CO_2 Storage Resource Catalogue

Cycle 4 Report

MENA

August 2024

OIL AND GAS CLIMATE INITIATIVE

GLOBAL CCS INSTITUTE

HALLIBURTON

International Association of Oil & Gas Producers

Amounts of CO_2

Stored

0 Gigatonnes

Commercial

0 Gigatonnes

Sub-commercial

13.2 Gigatonnes

Undiscovered

18.4 Gigatonnes

Appendix D : Middle East & North Africa

Algeria, Egypt, Israel, Kuwait, Lebanon, Libya, Morocco, Oman, Qatar, Saudi Arabia, Syria, Tunisia, Turkey, UAE

Document Summary			
Client	Oil and Gas Climate Initiative (OGCI)		
Title:	CO_2 Storage Resource Catalogue – Appendix D: Middle East and North Africa		
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Important notice

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1 Algeria

1.1 Summary

Algeria was assessed during Cycle 4. The CSRC has identified a CO2 storage resource for Algeria as follows:

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	0.013	0.013
Undiscovered	1.033	0.000
Aggregated*	1.046	0.013

* 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 Algeria

- Starting in the 1990s, sites were assessed for storing CO2 to make gas fields cleaner. The Krechba field, capable of holding 17 million tonnes, was selected for the In Salah project. Between 2004 and 2011, this project stored 3.8 million tonnes of CO2. The remaining 13.2 Mt is categorised as Contingent Storage Resources – Not Viable as no plan for re-injection has been recorded.

- IEAGHG reported in 2009 the storage resource potential with CO2 EOR in oilfields for Algeria within Trias/Gadames and Illizi Basin with 1.4 Gt and 0.3 Gt, respectively. However, these basins cover multiple countries and the portion for Algeria cannot be determined yet.

- In 2016, Aktouf et al. started the CO2 resource evaluation of deep saline aquifers in Algeria, covering six sedimentary basins in Southwest Algeria, namely Bechar, Tindouf, Reggane, Cuvette de Sbaa, Ahnet, Gourara, at basin screening level.

- Ahnet and Gourara basins have the highest potential for storage, with 12 saline aquifer sites identified.

- Estimations of the CO2 storage capacities of these sites vary from 1 Gt to over 5 Gt.

- Algeria has a low score of 37 in the CCS Chart of Legal and Regulatory Indicator system, highlighting that there is no CCS-specific regulatory system currently. The In Salah project was governed under the Hydrocarbon Law (Law No. 19-13) and Executive Order No. 06- 138 of April 15, 2006, for emission regulation.

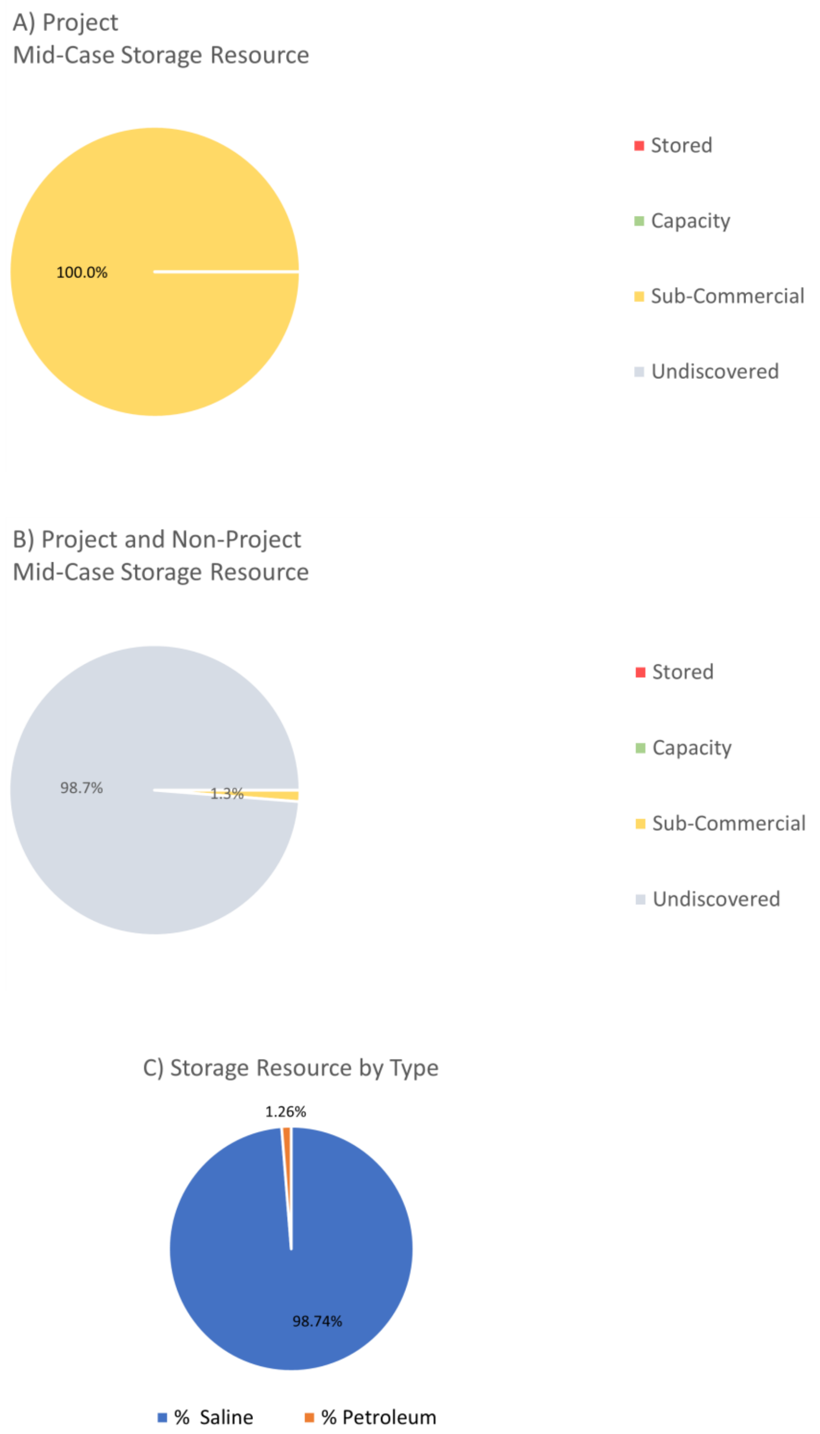


Figure 1-1: Algeria spread of Storage Sites

a) Spread of storage resources in Algeria. Sites (XX) across SRMS classifications where a project has been specified. b) Spread of storage resources in all Algeria sites across SRMS classifications; both project specified and not. c) Split of Algeria 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.

1.2 Resource Statement

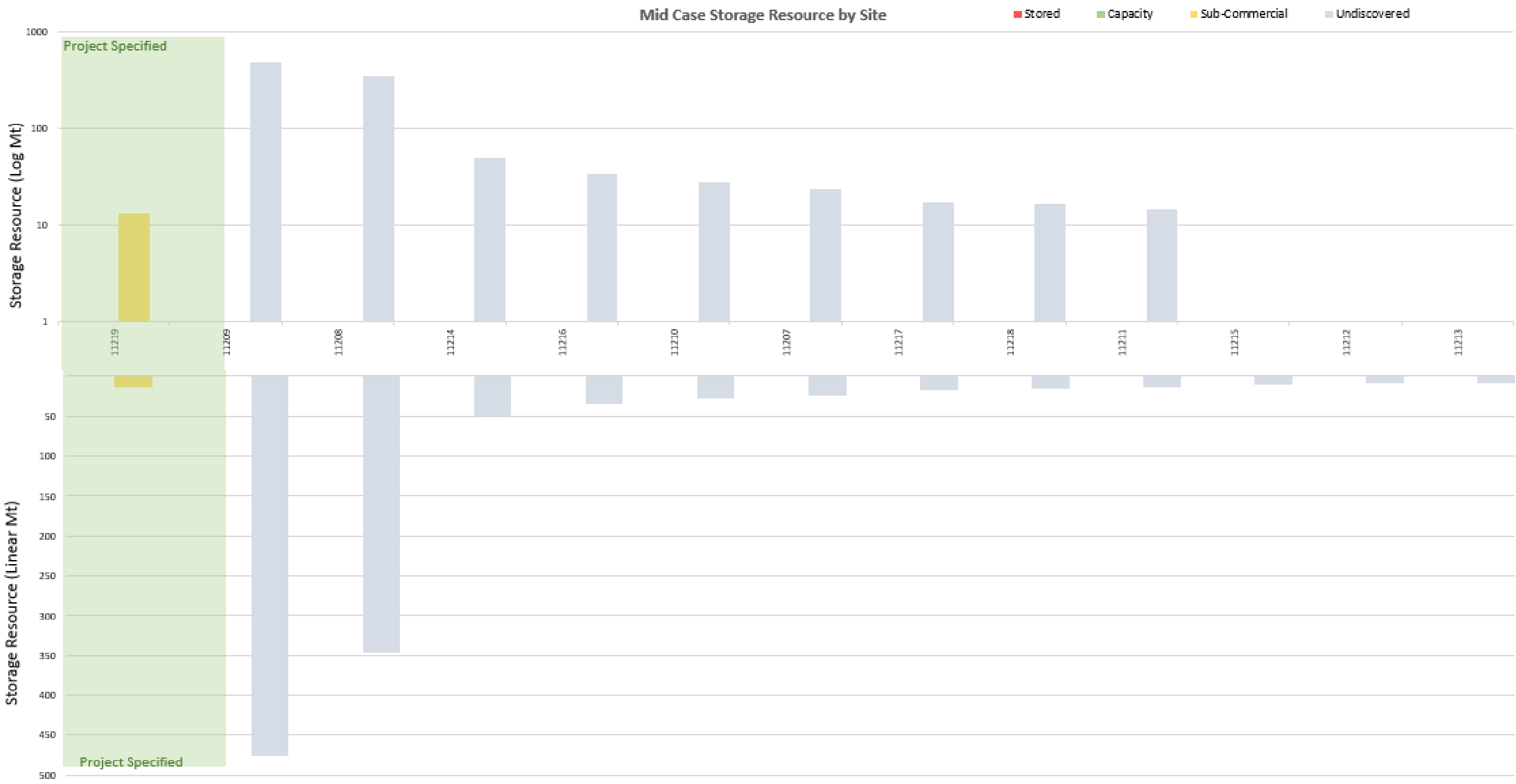


Figure 1-2: Storage resource summary for Algeria compiled in the CSRC.

