Global Storage Portfolio

A global assessment of the geological CO₂ storage resource potential

Global CCS Institute

March 2016
Project Team

The Global Storage Portfolio report was prepared by the Global CCS Institute. Dr Christopher Consoli, Senior Adviser – Storage, Asia Pacific was the project’s author.

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EXECUTIVE SUMMARY

Carbon capture and storage (CCS) could contribute up to 13% of the greenhouse gas (GHG) mitigation effort between 2015 and 2050 according to the International Energy Agency. This equates to 95 gigatonnes (Gt) of permanent geological storage (herein storage) of anthropogenic carbon dioxide (CO₂). Hence, a central issue in storage is: is there sufficient storage space available to support the industrial-scale deployment of CCS required to achieve GHG mitigation targets over the coming decades?

Answering this question is a challenge because geological storage requires subsurface environments with particular sets of characteristics that can ensure sufficient space is available for the permanent storage of injected CO₂. Regional assessments that estimate storage potential over wide geographical areas, for example national surveys, are the first step to answering this question. These assessments typically focus on the technical aspects of storage and can provide valuable information to policy makers, regulators and industry on the distribution and scale of the storage potential to support CCS deployment. The main outcome from a regional assessment is the estimation of storage resource, which is the potential storage space that could be utilised, subject to engineering, economic and regulatory factors.

The primary purpose of the Institute’s Global Storage Portfolio is to collate and summarise published regional assessments of key nations. The Portfolio also summarises key data on a nation’s readiness to host a commercial, large-scale project. For this reason, only proven storage scenarios including deep saline formations (DSF), depleted/depleting oil and gas fields (DGOF) and enhanced oil recovery using CO₂ (CO₂-EOR) are considered. The analysis has found that:

- Substantial storage resources are present in most key regions of the world.
- Reliable methodologies to determine and classify regional storage resources are available and have been widely applied, although there is no formally recognised international standard.
- The level of resource assessment undertaken and the availability of characterisation data is highly variable across regions.
- The level of detail a regional resource assessment has progressed as well as the policy, legal and regulatory frameworks are key criteria that can be used to gauge the readiness of any given nation to deploy a CCS project.

Based on the above findings, it is important to state that each resource value should not be compared or collated to represent storage resource globally. This is largely because in each assessment the geological parameters, calculation method, quality of data and level of detail is different. Note also that regional storage resource does not equate to proven storage capacity, which can only be obtained through detailed site-scale appraisal and include engineering, economic, legal and regulatory factors. Each of these factors affect the final amount of CO₂ able to be injected and stored. Also, this portfolio is accurate as of the published date and reflect the current publically available sources of information. It is designed to be updated periodically. As research and storage exploration continues over time, the suitability of basins for storage will evolve along with the storage resources.
The storage resources are grouped into five regions, Asia-Pacific (fourteen countries), Americas (five countries), Middle East (three countries), Europe and Russia (EU plus three countries) and Africa (four countries). The resulting portfolio will enable the reader to rapidly establish a snapshot of a country's storage resource and potential to deploy a large-scale project. A summary of key results are detailed in Table 1.

<table>
<thead>
<tr>
<th>COUNTRY</th>
<th>ASSESSMENT STATUS¹</th>
<th>ESTIMATED RESOURCE (GTCO₂)</th>
<th>RESOURCE LEVEL²</th>
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</thead>
<tbody>
<tr>
<td>ASIA-PACIFIC</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Australia</td>
<td>Full</td>
<td>227-702</td>
<td>Effective</td>
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<tr>
<td>Bangladesh</td>
<td>Limited</td>
<td>20</td>
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<td>USA</td>
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<td>2,367-21,200</td>
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</table>

¹ For definition see section 2.3.1 Classification of the assessment.
² For definition see section 2.3.2 Classification of the resource.
### MIDDLE EAST

<table>
<thead>
<tr>
<th>Country</th>
<th>Access</th>
<th>Value</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jordan</td>
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<td>9</td>
<td>Theoretical</td>
</tr>
<tr>
<td>Saudi Arabia</td>
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<td>5-30</td>
<td>Theoretical</td>
</tr>
<tr>
<td>UAE</td>
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<td>Theoretical</td>
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### EUROPE AND RUSSIA

