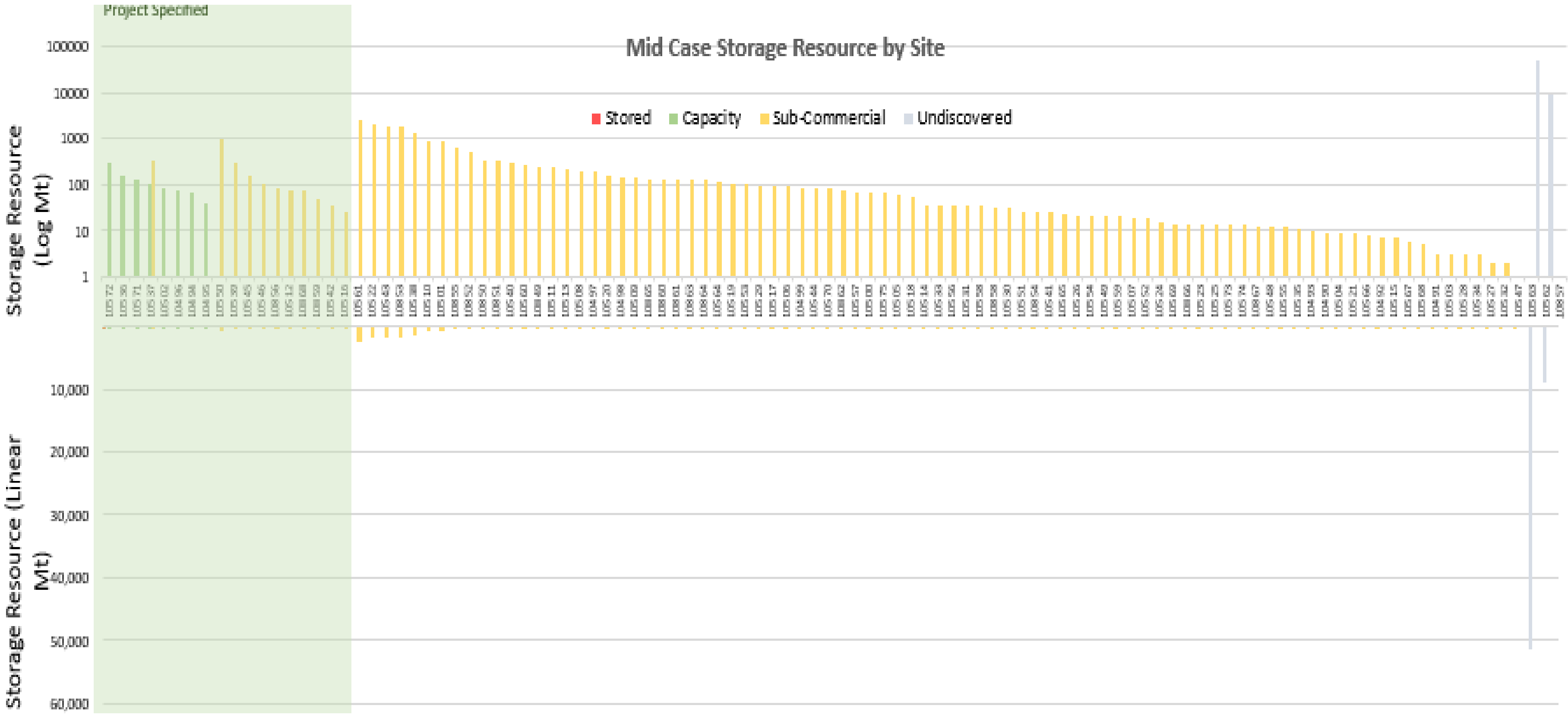


Figure 21-2 : Storage resource summary for the UK region compiled in the CSRC. Graph above is log scale and graph below is linear. Projects were not specified for any of these sites.