The graph above is a log scale, and the graph below is linear. The green box highlights sites where a project has been specified.

1.3 Evaluation History

Starting in the 1990s, a thorough evaluation was initiated to identify suitable sites for storing CO2, especially those produced alongside natural gas, as part of efforts to mitigate climate change. The In Salah CCS Project was successful, storing 3.8 Mt of CO2 with a total storage resource of 17 Mt reported.

In 2009, IEAGHG conducted a study on oil fields' potential for EOR and CO2 storage, revealing that Algeria's Trias/Gadames and Illizi Basin oilfields possess substantial CO2 storage potential, estimated at 1.4 Gt and 0.3 Gt, respectively. However, delineating the specific portion of these storage capacities attributable to Algeria is challenging. These basins stretch across national boundaries (Libya and Tunisia), complicating the estimation of Algeria's share of the storage potential due to the absence of detailed, country-specific information.

Further expanding the scope of CO2 storage assessment, in 2016, Aktouf et al. began exploring the potential of deep saline aquifers in Algeria for CO2 storage. This research covered six major sedimentary basins in Southwest Algeria: Bechar, Tindouf, Reggane, Cuvette de Sbaa, Ahnet, and Gourara. Among these, the Ahnet and Gourara basins were identified as having the highest potential for CO2 storage. Twelve sites within these basins were recognised for suitability and subsequently added to the CSRC. The estimated storage capacity of these sites ranges from 1 Gt to over 5 Gt, highlighting the significant potential of Algeria's geological formations in contributing to global CO2 storage potential.

1.4 Resource Review

Although some storage potential is identified in depleted fields in Algeria, most of the reported storage resource potential lies in saline aquifers.

1.4.1 Major Projects

In Algeria, the In Salah project, operational between 2004 and 2011, successfully stored 3.8 Mt CO2 in the Krechba field. The CO2 is injected into the aquifer leg of a 20m thick carboniferous sandstone reservoir with a depth of approximately 1800 – 1900 m. Three long-reach horizontal injection wells are used to inject the CO2 into the down-dip aquifer leg of the gas reservoir. The injection was halted due to potential geophysical risks, specifically reservoir fluid pressures (Ringrose et al., 2013).

Key lessons from the project include the critical importance of detailed geological and geomechanical characterisation, regular risk assessments, and flexibility in the design and operation of the capture, compression, and injection system. It underscores the value of integrating diverse data sets for comprehensive risk analysis and highlights innovative monitoring methods that have enhanced the understanding of geomechanical responses to CO2 injection.

This project is an essential case study, offering valuable insights for other CCS projects regarding monitoring, modelling, and verification techniques, particularly in managing site-specific risks and ensuring long-term storage integrity. It emphasises the ongoing need for adapting monitoring strategies based on operational feedback and evolving risk profiles, contributing significantly to the global knowledge base on CCS technology implementation and optimisation.

A total storage of 17 Mt was reported for this site. 3.8 Mt is registered as Stored, and the remaining 13.2 Mt resources are registered under Contingent Storage Resources—Not Viable in the CSRC. The Krechba continued its gas production, enabling the potential of additional storage resources from pressure depletion. As of 2011, no reported intention to reinject into the same site has been reported.

1.4.2 Depleted Oil & Gas Fields

There is no detailed review of the storage potential in depleted oil and gas fields beside the In Salah project. The IEAGHG study on oilfields for EOR shows that the resources overlay multiple basins. These basins stretch across national boundaries (Libya and Tunisia), complicating the estimation of Algeria's share of the storage potential due to the absence of detailed, country-specific information. No specific calculations have been made yet for the depleted oil and gas fields.

1.4.3 Saline Aquifers

The most recent work undertaken to evaluate storage potential in Algeria has focused on saline aquifers. Aktouf et al.'s (2016) study assesses deep saline aquifers in Algeria's Saharan platform, particularly the Ahnet–Gourara Basin, highlighting their suitability for CO2 storage based on geological and practical criteria.

Assessing the geological sequestration capacity (GSC) in Algerian deep saline aquifers, mainly using the Cambro–Ordovician quartzitic sandstone layers interlaced with laminated and dispersed clay, highlights their suitability for CO2 storage. These formations are well-sealed by a minimum of 200 meters of Silurian clay caprock, ensuring the containment of CO2 within the reservoirs. However, estimating the effective storage capacity faced challenges due to the variability in the storage efficiency factor, Esalin.

Based on conservative assumptions about the proportion of pore volume that could be filled—ranging from 0.54% to 5.4%—the estimated effective storage capacity for CO2 in these areas ranges between 1 gigaton (GT) and 5 gigatons (Gt), indicating a significant potential for long-term CO2 sequestration in Ahnet-Gourara basin. Twelve sites identified within the basin, namely Akablie 1, Akablie 2, Tindikelt Nord, Ahnet Centre, Amsari, Idjarane West, Timimoune 1, Timimoune 2, Timimoune South, Gourara 1, Gourara 2 and Gourara 3. Regulatory Framework

1.5 Regulatory Framework

Algeria has been evaluated under the 2021 GCCSI CCS readiness index. CCS projects (e.g. In

Salah CCS) are regulated by specific legislation that governs hydrocarbon activities and environmental protection, highlighting its importance in both energy production and environmental sustainability.

The Hydrocarbons Law (Law No. 19-13 of 11 December 2019) provides the legal framework for all hydrocarbon-related activities in Algeria, including exploration, production, processing, transportation, and distribution. This law is crucial for the In Salah project as it regulates the operational aspects of gas extraction and the subsequent carbon capture and storage processes.

Executive Order No. 06-138 of April 15, 2006, plays a significant role in environmental protection related to the project. This order sets the standards for emissions into the atmosphere, including gases, fumes, vapour, and solid or liquid particles. It also outlines the conditions and mechanisms for monitoring and controlling these emissions. This ensures that the project adheres to strict environmental standards, reducing the environmental impact of gas extraction and processing activities.

These legislative measures established a comprehensive legal and regulatory framework for the In Salah project, ensuring it ran smoothly and responsibly. Future projects may employ the same regulatory framework, as specific CCS laws may not be available in the near future.

1.6 Issues for the Assessment

Lack of dynamic modelling and ready access to site-specific data was the main issue for this assessment cycle. The provided value for the deep saline aquifers of the Ahnet–Gourara Basin is a conservative estimate. This estimation primarily relies on available data, yet it acknowledges the potential for higher capacity as exploration continues. Specifically, regions like the Bechar and Tindouf basins, which are currently underexplored and lack comprehensive data, could reveal additional promising reservoirs. This possibility suggests that the actual potential of Algeria's deep saline aquifers could significantly exceed the initial conservative estimates once more geological data becomes available and additional areas are thoroughly assessed.

1.7 Future Updates

1.7.1 Future CRSC Cycles

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

2 Egypt

2.1 Summary

Egypt was assessed during Cycle 4. The CSRC has identified a CO2 storage resource for Egypt as follows:

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 2-1: Storage resource classification summary for Egypt

- Egypt's CCS potential lies in depleted oil and gas reservoirs, which will provide over 240 Mt CO2 storage by 2030 across 26 fields. Without details of the storage sites given in the World Bank evaluation, this figure could not be registered in the catalogue.
- Egypt announced an algae-based biofuel project that will capture 25,000 to 30,000 tonnes of CO2 annually. Two other projects focused on biodegradable plastics and converting plastic waste into oil.
- The regulatory framework is incomplete and lacks CCS-specific guidelines. Recent amendments to the Investment Law expedite strategic CCS project approvals, but broader regulatory adjustments are needed for classification, tenure, monitoring, and liability.
- Further research is required to assess saline aquifers comprehensively.

2.2 Evaluation History

Egypt has potential for CCS, especially in its depleted oil and gas reservoirs, as apparent from the 2013 study by the World Bank. The assessment of geological CO2 storage capacity is focused on the main oil and gas producing regions of the Nile Delta, the offshore Mediterranean, the Gulf of Suez, and the Western Desert. A mix of oil and gas reservoirs will provide over 130 Mt CO2 storage by 2020, increasing to more than 240 Mt CO2 over 26 fields by 2030. Unfortunately, the study does not specify the field names and formations being considered for storage. Hence, no storage resources can be registered in the database. Additionally, no assessment of saline aquifers was performed in this study due to the lack of data on such formations.

2.3 Resource Review

Egypt’s storage resources evaluation has focused on oil and gas fields and has focused minimally on saline aquifers.

2.3.1 Major Projects

Egypt's first CCS project focuses on an algae-based biofuel facility that captures and stores 25,000 to 30,000 tonnes of CO2 annually. The initiative is part of Egypt's commitment to reducing emissions and transitioning to a more sustainable energy model (Carbon Herald, 2022).

Additionally, two other projects were announced within the same report:

- One project aims to generate biodegradable plastics, which is expected to prevent the emission of 45,000 tonnes of CO2 each year.
- Another will convert plastic waste into oil, potentially saving around 63,000 tonnes of CO2 annually.

Details on the status of these projects are not widely disclosed, but their overall impact is anticipated to be significant for Egypt's emissions targets.