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<th>Value</th>
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<td>Norway</td>
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<td>UK</td>
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<td>78</td>
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### AFRICA

<table>
<thead>
<tr>
<th>Country</th>
<th>Access</th>
<th>Value</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>Algeria</td>
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<td>10</td>
<td>Theoretical</td>
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<tr>
<td>Morocco</td>
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</tr>
<tr>
<td>Mozambique</td>
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<td>2.7-229</td>
<td>Theoretical</td>
</tr>
<tr>
<td>South Africa</td>
<td>Moderate</td>
<td>162</td>
<td>Theoretical</td>
</tr>
</tbody>
</table>

**Note:** Each resource value was developed independently and should not be compared or collated to represent storage resource globally.
1 Introduction

Industrial-scale, geological storage of anthropogenic CO$_2$ (herein referred to as storage) has been successfully and securely demonstrated at a number of sites around the world over the past two decades, both in deep saline formations (DSF) and associated with enhanced oil recovery (CO$_2$-EOR) operations. Storage has been undertaken in both onshore and offshore environments. This has built on the knowledge base already derived from more than 40 years of CO$_2$-EOR operations in North America, which have predominantly utilised CO$_2$ extracted from natural geological reservoirs. Large-scale storage in depleted gas and oil fields (DGOF) can also be considered as a mature storage option, given the industrial analogues offered by natural gas storage operations.

The IEA$^3$ and IPCC$^4$ both confirm that carbon capture and storage (CCS) is a critical component in reducing emissions to avoid climate change. The IEA predicts between now and 2050, 95 gigatonnes (Gt; billion tonnes) of storage capacity will be required if CCS is to contribute up to 13% of emissions reductions necessary to limit atmospheric temperature rises to 2$^\circ$Celsius. The Global CCS Institute (2014) and many other CCS authorities have cited that the identification and quantification of storage sites is a critical component to the deployment of CCS Projects. Furthermore, not knowing how much storage potential is available to individual countries and delaying identification of specific sites will delay the acceleration of CCS. The availability of storage space for injected CO$_2$ is a critical precondition of a CCS project.

Hence, the Institute has undertaken a global review of data from storage resource assessments based on publically available information as of December 2015. This portfolio is accurate as of the published date and reflect the current publically available sources of information. It is designed to be updated periodically. As research and storage exploration continues over time, the suitability of basins for storage will evolve along with the storage resources. The results have been summarised in Table 1.

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2 Portfolio Methodology and Definitions

The primary purpose of the Institute's Global Storage Portfolio is to collate and summarise the regional assessments of key nations. This portfolio focusses on nations that have been the subject of published, English-written (or translated) storage resource assessments. It is grouped in five regions, Asia-Pacific (fourteen countries), Americas (five countries), Middle East (three countries), Europe and Russia (EU plus three countries) and Africa (four countries).

2.1 Storage assessments

The aim of any storage assessment is to characterise the subsurface to identify sufficient storage space for the permanent storage of injected CO\textsubscript{2}.

A storage assessment can be broadly split into two contrasting scales:

- Regional, in which the storage resource will be estimated by characterising the geological technical factors but not engineering, economic, legal or regulatory constraints.
- Site-specific, where capacity is accurately determined after detailed characterisation.

Characterisation is the term used for the process whereby information and data are collected and analysed to improve understanding of subsurface geological conditions. The geological characteristics that are either essential or preferable for secure and efficient geological storage are well understood and therefore screening criteria can be developed to identify suitable geological formations for storage. The first basic requirement for large-scale storage is the presence of thick sequences of sedimentary rocks referred to as basins. The characterisation of the basins can then enable ranking and in some cases elimination of a basin from further consideration using the criteria below:

- Depth: basins that extend to less than 1,000 metres depth are unlikely to have sufficient reservoir thickness at depths where efficient use of pore space for storage is achieved
- Stratigraphy: the sedimentary sequence should include suitable reservoir layers and at least one major, extensive, regional-scale sealing layer
- Pressure regime: storage in basins with over-pressures in potential reservoirs may be problematic
- Seismicity: basins with low levels of natural seismicity are favourable for storage, whereas basins in highly active seismic zones require more extensive characterisation
- Geothermal regime: high temperature gradients (>350°C/kilometre) may lead to unsuitable conditions for storage
- Faulting and fracturing: basins or zones with a high degree of recent faulting and fracturing (for example, transecting sealing rocks) should be avoided due to risks associated with potential leakage.