21.3 Evaluation History

The most widespread source for the estimation of CO_2 storage resources within the UK is still *CO_2Stored*, the UK CO_2 Storage Evaluation Database, hosted and under development by the British Geological Survey and The Crown Estate and under license from the Energy Technologies Institute (ETI) [8]. Unfortunately, due to the restriction of the CO_2Stored license for non-commercial use only, it has not been used directly in previous CSRC Cycles. Cycle 1 was heavily reliant on literature that references the values from CO_2Stored. The main source in cycle 1 was summary sheets created by the Energy Technologies Institute (ETI) [1]. Additional sites included in Cycle 4 that were not previously included in Cycle 1 & 2 are from the same publication. Additional updates in Cycle 4 include resources delineated in the UK CO_2 storage license round. These sites storage volumes and associated data are taken from the operator's summary reports, some limited academic papers and government reports. Some simulations for various sites exist in public literature, e.g. Pickerill, and have been used to update storage estimates where applicable. A paper by Karvounis and Blunt 2021 [2] calculated volumes based on pressure dissipations/limitation modelling and derived a more refined range of storage of resource estimates for some fields across the UK. These have not been used in Cycle 4 due to the results being presented in a non-tabular range, which limits the accuracy with which a range can be defined for the criteria used by the CRSC.

21.4 Resource Review

21.4.1 Major Projects

The UK has four major projects underway (from Track 1 and Track 2 UK government funding) and others in the early stages of assessment.

1. Track 1 Cluster funding includes HyNet North West and the Northern Endurance Partnership. HyNet North West is a project with several components that include the production, transport, and storage of low-carbon hydrogen in several fields in the North West and North Wales [3]. There is also a CO_2 storage element to help decarbonise heavy industry and hydrogen production, which will transport CO_2 to the Hamilton and Lennox depleted gas fields. The project aims to reach FID in mid-2024.

2. The Northern Endurance partnership will enable the Net Zero Teeside and East Coast Cluster projects to store and transport CO_2. It is hoped to reach FID in September 2024 [4,5]. It is expected that volumes of 100 Mt will be captured and stored during Phase 1. These volumes are therefore placed in the SRMS class as Justified for Development. According to the Northern Endurance Partnership, Endurance has the capacity to store 450 Mt. If additional sites are included surrounding Endurance then the capacity can increase to 1 billion tonnes. The remaining resources (450Mt - 100Mt = 300Mt) in cycle 4 are placed in the contingent classes.

3. Track 2 Cluster funding is now confirmed for the Acorn Project. Acorn has received licenses

from the NSTA for Acorn and East Mey, which will expand the total storage to around 240MT. Acorn is expected to store at least 5Mt/yr by 2030 from several emitters in Scotland, the UK and Europe. There is potential for non-pipeline transport via shipping [6,7].

4. Viking CCS has also been approved for Track 2 funding and is expected to start operating in 2027. It is projected to store 10Mt/yr by 2030 from major emitters in the Humber regions and up to 15Mt by 2035. FID is expected in 2024. Viking CCS plans to use decommissioned pipelines to transport CO_2. Storage will be in the depleted Viking gas fields, with up to eight reservoirs available [8].

Early development projects are underway in some recently acquired license blocks. Two projects from Perenco, Orion (Amethyst and West Sole fields) and Poseidon (Leman field and others), aim to deliver CO_2 capture and storage.

The Poseidon project plans to come online in 2029. Injection rates of 1.5 million tonnes per annum (Mtpa), increasing to ~10Mtpa by 2034 and peaking at ~40Mtpa, over 40 years, are cited. It will serve the decarbonisation of East Anglia, Greater London, and Southeast England. The combined storage resource for this project includes the Leman field, a mixture of saline aquifers (including the Bunter Closure 9) and depleted gas fields surrounding Leman. Combined resources are estimated at having a resource capacity of 935Mt [14]. It is not stated in the literature which fields and aquifers will potentially be used. 1.5 Mt is cited as the initial injection volumes. Only 37.5 Mt (1.5 Mt x 25yrs) can be classed as development pending at present under the current project phase which is still in FEED. It is expected to be ramped up to 40Mtpa when at full operating scale– the exact timeline of which is not stated. As yet it is not possible to clearly define how much will be injected into the full complex and when. The remaining 897.5 Mt is classed as development unclarified until further details emerge on the development plans. Double counting may be an issue here but as yet due to limited information; it is not possible to define which sites will provide the expected portion of the full resources quoted. Future cycles will need to focus on monitoring up to date literature on this project to provide more refined SRMS estimates.