2.3.2 Depleted Oil & Gas Fields

Egypt’s CCS potential hinges on the availability of oil and gas reservoirs nearing the end of their economic lives. The World Bank reported by 2020, eight of the largest oil fields are set to offer a cumulative storage capacity of over 60 Mt CO2. By 2030, this capacity will almost triple to over 140 Mt CO2 across 14 fields, covering nearly all the oil reservoir storage available until 2050. This timeline aligns well with CCS project implementation and ensures that the depletion of these oil fields will not constrain their availability for geological CO2 storage in the medium term. Similarly, Egypt’s younger gas sector will see its reservoirs become available later. By 2020, nine gas fields will offer over 75 Mt CO2 of storage capacity, comparable to the oil fields. By 2030, the combined capacity of 12 gas fields will exceed 100 Mt CO2. Overall, a combination of oil and gas reservoirs will offer over 130 Mt CO2 of storage by 2020, growing to more than 240 Mt CO2 across 26 fields by 2030.

2.3.3 Saline Aquifers

SLB (2024) conducted a screening and ranking analysis identifying 16 potential CO2 storage sites in the Nile Delta region, with a maximum estimated storage capacity of 622 million metric tonnes. The study recognised the potential of saline aquifers for carbon storage, particularly those in the Nile Delta region, including the El Wastani, Lower Pliocene, and Abu-Madi Formations. However, the article only provides high-level results of SLB's CCS screening, with no specific details on the storage sites or the distribution of the storage resources according to the formations. This lack of detail prevents the information from being reported in the database, highlighting the need for further research.

2.4 Regulatory Framework

Egypt's legal and regulatory framework for CCS is incomplete and uncertain, lacking specific laws and guidelines tailored to CCS activities. Recent amendments to the Investment Law No. 72 of 2017 now classify specific CCS projects that meet particular conditions as strategic or national projects, providing an expedited approvals pathway. Without this classification, projects face a more complex and uncertain permitting process.

Existing environmental and resource regulations could be adjusted to include CCS operations, but challenges remain around classifying CO2 as either waste or a resource. Broader regulatory changes are also required to address tenure, monitoring, project closure, and liability. Furthermore, various regulators currently oversee different aspects of CCS projects, necessitating more precise definitions of roles and responsibilities to reduce ambiguity and ensure effective management throughout the project lifecycle.

2.5 Issues for the Assessment

The assessment of resources in this evaluation cycle revealed limited data about storage sites, well control, and geological formation parameters. More comprehensive data collection and analysis are needed to refine the understanding of these sites. Due to this lack of information, no storage resources were included in the Cycle 4 assessment. This underscores the need for more detailed research and data acquisition to gauge and maximise Egypt's CCS potential accurately.

2.6 Future Updates

2.6.1 Future CRSC Cycles

Future research and pilot projects, particularly in deep saline aquifers and other novel storage sites, will be critical to refining the storage capacity estimates and ensuring CCS projects' operational safety and integrity. Should any further development in Egypt’s storage systems occur, this should be reviewed annually to ensure the Global Storage Catalogue is up to date.

3 Israel

3.1 Summary

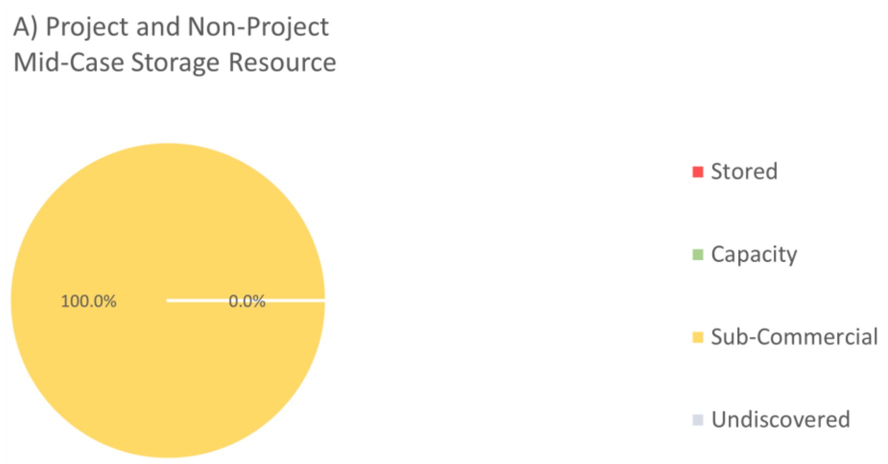
Israel was assessed during Cycle 4. The CSRC has identified a CO2 storage resource for Israel as follows:

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	11.759	0.000
Undiscovered	0.000	0.000
Aggregated*	11.759	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 Israel

- Reported storage resources were calculated for saline formations in the Negev region of southern Israel.
- The storage resource potential of Israel is based on two main studies of the same Negev region – Calvo and Gvirtzman, 2013 and Taragan, 2018.
- The evaluated potential storage sites in Israel are onshore in the Sinai-Levant basin; however, additional CO2 storage resource potential is likely present in Israel's offshore gas fields.
- 5 sites with assessed storage potential were identified in Cycle 4.
- Israel does not currently have a CCS-specific regulatory framework.



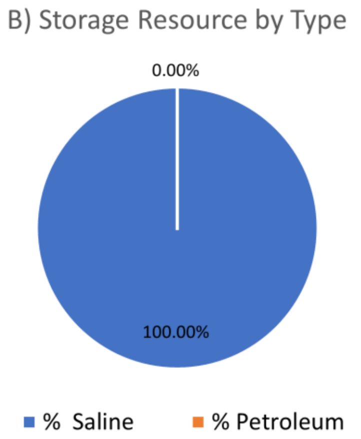


Figure 3-1: Israel spread of Storage Sites

a) Spread of storage resources in Israel. Sites (XX) across SRMS classifications where a project has been specified. b) Spread of storage resources in all Israel sites across SRMS classifications; both project specified and not. c) Split of Israel 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 Algeria compiled in the CSRC.

The graph above is a log scale, and the graph below is linear. The green box highlights sites where a project has been specified.

3.3 Evaluation History

Evaluation of potential storage resources in Israel is limited. In 2013, authors at the Geological Survey of Israel completed the first basin-scale study evaluating the CO2 storage resources in deep saline formations of the Negev region onshore, southern Israel (Calvo and Gvirtzman, 2013). This study evaluated the Cambrian through Cretaceous section and identified three storage formation/seal pairs which they named, the "Lower Aquifer," "Middle Aquifer," and "Upper Aquifer." This study was followed by Taragan (2018) which evaluated the same onshore region but included additional deep saline formations in the "Lower Aquifer" described by Calvo and Gvirtzman (2013). Taragan (2018) also updated the Calvo and Gvirtzman study with new storage efficiency factors, new grid interpolation analysis, and grid-based porosity. No additional studies of CO2 storage resources have been published since the Taragan (2018) evaluation.

3.4 Resource Review

Although there is some identified storage potential in Israel's onshore deep saline formations, additional storage resource potential is likely in the gas fields and saline formations of Israel's offshore basins.

3.4.1 Major Projects

In Israel there are currently no major projects as defined by the CSRC. If supplementary information and data can be accessed, this statement may be updated.

3.4.2 Depleted Oil & Gas Fields

No review of CO2 storage resource potential in depleted oil and gas fields is available in the public domain.

3.4.3 Saline Aquifers

Work undertaken to-date evaluating storage potential in Israel has focussed on saline aquifers.

In the Negev region of southern Israel, Calvo and Gvirtzman (2013) identified three storage formation/seal pairs which they named, the "Lower Aquifer," "Middle Aquifer," and "Upper Aquifer." The Upper Aquifer (Cretaceous) was not evaluated because of its shallow depth. Additionally, areas less than 800 m depth, areas where the seal (aquitard) is less than100 m thick, and areas within 10 km of fault traces or erosional formation outcrops were excluded from their analysis. The Lower (Cambrian through Triassic) and Middle (Jurassic) Aquifers were estimated to contain a total of 6.17 Gt and 8.69 Gt of CO2 storage resources, respectively. Calvo and Gvirtzman (2013) further split these resources into economic ("Level I") and uneconomic ("Level II") resources based on their depth. Resources deeper than 2500 m were considered "Level II" and uneconomic. Calvo and Gvirtzman (2013) determined only 1.82Gt of CO2 storage resources from the Lower Aquifer and 4.42 Gt of CO2 storage resources from the Middle Aquifer are considered economically viable.

Taragan (2018) reevaluated the same Negev region. The 2018 analysis focused on the Lower Aquifer, splitting the section into the Aquifer's four storage formations as well as calculating a composite analysis of the entire Lower Aquifer section – collectively referring to the composite Lower Aquifer section as the "Permian Aquifer." Taragan (2018) updated the Calvo and Gvirtzman (2013) analysis by using a porosity grid for each formation instead of a constant porosity, increasing the storage efficiency factor (from 2% to 3.4%) based on known net-to-gross values, and improving the grid interpolation methodology. The Permian Aquifer comprises the Sa'ad Formation (Early Permian), Arqov Formation (Late Permian), Shezaf Formation (Late Permian) and the Yamin Formation (Late Permian to Early Triassic), which were estimated to hold 891 Mt, 846.2 Mt, 1011.3 Mt, and 320.9 Mt of CO2 storage resources, respectively.

Taragan (2018) determined the composite Permian Aquifer contains 3.3508 Gt of CO2 storage resources; however, when buffers are imposed on areas with less than 100 m of overlying seal or areas within 10 km of major faults, the CO2 storage resources decrease to only 1.53Gt.

The storage resource for saline aquifers in Israel are classified as Discovered: Inaccessible by the SRMS. While the two studies described herein provide proof of storable quantities of CO2, no CCS-specific regulatory framework is in place. Should a framework become established, the evaluated storage resources would likely be classified as sub-commercial, Contingent: Development Not Viable until a project is defined to develop the resources commercially.

3.5 Regulatory Framework

Israel does not currently have a CCS-specific regulatory framework.

As of 2023, countries in the Middle East and Africa have again received assessment scores at the lower end of the spectrum, with four of the 10-lowest scoring nations coming from this region. This result indicates their legal regimes include only a few CCS-specific or existing laws that are applicable across parts of the CCS project lifecycle.