2.2 Storage scenarios

Only proven storage scenarios including deep saline formations (DSF), depleted/depleting oil and gas fields (DGOF) and enhanced oil recovery using CO\textsubscript{2} (CO\textsubscript{2}-EOR) are considered in this Portfolio. Each scenario has different factors that may affect the storage resource estimate.

Deep saline formations (DSF)

Deep layers of porous and permeable rock in which pore spaces are filled with saline groundwater (alternatively termed 'brine'). DSF have the largest resource potential of any storage scenario.
However, information available for characterisation of DSF may in some regions be limited, leading to broad assumptions in resource estimation.

Depleted oil and gas fields (DGOF)

The nature of most regional assessments means this Portfolio did not distinguish between producing or closed/abandoned oil and gas fields, where the extraction of hydrocarbons has ceased due to the exhaustion of economic reserves. The key concept for this storage scenario is that CO\(_2\) may be injected for solely storage purposes after the cessation of oil or gas production, either now or at some point in the future.

Depleted fields have, by definition, retained buoyant fluids (often including CO\(_2\)) over long periods of geological time, giving confidence that sealing layers above the reservoir will securely contain injected CO\(_2\). Proprietary issues can affect the availability of data upon which resource assessments are made. However, there is often enough available information on oil and gas fields in the public domain to allow screening of storage opportunities and meaningful assessments of regional resources.

CO\(_2\)-EOR

EOR is a tertiary method to boost production in a typical production life cycle. EOR, including CO\(_2\), typically involves the injection of substances that help mobilise remaining oil in the reservoir through various physical and chemical processes. Storage resources associated with EOR as estimated in this study refer only to the injection of anthropogenic source of CO\(_2\).

CO\(_2\)-EOR sites are operated to maximise incremental oil recovery and minimise the purchase of CO\(_2\). With time, EOR sites typically return an increasing proportion of injected CO\(_2\) to the surface with produced oil; however, the use of recycling systems ensures that losses of CO\(_2\) to the atmosphere are near to zero. Ultimately, virtually all purchased CO\(_2\) will be securely retained in the subsurface – this is often referred to as incidental storage.

Commercial sensitivities dictate that much of the detailed information around operational oilfields is proprietary. Nevertheless, publicly available information on oilfield characteristics is often sufficient to be used in the assessment of potential storage resources associated with CO\(_2\)-EOR operations. Many assessments include ‘next generation’ EOR technologies, including injection into unconventional reservoirs (*tight* oil/shale gas) or residual oil zones (ROZs), which offer significant additional potential.

2.3 Storage resource classification schemes and methods

The estimation of regional storage resources is an important exercise, enabling industry, regulators, policy makers and other stakeholders to better understand the potential deployment of CCS. Reliable quantification and classification of storage resources will also be required as pore space within storage reservoirs becomes a commodity to be utilised by CCS projects. Classification schemes track the technical, economic and regulatory maturity of resource assessments.

However, the quantification of storage resources is complex and may depend on a number of technical factors. Several alternative quantification methodologies and associated classification schemes have been proposed, although none have yet been adopted as a standard approach.

2.3.1 Resource calculation methods

Most regional assessments have been based on static, volumetric calculations (note that storage resources are quoted as a mass of CO\(_2\)). To calculate the volume of a DSF reservoir the following basic steps were typically undertaken by each assessment:
1. Determine the total pore volume of a potential storage formation(s) by multiplying the estimated areal extent, thickness and porosity of the formation(s) at depths suitable for storage. Although mathematically simple, these calculations may give rise to significant variations between assessments as each may use different geological parameters, reservoir conditions, definition of storage space, quality of data and level of detail (and effort).

2. Determine the proportion of the total pore volume that can be physically accessed and occupied by injected CO$_2$ by using a storage efficiency factor ($E$). Assumed values for $E$ vary according to such factors as the scale of assessment, formation rock-type and pressure/liquid flow regime. $E$ values could range from under 1 % for ‘closed’ DSF to above 5 per cent for an ‘open’ DSF systems, and have increasingly become derived from dynamic modelling results for selected case study sites or formations. A probabilistic range of $E$ factors is often used to cater for uncertainty in geological properties and subsurface conditions.