Orion aims to inject 1 Mtpa, rising to 6 Mtpa with injection commencing in 2031. Orion will serve the Humber area and have a maximum capacity of 126 Mt of CO_2 [9,10, 14]. Orion is aimed to provide additional capacity for decarbonization of the Humber area over a planned 30 year period. Orion will use both the Amythyst and West Sole fields with pipeline transport from the Dimlington CO_2 processing terminal. At present at an initial injection rate of 1Mtpa over 30 years, provides a resource of 30Mt for development pending as the project is still in FEED stage.

21.4.2 Depleted Oil & Gas Fields

The status of the UK's depleted oil and gas field storage potential has changed very little since Cycle 3 with respect to all remaining discoveries, with some awaiting a detailed study. Regarding SRMS classification, many sites have now been classified as 'Justified for

Development' based on the advancement of the cluster projects over the last few years. Some adjustments to volumes have been made based on research over the past two years and the advancement of project studies. All projects have yet to reach FID. This is anticipated to happen for some projects in 2024. Several sites have also been targeted by recent license awards and have therefore moved up the classification system to 'Development on Hold'. The Hewett field has also received a submission for a Carbon Storage License (by ENI) and is under appraisal as the storage element of the Bacton Thames Net Zero Initiative [13].

Several new sites have been added based on the license awards. Four fields offshore Shetland (Magnus, Tern, Eider and Thistle) were awarded to Enquest [11,12], two depleted fields in the SNS were awarded to Perenco (Amethyst and West Sole) [9,10] with two additional fields (Indefatigable and Sean) were awarded to Shell. Volumes and data for these sites are very limited (Sean fields are omitted from the database due to no publicly reported volumes). Most information is found in company reports and investor presentations. Future cycles will benefit from updates if the license holders publish in-depth studies.

21.4.3 Saline Aquifers

The status of the UK's saline aquifers remains unchanged since Cycle 3 with respect to all remaining discovered (with very few as undiscovered) due to the region's wealth of oil and gas wells. Several of the Bunter sites (36,38,39,40) have been included in the development plans for Endurance and are awaiting a more detailed assessment. These have been reclassified as 'On Hold' due to being situated in an awarded license block.

21.5 Regulatory Framework

The UK is the second most highly rated country in the GCCSI Policy Indicator Report (score of 68) due to the ambitions for CCUS deployment outlined in the Clean Growth Strategy in 2017. In 2020 and 2021, the UK Government released their Energy White Paper detailing how the UK energy supply will meet Net Zero ambitions and pledged £1 billion towards the development of a series of clusters and hubs across the UK, further demonstrating its commitment to the UK CCS industry. The UK is one of five countries that have ratified the Article 6 amendment to the London Protocol. It is working with countries through the North Sea Basin Taskforce and others to advance ratification further. The UK also participates in ERA-NET to accelerate CCS technologies with 8 other European countries and funds many ventures for the low-carbon industry. On an international front, the UK is committed to convening and leading a new international working group to drive down costs and accelerate CCUS deployment. It has achieved this with several investment and collaboration initiatives.

21.6 Issues for the Assessment

The restrictions on commercial access to CO_2Stored still hinder the wealth of data that could be added to the CSRC for the UK. As a result, storage volumes rely on access to publications referencing the CO_2Stored database or other publications showing more detailed studies on individual sites that exhibit good storage potential. As with Cycle 3, this may lead to an underrepresentation of storage volumes. With respect to the UK projects cited by storage license holders, access to the source of the research for the volumes they publish on websites and presentations is not available. Hence, the volumes they cite are taken at face value on their company publications. Any future published works on these sites and projects will need to be reviewed for a more in-depth analysis of potential storage volumes.

21.7 Future Updates

21.7.1 Future CSRC cycles

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

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