3.6 Issues for the Assessment

Lack of dynamic modelling, consideration of formation pressure, and ready access to site-specific data are the main issues for Israel in this assessment cycle. Israel has not undertaken a country-wide evaluation of CO2 storage resource potential. This means that the Catalogue risks an underestimation of Israel's storage potential.

3.7 Future Updates

3.7.1 Future CRSC Cycles

Should any further development in the Israel storage systems occur, this should be reviewed on an annual basis to ensure the Global Storage Catalogue is up to date.

4 Kuwait

4.1 Summary

Kuwait was assessed during Cycle 3. The CSRC has identified a CO2 storage resource for Kuwait as follows:

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	0.44	0.00
Aggregated*	0.44	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 Kuwait

- Kuwait has one site in the CSRC: 1 saline aquifer (Undiscovered; 0.440 Gt).
- The identified site in Kuwait is classed as "Undiscovered: Inaccessible" due to the lack of CCS regulatory framework for the country.
- There currently are no defined CCS projects in Kuwait.

4.2 Evaluation History

Subsurface geologic data in Kuwait is highly restricted and no comprehensive evaluations of the CO2 storage potential of Kuwait have been completed. Kuwait's proven crude oil reserves exceed 100 billion barrels [1]. This suggests significant unassessed geologic storage likely exists in Kuwait's depleted oil and gas fields and saline aquifers.

4.3 Resource Review

4.3.1 Major Projects

No CCS project announcements have been made for Kuwait.

4.3.2 Depleted Oil & Gas Fields

Kuwait is a prolific hydrocarbon producing country, but its resources for the geologic storage of CO2 have not been characterized. Its world-class oil and gas resources suggest significant potential for geologic storage of CO2.

4.3.3 Saline Aquifers

One study, by Neele et al. [2], surveyed the CO2 storage potential in Kuwait and determined the optimal storage site in the country to be the Kra Al-Maru trend. The Kra Al-Maru trend is approximately 320 km2 and comprises three suitable Cretaceous sandstone reservoirs (Wara Fm., Burgain Fm., and Zubair Fm.). Reservoir thicknesses, porosities, or permeabilities were not provided in the Neele et al. evaluation, but the authors report the formations span "several hundred meters" in thickness, at depths between 2000 and 3000 m with "good to excellent reservoir quality." The regional containment unit is the Ahmadi Formation – a shale unit ranging in thickness from 52 to 128 m. Static and dynamic 3D geologic models were developed for the site, but no details on the modelling were published, apart from the total storage resource of 440 MtCO2 (over the assumed 40-year life of the capture facilities).

4.4 Regulatory Framework

Kuwait has not developed a CCS-specific regulatory or legal framework and has not been evaluated in the GCCSI CCS Readiness analysis.

4.5 Issues for the Assessment

Very little subsurface data is publicly available for Kuwait, so although the CO2 storage potential in the country is likely high (implied by its extensive oil and gas resources), the total CO2 storage picture remains unclear. The Neele et al. [2] evaluation which is assessed here is problematic because very little information is published on their storage modelling work. While their evaluation appears to have been robust with a 3D geologic model and dynamic simulation, no reservoir, well, or injection data were provided. Importantly, it is unknown how their storage resources are partitioned amongst the three reservoir intervals in the Kra Al-Maru trend.

Additionally, some amount of containment risk for future projects exists in the study area, as the authors note the CO2 is expected to encounter two legacy wells. Well locations and a detailed map of the study area were not provided.

As a result of the low maturity of the resource estimation, only a single value is provided for the assessed resource and has been recorded as the 'Mid-Range' estimate of resource potential. As future studies are planned in Kuwait, effort needs to be made to move towards generating probabilistic resource evaluations.

4.6 Future Updates

4.6.1 Future Updates for Evaluators

A comprehensive, country-wide assessment of Kuwait's geologic storage resources is required for both saline reservoirs and depleted oil and gas fields. While the Neele et al. [2] publication did conduct a country-wide screening, they focused solely on identifying the optimal storage site, rather than completing a comprehensive storage evaluation. In order to fully understand the CO2 storage resources of the country, all possible sites need to be characterized and assessed.

4.6.2 Future CRSC Cycles

Updates to this Cycle 3 assessment should be completed if additional studies on Kuwait's storage resources become available.

5 Lebanon

5.1 Summary

Lebanon was assessed during Cycle 4. The CSRC has identified that Lebanon 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 5-1: Storage resource classification summary for Lebanon

5.2 Evaluation History

Lebanon was reviewed during Cycle 4. Lebanon is not a hydrocarbon producing nation; however, its offshore territorial waters include a portion of the Sinai-Levant basin which hosts giant gas fields to its south. Evaluations of the saline formations in the offshore Sinai-Levant Basin and any onshore basins should form the subject of any future evaluation effort.

5.3 Regulatory Framework

Lebanon has not developed CCS-specific regulatory or legal framework and has not been evaluated in the GCCSI CCS Readiness Index.

5.4 Future Updates

5.4.1 Future Updates for Evaluators

A comprehensive, country-wide assessment of Lebanon's geologic CO2 storage resources is required for both saline formations any discovered hydrocarbon fields.

5.4.2 Future CRSC Cycles

Updates to the Cycle 4 assessment should be completed if studies on Lebanon's CO2 storage resources become available.

6 Libya

6.1 Summary

Libya was assessed during Cycle 4. The CSRC has identified that Libya has zero published storage resource estimates and therefore no applicable 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 6-1: Storage resource classification summary for Libya

6.2 Evaluation History

Libya was reviewed during Cycle 4. CO2 storage in Libya's depleted oil fields (for the purposes of enhanced oil recovery) and gas fields were estimated by the IEAGHG in 2009 and published in two separate publications (IEAGHG, 2009a, 2009b). Storage resources in these evaluations are summarized below. Although Libya is a prolific hydrocarbon producing country, its CO2 storage resources have not yet been characterized in the public domain beyond these two high-level IEAGHG studies. Its world-class oil and gas resources suggest significant potential for geologic storage of CO2 and should form the subject of any future evaluation effort.

6.3 Resource Review

6.3.1 Depleted Oil & Gas Fields

The IEAGHG estimates 3.4 GtCO2 could be stored in oil fields of the Sirte Basin for the purposes of enhanced oil recovery (EOR) (IEAGHG, 2009b). Because CO2 EOR projects are not accounted for in the SRMS, these resources were not assessed in this cycle.

The IEAGHG also estimates 2.0 Gt of CO2 storage resources exist in gas fields of the Sirte Basin; however, this estimate includes discovered conventional gas reserves, estimated "grown" gas resources, and estimated undiscovered gas resources (IEAGHG, 2009a). The IEAGHG combined these three classes of resource to estimate the Sirte Basin's CO2 storage resource. Because these three resource classes cannot be separated in the published IEAGHG analysis, they were not included in this cycle's summary. A portion of the 2.0 Gt estimated CO2 storage resource in the Sirte Basin's gas fields would be considered discovered resources according to the SRMS and the balance would be considered undiscovered resources; however, because Libya does not have CCS-specific regulatory or legal framework, all 2.0 Gt would be classed as Inaccessible resources.

6.3.2 Saline Formations

Estimates of CO2 storage resources in Libya's saline formations have not been published.

6.4 Regulatory Framework

Libya has not developed CCS-specific regulatory or legal framework and has not been evaluated in the GCCSI CCS Readiness Index.

6.5 Future Updates

6.5.1 Future Updates for Evaluators

A comprehensive, country-wide assessment of Libya's geologic CO2 storage resources is required for both saline formations and depleted oil and gas fields.

6.5.2 Future CRSC Cycles

Updates to the Cycle 4 assessment should be completed if studies on Libya's CO2 storage resources become available.

7 Morocco

7.1 Summary

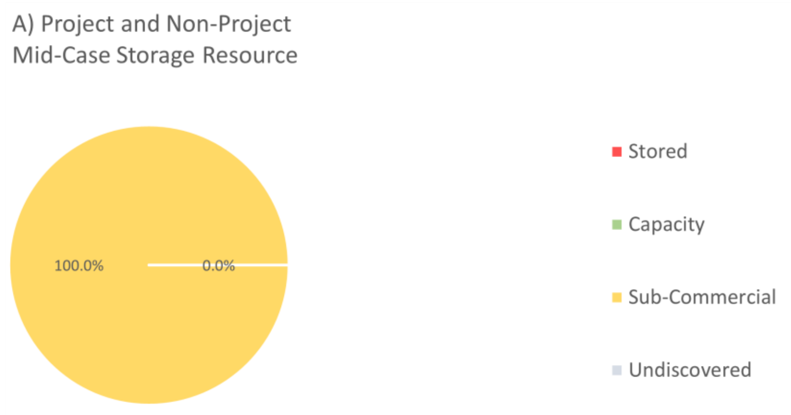
Morocco was assessed during Cycle 4. The CSRC has identified a CO2 storage resource for Morocco as follows:

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	0.630	0.000
Undiscovered	0.000	0.000
Aggregated*	0.630	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 7-1: Storage resource classification summary for Morocco

- The EU-funded COMET project resource evaluation is the first resource evaluation for Morocco.
- The resource evaluation is basin-scale and only considers Morocco's CO2 storage resources onshore in oil and gas fields and saline formations.
- Although Morocco has several basins onshore, only basins in northern Morocco, proximal to CO2 sources were evaluated.
- 3 sites with assessed storage potential were identified in Cycle 4.
- Morocco does not have a CCS-specific regulatory framework.



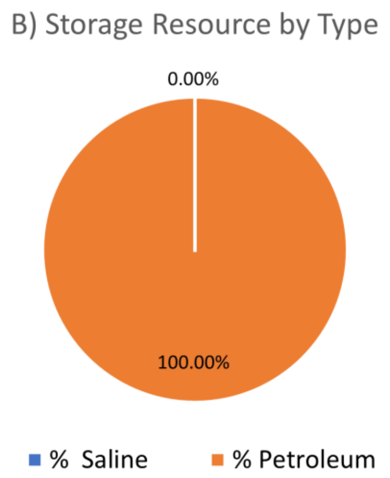


Figure 7-1: Morocco spread of Storage Sites

a) Spread of storage resources in Morocco. Sites (XX) across SRMS classifications where a project has been specified. b) Spread of storage resources in all Morocco sites across SRMS classifications; both project specified and not. c) Split of Morocco 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.

7.2 Resource Statement

Figure 7-2: Storage resource summary for Morocco compiled in the CSRC.

The graph above is a log scale, and the graph below is linear. The green box highlights sites where a project has been specified.

7.3 Evaluation History

Evaluation of potential storage resources in Morocco is limited. In 2013, the EU-funded COMET project completed Morocco's first study evaluating its onshore CO2 storage resources in deep saline formations and oil and gas fields in three basins in close proximity to CO2 emissions sources (Boavida et al., 2013). CO2 storage resources in the Gharb, Doukkala, and Essaouira basins were evaluated, but additional potential is possible in other basins (i.e., Guercif, Souss, Tarfaya, Layaoune, and Dakhla) –most of which are not in close proximity to CO2 emissions sources. The Tadla basin was not considered in the study due to its strategic drinking water resources. No additional studies of CO2 storage resources have been published since the Boavida (2013) evaluation.

7.4 Resource Review

Although the COMET project included CO2 storage resource potential in depleted fields in Morocco, Carneiro et al. (2015) estimated more than 95% of the evaluated CO2 storage resource resides in deep saline formations. Additional storage potential likely exists in Morocco's offshore basins.

7.4.1 Major Projects

In Morocco there are currently no major projects as defined by the CSRC. If supplementary information and data can be accessed, this statement may be updated.

7.4.2 Depleted Oil & Gas Fields

No comprehensive, detailed review of storage potential in depleted oil and gas fields is available in the public domain. The COMET project discarded structures comprising less than 3 Mt. No specific calculations were provided in the Boavida et al. (2013) or Carneiro et al. (2015) publications.

7.4.3 Saline Aquifers

Carneiro et al. (2015) estimated the majority of CO2 storage resources in the basins studied reside in saline formations. Estimated storage resources for depleted oil and gas fieds and saline formations were lumped together in the COMET project. Three sites were evaluated. The Gharb basin is estimated to have limited CO2 storage resource potential, with just 4 Mt. The Doukkala and Essaouira basins are estimated to have 147 Mt and 265 Mt of CO2 storage resource, respectively. The basin-level CO2 storage resource estimates for Morocco are classified as Discovered: Inaccessible by the SRMS. These estimates are "basin play"-scale resources.

Morocco's offshore basins likely contain additional CO2 storage resources but were not considered in the COMET project study due to the proprietary nature of offshore data.

7.5 Regulatory Framework

Morocco does not have a CCS-specific regulatory framework.

As of 2023, countries in the Middle East and Africa have again received assessment scores at the lower end of the spectrum, with four of the 10-lowest scoring nations coming from this region. This result indicates their legal regimes include only a few CCS-specific or existing laws that are applicable across parts of the CCS project lifecycle.

7.6 Issues for the Assessment

The COMET project is the only public CO2 storage resource study for Morocco. Because the project was undertaken at a high level, at basin scale, a detailed, comprehensive country-wide evaluation of Morocco's CO2 storage resources is required. Lack of dynamic modelling, consideration of formation pressure, and ready access to site-specific data are the main issues for Morocco in this assessment cycle.

Additionally, Morocco's offshore CO2 storage resources must be evaluated in the same manner. Currently the Catalogue's assessment represents a low-confidence minimum estimate of Morocco's CO2 storage resource potential.

7.7 Future Updates

7.7.1 Future CRSC Cycles

Should any further development in the Morocco storage systems occur, this should be reviewed on an annual basis to ensure the Global Storage Catalogue is up to date.

8 Oman

8.1 Summary

Oman was assessed during Cycle 3. The CSRC has identified a CO2 storage resource for Oman as follows:

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	0.558	0.558
Aggregated*	0.558	0.558

* 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 Oman

Storage resource potential is present in both saline aquifers and oil and gas fields.

- Oman has zero sites in the CSRC database.

8.2 Evaluation History

Oman was reviewed during Cycle 3 [3]. Although Oman is a prolific hydrocarbon producing country, its resources for the geologic storage of CO2 have not yet been characterized in the public domain. Its world-class oil and gas resources suggest significant potential for geologic storage of CO2 does exist and should form the subject of any future evaluation effort.

8.3 Regulatory Framework

Oman has not developed CCS-specific regulatory or legal frameworks and has not been evaluated in the GCCSI CCS Readiness Index.

8.4 Future Updates

8.4.1 Future Updates for Evaluators

A comprehensive, country-wide assessment of Oman's geologic storage resources is required for both saline reservoirs and depleted oil and gas fields.

8.4.2 Future CSRC Cycles

Updates to the Cycle 3 assessment should be completed if studies on Oman's CO2 storage resources become available.

9 Qatar

9.1 Summary

Qatar was assessed during Cycle 3. The CSRC has identified a CO2 storage resource for Qatar as follows:

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	0.01	0.01
Undiscovered	0.22	0.216
Aggregated*	0.23	0.225

* 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 Qatar

- Qatar has one site in the CSRC: 1 saline aquifer (Discovered/Undiscovered; 0.225 Gt).
- The discovered portion of the identified site in Qatar is classed as "Sub-Commercial: Inaccessible" and the remainder of the site is classed as "Undiscovered: Inaccessible" due to the lack of a CCS regulatory framework for the country.
- There are currently three defined CCS projects in Qatar (Qatar LNG CCS, Qatar Fuel Additive Company CCS, North Field East Project).

9.2 Evaluation History

Subsurface geologic data in Qatar is highly restricted and no comprehensive evaluations of its CO2 storage potential have been completed. The world's largest non-associated gas field (> 900 TCF [4]) is in Qatar, in addition to other substantial oil and gas resources. Significant unassessed geologic storage likely exists in depleted oil and gas fields as well as saline aquifers.

9.3 Resource Review

9.3.1 Major Projects

- In February of 2021, Qatar Petroleum announced a final investment decision of 28 billion dollars for development of the North Field East Project (NFE), which will be the world's largest LNG project. The project will comprise 4 LNG trains with a carbon capture and storage system to be integrated with the existing Ras Laffan (Qatar LNG) CCS project [5].
- Qatar Fuel Additive Company currently captures 0.2 Mtpa at its methanol refinery [6].

- The Ras Laffan LNG CCS facility has been operational since 2020. Its initial capture rate is 2.1 Mtpa, but is projected to grow to 5 Mtpa by 2025 [6].

9.3.2 Depleted Oil & Gas Fields

Qatar is a prolific hydrocarbon producing country, but its resources for the geologic storage of CO2 have not been characterized. Its world-class oil and gas resources suggest significant potential for geologic storage of CO2 exists.

9.3.3 Saline Aquifers

One evaluation, by Ahmed and Nasrabadi [4], has characterized the storage potential of the Aruma saline aquifer in Qatar. The aquifer is a granular limestone averaging 130 m in thickness over an area of 1985 km2. These authors published well data for four new deep wells in the Aruma aquifer, but data for the existing 11 wells in the evaluation area were not provided. The Ahmed and Nasrabadi [4] evaluation tests two CO2 development plans: one model comprising 8 injectors and one model comprising 6 injectors with 2 brine producers. The 6-injector model did not exceed the overburden fracture pressure and was able to inject 225 MtCO2 into the formation.

9.4 Regulatory Framework

Qatar has not developed CCS-specific regulatory or legal frameworks and has not been evaluated in the GCCSI CCS Readiness analysis.

9.5 Issues for the Assessment

Very little subsurface data is publicly available for Qatar, so although the CO2 storage potential in the country is likely high (implied by its extensive oil and gas resources), the total CO2 storage picture remains unclear. The Ahmed and Nasrabadi study [4] assessed here is problematic because their model includes reservoir depths of 300-400 m, which is well above the generally accepted 800 m threshold depth for dense phase geologic storage of CO2.

While the current storage assessment appears robust with a 3D geocellular model and dynamic simulation, some amount of containment risk for future projects exists in the study area due to the 15 legacy wells.

Pressure data from the wells was not provided. The simulation model calculated an assumed initial pressure based on a hydrostatic pressure gradient. Porosity and permeability data were averaged for the CSRC database with values ranging from 11% - 16% and 2263mD - 4187mD, respectively.

As a result of the low maturity of the resource estimation, only a single value is provided for the assessed resource. This has been recorded as the 'Mid-Range' estimate of resource potential. As future studies are planned in the region, an effort needs to be made to move towards generating probabilistic resource evaluations.

9.6 Future Updates

9.6.1 Future Updates for Evaluators

A comprehensive, country-wide assessment of Qatar's geologic storage resources is required for both saline reservoirs and depleted oil and gas fields. Future studies should focus on storage resources at suitable depths (exceeding 800 m) for geologic storage of CO2.

9.6.2 Future CSRC cycles

Updates to this Cycle 3 assessment should be completed if additional studies on Qatar's storage resources become available.

10 Saudi Arabia

10.1 Summary

Saudi Arabia was assessed during Cycle 3. The CSRC has identified a CO2 storage resource for Saudi Arabia as follows:

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	0.742	0.00
Undiscovered	0.00	0.00
Aggregated*	0.742	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 10-1: Storage resource classification summary for Saudi Arabia.

- Saudi Arabia has one site in the CSRC: 1 oil field (Discovered: Inaccessible; 0.742 Gt).
- The identified site in Saudi Arabia is classed as "Discovered: Inaccessible" due to the lack of a CCS-specific regulatory framework for the country.
- Saudi Arabia currently has one defined project – the Uthmaniyah CO2-EOR demonstration project (0.8 Mtpa) [7].

10.2 Evaluation History

Subsurface geologic data in Saudi Arabia is highly restricted. Several publications have noted the highly suitable geologic storage resources in the country, yet the majority of storage resource characterization to-date has been high-level and regional in scope [8], [9]. Saudi Arabia's proven crude oil reserves exceed 260 billion barrels [1]. This tremendous volume of oil resources suggests significant unassessed geologic storage for CO2 likely exists in Saudi Arabia's depleted oil and gas fields and saline aquifers.

Several authors have developed geologic models of geologic formations in Saudi Arabia. Issautier et al. [10] conducted a detailed outcrop-based sequence stratigraphic analysis of the Late Triassic Minjur sandstone. The authors constructed a geologic model from their outcrop analysis and estimated a theoretical 20 km x 20 km x 80 m Minjur sandstone reservoir could hold a mass of 30.5 MtCO2. Khan et al. [11] studied the geomechanical response to CO2 injection in Saudi Arabia's Cretaceous Biyadh sandstone. While their study did not focus on storage resources, their model estimated a theoretical 8 km2 Biyadh sandstone reservoir could hold a mass of approximately 5 MtCO2. These theoretical resource calculations could be useful in future quantitative subsurface CO2 storage resource evaluations.

The storage resources assessed in this cycle for Saudi Arabia were published in a presentation by Salas et al. [12]. These authors built dynamic 3D models of the Permian Unayzah Formation and estimated 741.47 Mt CO2 could be stored (employing the US DOE methodology). Very little information was provided for their work, but the presentation describes facies models and indicates subsurface well control, and thus could be classified as discovered resources in the CSRC.

10.3 Resource Review

10.3.1 Major Projects

- The Uthmaniyah CO2-EOR project captures 0.8 Mtpa CO2 from the Hawiyah Natural Gas Liquids processing facility and transports it 85 km for storage and enhanced oil recovery in the Uthmaniyah oil field [7].

- Saudi Aramco and Hyundai Heavy Industry Holdings signed a Memorandum of Understanding in March 2021 for development of blue hydrogen in South Korea [13]. Ships will bring liquified petroleum gas from Saudi Arabia to South Korea for blue hydrogen production and the captured CO2 will be shipped back to Saudi Arabia for enhanced oil recovery.

10.3.2 Depleted Oil & Gas Fields

Saudi Arabia is a prolific hydrocarbon-producing country and features the world's largest onshore oil field (Ghawar field). Its geologic storage resources for CO2, however, have not been adequately characterized. Salas et al. [12] have estimated 741.47 MtCO2 are present for one site in the Unayzah Formation; however, many more world-class oil and gas resources exist beyond this site, suggesting significant additional storage potential beyond what Salas et al. [12] have published.

10.3.3 Saline Aquifers

Saudi Arabia's geology is highly suitable for geologic storage of CO2 [8], [9], but country-wide characterization of its saline aquifer storage resources has not been completed.

10.4 Regulatory Framework

While Saudi Arabia has allowed state-owned enterprises to utilize CCS for enhanced oil recovery operations, the government has yet to establish a CCS-specific regulatory or legal framework which would encourage private investment in CCS projects.

10.5 Issues for the Assessment

Very little subsurface data is publicly available for Saudi Arabia, so although the CO2 storage potential in the country is likely high (suggested by its extensive oil and gas resources), the total CO2 storage picture remains unclear.

The resources assessed in this cycle provided very little information about storage sites, well control, and formation parameters. We've included the resources as Discovered: inaccessible, but significantly more information is needed to mature these resources toward commerciality. Additional published geologic models of Saudi Arabian geologic formations reviewed in this Cycle are not valid subsurface models (i.e. they are either outcrop models or strictly theoretical block-models). As such, these data cannot be included in the CSRC.

10.6 Future Updates

10.6.1 Future Updates for Evaluators

A comprehensive, country-wide evaluation of Saudi Arabia's geologic storage resources is required for both its saline utilizing well- and seismic- data to constrain model dimensions and stratigraphic architecture. To fully understand the CO2 storage resources of the country, all possible sites need to be characterized and assessed.

10.6.2 Future CRSC Cycles

Updates to this Cycle 3 assessment should be completed if additional evaluations of Saudi Arabia's storage resources become available.

11 Syria

11.1 Summary

Syria was assessed during Cycle 4. The CSRC has identified that Syria has zero published storage resource estimates and therefore no applicable 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 11-1: Storage resource classification summary for Syria

11.2 Evaluation History

Syria was reviewed during Cycle 4. Although Syria comprises sedimentary basins with significant hydrocarbon discoveries, its CO2 storage resources have not yet been characterized in the public domain and should form the subject of any future evaluation effort.

11.3 Resource Review

Syria is situated tectonically among the Dead Sea Fault System to the west, the East Anatolian Fault System to the north, the Euphrates Fault System to the east and the Palmyrides fold and thrust belt in the south (Brew et al., 1997). These tectonic systems have established numerous hydrocarbon-bearing geologic structures and deep sedimentary basins capable of storing CO2. Over 1 billion barrels of recoverable oil reserves have been discovered in Syria, indicating the geologic elements for CO2 storage exist in the country (Brew et al., 1997).

11.4 Regulatory Framework

Syria has not developed CCS-specific regulatory or legal framework and has not been evaluated in the GCCSI CCS Readiness Index.

11.5 Future Updates

11.5.1 Future Updates for Evaluators

A comprehensive, country-wide assessment of Syria's geologic CO2 storage resources is required for both saline formations and depleted oil and gas fields.

11.5.2 Future CRSC Cycles

Updates to the Cycle 4 assessment should be completed if studies on Syria's CO2 storage resources become available.

12 Tunisia

12.1 Summary

Tunisia was assessed during Cycle 4. The CSRC has identified that Tunisia has zero published storage resource estimates and therefore no applicable 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 12-1: Storage resource classification summary for Tunisia

12.2 Evaluation History

Tunisia was reviewed during Cycle 4. Although Tunisia comprises sedimentary basins with significant hydrocarbon discoveries, its CO2 storage resources have not yet been characterized in the public domain and should form the subject of any future evaluation effort.

12.3 Resource Review

Paleozoic and Mesozoic formations of the Ghadames Basin extend into southern Tunisia and Mesozoic to Cenozoic formations of the Pelagian Basin extend into northeastern Tunisia (Echikh, 1998; Schenk et al., 2019). Hydrocarbon discoveries in both basins indicate potential CO2 storage resources exist.

12.4 Regulatory Framework

Tunisia has not developed CCS-specific regulatory or legal framework and has not been evaluated in the GCCSI CCS Readiness Index.

12.5 Future Updates

12.5.1 Future Updates for Evaluators

A comprehensive, country-wide assessment of Tunisia's geologic CO2 storage resources is required for both saline formations and depleted oil and gas fields.

12.5.2 Future CRSC Cycles

Updates to the Cycle 4 assessment should be completed if studies on Tunisia's CO2 storage resources become available.

13 Turkey

13.1 Summary

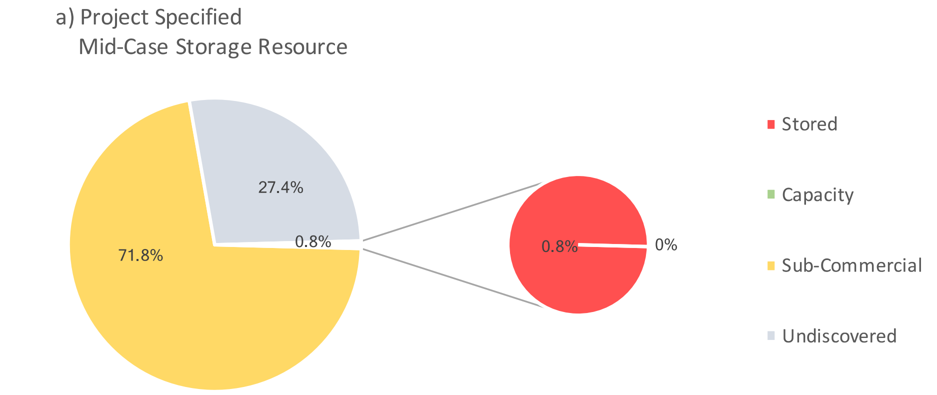
Turkey was assessed during Cycle 4. The CSRC has identified a CO2 storage resource for Turkey as follows:

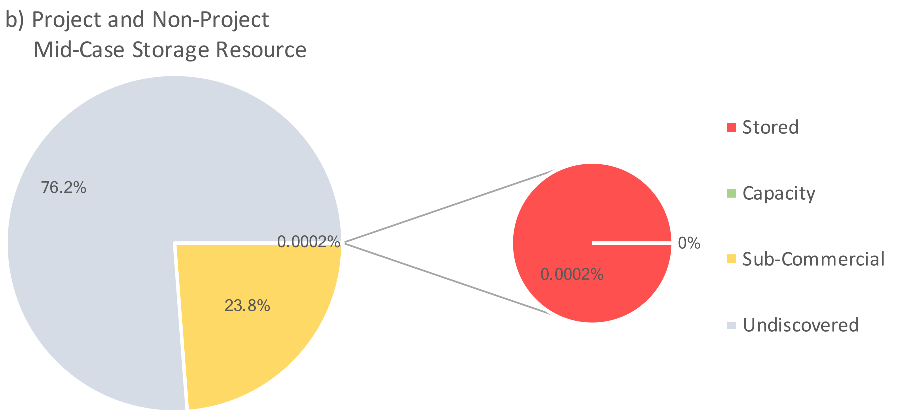
Classification	CO_2 storage resource (Gt) Project and no project	CO_2 storage resource (Gt) Project specified only
Stored	0.000	0.000
Capacity	0.000	0.000
Sub-Commercial	0.0003	0.000
Undiscovered	0.000	0.000
Aggregated*	0.0003	0.000

* 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 13-1: Storage resource classification summary for Turkey

- Turkey has one site registered in the database: Caylarbasi field in Thrace Basin with 0.3 Mt (0.0003 Gt) storage resources (Discovered-Inaccessible)
- There is no record of saline aquifer resources in the database due to insufficient supporting information.
- There is an absence of CCS-specific policy and regulation to support investments in storage development. CO2 EOR has been implemented within the nation. It is imperative that the government prioritise the development of regulations specific to CCS to improve the economic feasibility of storage resources.





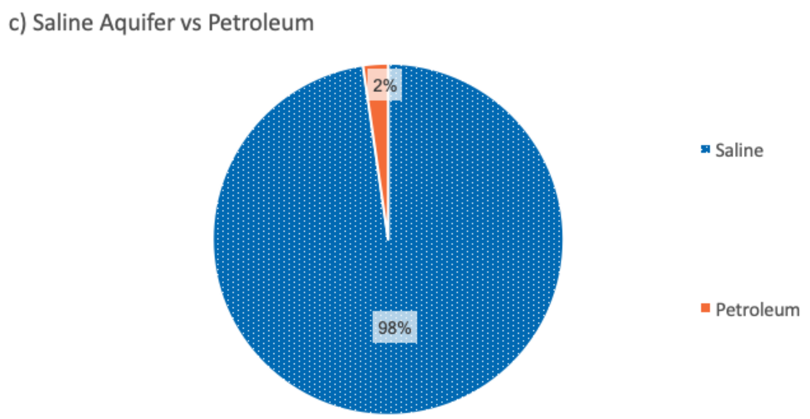


Figure 13-1: Turkey spread of Storage Sites

a) Spread of storage resource in Turkey (xx) across SRMS classifications, where a project has been specified. b) Spread of storage resource in all Turkey sites across SRMS classifications; both project specified and not. c) Split of Turkey 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.

13.2 Evaluation History

The assessment of storage potential in Turkey has focused mainly on depleting oil and gas fields. The deep saline aquifers in the Thrace region, Central Anatolia and Southeastern Turkey and the salt caverns of soda mines have also been identified as potential candidates for CO_2 storage by Okandan et al. (2011). One of the focal points of the study was the Çaylarbaşı oil field, selected for its favourable geological characteristics and proximity to significant CO2 sources like a nearby cement factory. The field offers a dual benefit: enhanced oil recovery (EOR) through CO2 injection and subsequent CO2 sequestration after the EOR phase.

In 2013, the Turkish Ministry of Environment and Urbanization Capacity undertook estimation work for the potential CO_2 -EOR projects and the associated storage in the fields in Batman, Adıyaman and Thrace regions. The study reported the storage potential in these fields to be 108 Mt, but no nationwide survey for CO_2 storage potential has been carried out. (Dasture Energy, 2023). The details of this information are also absent, and the report is not readily available for public access. Hence, the resources are not included in the CSRC database.

13.3 Resource Review

Turkey's storage resources evaluation has focused on oil and gas fields and none on saline aquifers. The potential for storage in Turkey, mainly through enhanced oil recovery (EOR+) followed by CO2 storage, represents a significant opportunity for the country to address climate change while boosting its energy production efficiency.

13.3.1 Major Projects

There are no major projects in Turkey as defined by the CSRC. This statement may be updated if supplementary information and data can be accessed.

13.3.2 Depleted Oil & Gas Fields

The 2011 study by Okandan emphasises this potential through a detailed examination of the Caylarbasi field. This research delineated a 20-year project, split into 8 years of CO2 EOR and 12 years dedicated solely to CO2 storage, showcasing a dynamic simulation that projected a storage capacity of 0.3 Mt of CO2 (220 million standard cubic meters of CO2). The findings suggest that with an initial focus on EOR, the Çaylarbaşı field could significantly boost oil production while serving as a test bed for CO2 sequestration. It illustrates CCS's practicality and economic feasibility in Turkey, mainly if supported by appropriate economic incentives and regulatory frameworks.

The economic assessment within the study highlighted that for the project to be financially viable and significantly beyond the oil recovery phase, substantial incentives or funding mechanisms would be necessary to cover operational costs associated with CO2 sequestration. This finding points to the need for supportive policies to foster CCS deployment.

The 0.3 Mt from Caylarbasi is categorised as Discovered–Inaccessible because a regulatory framework supporting a storage undertaking is absent. By establishing CCS-specific regulations, the experience can be readily applied to enhance the economic viability of storage resources. In addition to the Çaylarbaşı field, the study also mentions the potential of natural CO2 fields, such as the one at Dodan, which has already contributed significantly to the Batı Raman EOR project. These fields present further opportunities for large-scale CO2 storage, suggesting that Turkey could leverage its existing oil and gas infrastructure for CCS.

This finding aligns closely with the broader evaluations by UNECE in 2021, which estimated Turkey's overall potential for EOR at 201 Mt of CO2. However, this recent study only provides a high-level overview of Turkey’s potential, and the resources could not be allocated to a specific formation and site. Hence, it is not included in the CSRC database.

13.3.3 Saline Aquifers

No evaluation of saline aquife4rs in Turkey has been conducted for Cycle 4.

13.4 Regulatory Framework

While Turkey has allowed companies to utilise CO2 for enhanced oil recovery operations, the government has not established a CCS-specific regulatory or legal framework to encourage private investment in CCS projects.

13.5 Issues for the Assessment

The resources assessed in this cycle provided little information about storage sites, well control, and formation parameters. The resources as classed as Discovered: inaccessible, but significantly more information is needed to mature these resources toward commerciality. This means that the Catalogue risks a significant underestimation of storage potential, or at a minimum, a poor representation of the details of the available resources and more work is required.

13.6 Future Updates

13.6.1 Future CRSC cycles

Future research and pilot projects, particularly in deep saline aquifers and other novel storage sites, will be critical to refining the storage capacity estimates and ensuring CCS projects' operational safety and integrity. Should any further development in Turkey’s storage systems occur, this should be reviewed to ensure the Global Storage Catalogue is up to date.

14 United Arab Emirates

14.1 Summary

The United Arab Emirates (UAE) was assessed during Cycle 3. The CSRC has identified a CO2 storage resource for the UAE as follows:

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	16.70	5.91
Aggregated*	16.70	5.91

* 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 UAE

- There are currently 4 sites all within one basin (Rub al Khali) in the UAE.
- Two of the sites are projects.
- All sites are saline aquifers.
- There are no operating CCS projects active in the UAE.
- The UAE government has recognized the need for CCS to reduce the countries emissions, Tsai 2014.

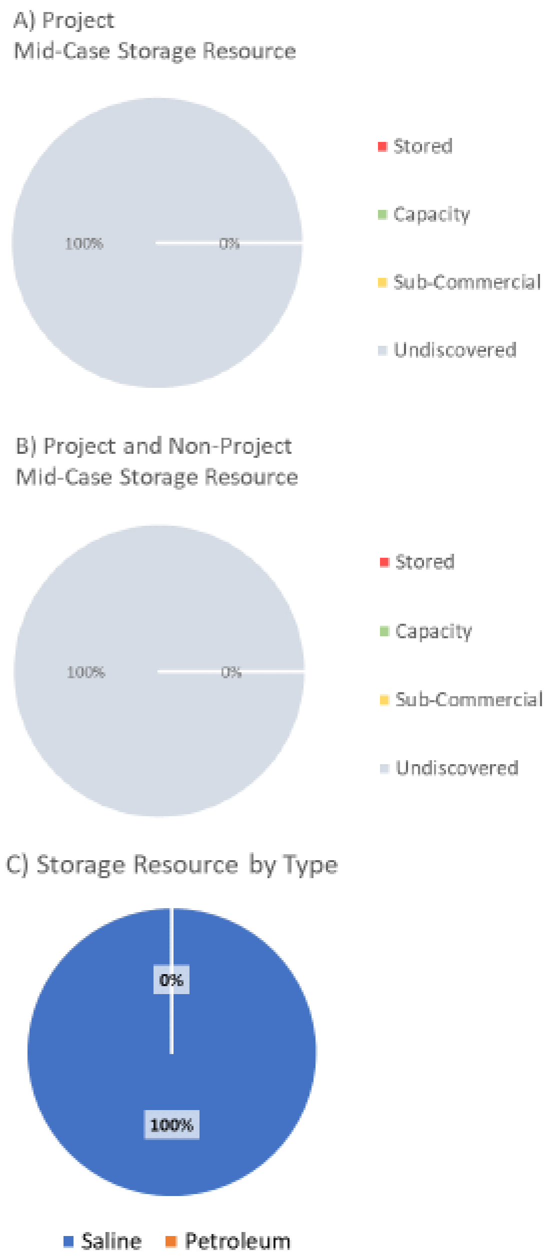


Figure 14-1: UAE spread of Storage Sites

a) Spread of storage resource in the UAE (4) across SRMS classifications, where a project has been specified. b) Spread of storage resource in all UAE sites across SRMS classifications; both project specified and not. c) Split of UAE storage resource between saline aquifers and hydrocarbon fields, both project specified and not.

14.2 Resource Statement

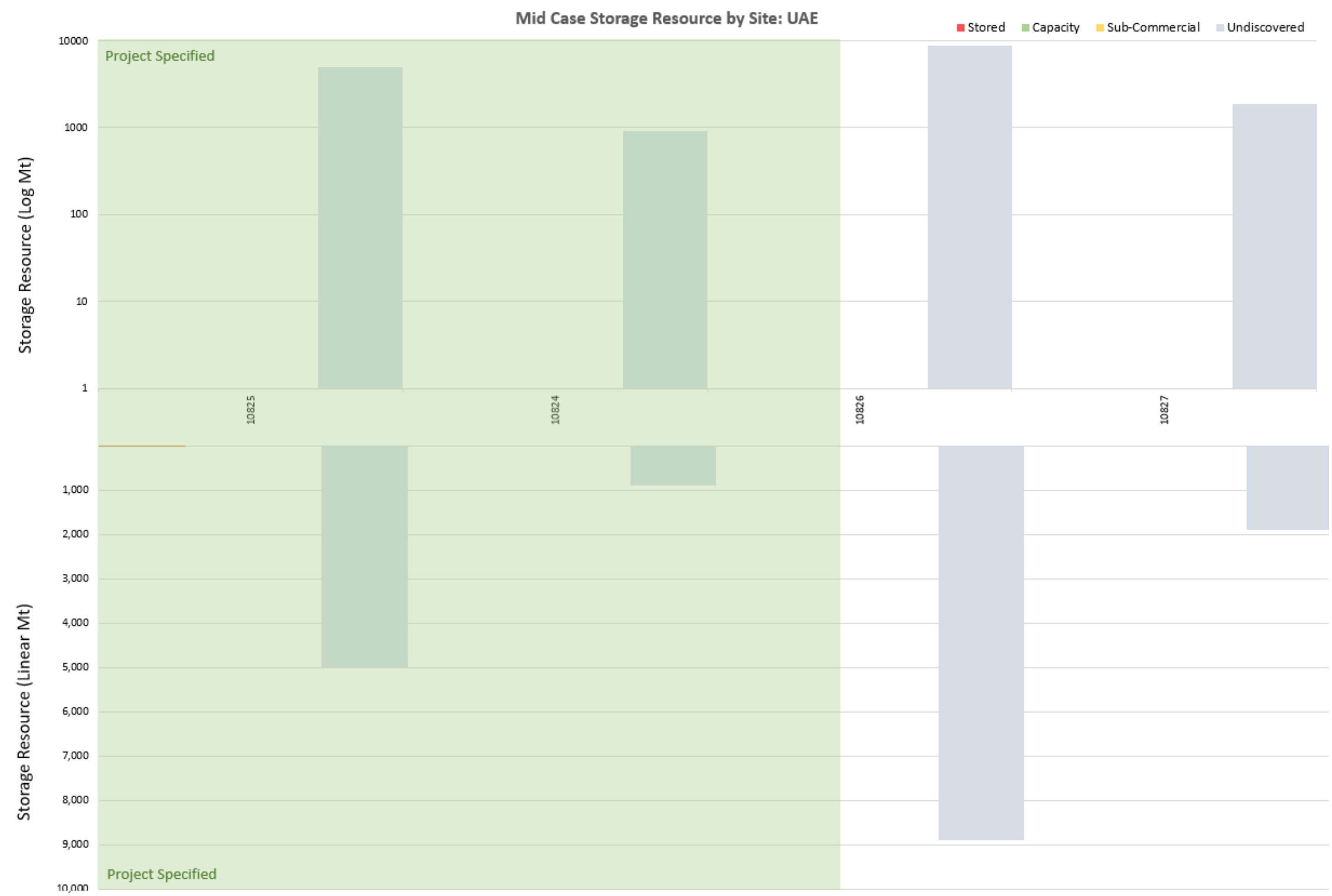


Figure 14-2: Storage resource summary for UAE compiled in the CSRC.

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

14.3 Evaluation History

There are three sources presenting potential resources for the UAE: Ajayi et al 2016 [14], Ajayi et al 2019 [15], and Khan et al 2019 [16]. All three provide information on the Lower Cretaceous Shuaiba Aquifer, but only Ajayi et al 2019 [15] expands this to include the Simsima, Umm Er Radhuma and Dammam aquifers. These three sit in the same AOI as Shuaiba but shallower in the stratigraphy (Upper Cretaceous, Palaeocene & Eocene respectively). Ajayi et al 2016 [14] and Ajayi et al 2019 [15] are linked studies and both are co-authored by Abu Dhabi National Oil Company which hints to their source of funding.

The earliest publication [14] initiates with site selection taking into account salt domes, abandoned oil and gas fields, and shallow and deep aquifers. The following criteria were considered during site selection: long-term storage capacity, permeability, sealing efficiency, closure and leakage conditions, risks (distance from cities), costs (distance from source) and available knowledge of reservoir continuity. Here the Shuaiba aquifer was identified as having the best potential for storing CO2, subsequently a large static geological model was created using well and seismic data. This model was then split up into downsized sector models in order to run dynamic simulations.

Ajayi 2019 [15] started by calculating a volumetric resource (from static models) for the Simsima, Umm Er Radhuman, Dammam and the Shuiaba aquifers. Out of these four, the Simsima and Shuiaba were chosen for dynamic simulation due to their favourable depth and reservoir properties. The simulations were run using GEM to account for buoyant trapping, solubility trapping and residual/ capillary trapping over 100 years of injection and 4000 years shut in. The end resource for the Shuaiba aquifer was the same as that presented in Ajayi 2016 [14]. However, in the 2019 paper, more information was given on well locations and well data allowing a portion of this site to have discovered status under the SRMS.

Khan 2019 [16] also presented a resource study of the Shuaiba aquifer using 2D numerical modelling over 20 years of injection at 0.73Mt/year. This study was also accompanied by an economic assessment using a chemical looping plant with hydrogen reformer as the source of CO2 to be stored. The final cost of CO2 storage was estimated at $4.58/ ton.

This study does not present a final resource, however, it is calculated at 14.6Mt after 20 years of injection, we know from Ajayi 2019 [15] that the Shuaiba aquifer can store 60 times this.

Published evaluations of potential storage resources in the UAE have focused on the Rub al Khali basin ([15] [14] [16]). Several storage types were considered: salt domes, abandoned oil and gas fields, and shallow and deep aquifers. Four saline aquifers (the Shuaiba, Simsima, Umm Er Radhuma, and Dammam formations) have been identified as having storage potential from these studies, which considered several screening criteria (long-term storage capacity, permeability, sealing efficiency, closure and leakage conditions, distance from cities, distance from source and available knowledge of reservoir continuity). Regional scale, static geological models have been built of each of these reservoirs, and deterministic estimates of storage resource have been calculated. Additional dynamic simulation of the Shuaiba and Simsima ([15]) aquifers provides notional storage development plans under two different injection scenarios.

14.4 Resource Review

14.4.1 Major Projects

The Abu Dhabi National oil company (ADNOC) has two capture projects currently operating. These are: Abu Dhabi CCS Phase 1 – Pre-combustion capture from the Al Reyadah steel plant in Mussafah (0.8Mt/year), and Abu Dhabi CCS Phase 2 – Post-combustion capture from a gas processing plant (1.9-2.3Mt/year). Both of these capture projects inject their CO2 into the same oil field, 43km from the Al Reyadah steel plant. Abu Dhabi CCS Phase 1 is the first and only fully commercial CCS facility for the iron and steel industries globally [17].

14.4.2 Depleted Oil & Gas Fields

No CO2 storage evaluations for depleted petroleum fields were found in the public domain for UAE. Due to the large number of hydrocarbon fields in the country, it is highly likely that some future depleted field storage potential does exist and future assessments of the UAE should attempt to quantify this. Ajayi et al 2016 [14] did consider depleted fields at the site selection and screening stage, but no details of field-based storage resources were provided in the publication.

14.4.3 Saline Aquifers

Ajayi et al 2019 [15] identified a total of 15.66 Gt storage resource split across 4 aquifers in the Rub Al Khali basin. The Shuaiba aquifer has been evaluated by two other published studies and appears to be the best candidate for storage. It consists of a large syncline (the Falaha syncline) surrounded by six anticlines that host petroleum fields. The Shuaiba aquifer lies in the Lower Cretaceous which is within the same stratigraphy as the six surrounding petroleum fields, which may provide useful dynamic datasets and proof of a working seal for the Shuaiba formation.

The Simsima aquifer sits above the Shuaiba in the Upper Cretaceous. Ajayi et al [15] used an optimization algorithm to pick suitable injection wells in both aquifers and suggests that 5 vertical wells in each aquifer can be used to inject a total of 5960 Mt over 100 years. Two additional aquifers, the Paleocene Umm Er Radhuma and Eocene Dammam formations, were considered to have less potential for CO2 storage due to shallow depth and poor reservoir properties. Resources for these were only calculated using the volumetric method. These two aquifers lie in the shallowest stratigraphy of the area of interest. Due to the lack of any CCS specific policy in the UAE, all resources are classed as inaccessible under the SRMS, with a small portion (6%) of the Shuaiba aquifer being discovered, inaccessible (51Mt).

14.5 Regulatory Framework

The second UAE NDC – UNFCCC submission (2020) commits the country to reducing emissions by 23.5% by 2030, relative to the business as usual scenario. This NDC specifically mentions that CCUS will be one of the measures used to bring this reduction into effect. The plan is to build on the success of the country's two CCS pilot projects which capture CO2 from steel and gas processing. As yet though, the country has not published any CCS specific policies or regulations (according to the CCS Readiness Index [18]). Currently all CCS activities are regulated on a case-by-case basis as all projects are operated by the government owned Abu Dhabi National Oil Company (ADNOC). The Masdar institute, Abu Dhabi has published a paper titled: Carbon Capture Regulation for The Steel and Aluminium Industries in the UAE: An Empirical Analysis [19], which could help to lead the way to a more country wide regulation system. Currently, however, all storage resources given in Cycle 3 for UAE sit in the inaccessible category due to this lack of CCS regulation and policy.

14.6 Issues for the Assessment

Ajayi 2019 [15] mentions that a database of 4768 wells was used to create the geo models, but that a lot of them had poor data quality for the aquifers above the Lower Cretaceous stratigraphy. This suggests that the level of published detail is not fully representative of the available data, resulting in a lower maturity classification for the identified storage resource. The stated resources may be able to progress through the SRMS classification if more information can be published. The two existing carbon storage projects in UAE are EOR pilot projects. These are not included in the CO2 Storage Resource Catalogue because the SRMS does not include EOR projects.

14.7 Future Updates

The resource added in Cycle 3 is solely for saline aquifers. Future assessments should look for any evaluations of depleted field storage resources as well as new evaluations of storage resource in saline aquifers.

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