3. The final step is to convert the volume of available pore space to a mass of CO$_2$ taking into account the properties of CO$_2$ at the assumed, or measured pressure and temperature conditions in the reservoir.

The resource calculation can then be modelled using probabilistic estimates, which accounts for uncertainty inherent in geological assessments by using ranges of data inputted into statistic simulations to get a final range of values. Finally, a few countries have progressed to dynamic simulations. This computer-based modelling technique simulates CO$_2$ injection into a reservoir, predicting the migration and ultimate fate of injected CO$_2$ in response to various physical and chemical processes. This modelling can assist in understanding of storage efficiency but typically requires detailed data to complete.

Regional assessments of storage resources associated with CO$_2$-EOR and DGOF may be undertaken using a similar approach to DSF. Most commonly, consideration of extracted and remaining hydrocarbon reserves allows a simple ‘mass balance’ approach to be adopted, typically expressed as original oil in place (OOIP), original gas in place (OGiP) or ultimate recoverable resource (URR).

In this Portfolio, the storage resource estimates are presented in gigatonnes (Gt) of CO$_2$ (rounded to the nearest integer) unless the value is relatively low or describing injection rate in which case the value is million tonnes (Mt), or million tonnes per annum (Mtpa), respectively. There has been no attempt to combine and standardise storage resource estimates from individual studies.
2.3.2 Classification of the resource

It is important to categorise a storage resource estimate based on the amount of data and degree of detail that has gone into that estimate. The CSLF classification scheme is the most widely adopted in the storage literature, classifying the pore space available for CO\textsubscript{2} storage into a hierarchical (but not necessarily sequential) pyramid scheme (Figure 1).

- **Theoretical resource**: the maximum amount of CO\textsubscript{2} that the geological body can ultimately permanently store. This is the most widely applied classification especially for multinational and national studies, or where data is limited.
- **Effective resource**: theoretical resource constrained by physical and chemical properties of the geological body. Typically applied at basin-scale, it requires measured data from the reservoir (or geological analogues). The confidence in effective resource estimates can vary widely.
- **Practical resource/capacity**: effective resource limited further by engineering and technical constraints, as well as economic factors and regulatory barriers. Generally only applied at site scale due to the large amount of data required to understand the geology. Transition from resource to capacity is upon commercial realisation of that pore volume.
- **Matched capacity**: practical capacity where injectivity rates of an operational storage project connected to a capture rate. Inherently, no regional assessment would be defined as a matched capacity.

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5 CSLF. 2007. *Estimation of CO\textsubscript{2} storage capacity in geological media.*
2.3.3 Classification of the assessment

Comparable to the storage resource estimate, it is also important to categorise the extent and level of detail that has gone into creating a regional resource assessment. The Institute uses a series of categories that reflect the level of assessment set according to the CSLF pyramid and how extensive that assessment has been across the country (Figure 2). Countries are categorised according to the following criteria:

- **Full**: comprehensive assessments (including published Atlases) that cover most or all potential storage basins with accompanying effective resource calculations
- **Moderate**: national studies/atlases without widespread effective resource calculations; or, partial coverage by state/province/basin scale atlases or detailed assessments
- **Limited**: more restricted studies, consisting of relevant research into selected basins or sites
- **Very limited**: minimal or no published research relating to storage potential.

![Geographical coverage of storage resources assessments](image)

Figure 2 Geographical coverage of storage resources assessments

2.4 Indicators: Storage Readiness, Policy, and Legal and Regulatory

The Institute has created a series of key indicators to track the progress of CCS in key nations, including the *Global Storage Readiness Assessment*, *Carbon Capture and Storage Policy Indicator* and *Carbon Capture and Storage Legal and Regulatory Indicator*. A summary of the definitions extracted from the indicators is outlined below. For the detailed methodology behind each section please see Appendix 1.

**Storage Readiness Indicator**

The *Global Storage Readiness Assessment* represents each nation’s ability to deploy multiple, large-scale storage projects assessed against a number of individual criteria and scored accordingly. For more information see Appendix 1.

From the scoring system, five broadly-defined bands have been used to categorise each country:
Global Storage Portfolio

- **Prepared for wide-scale storage:** Operating large-scale CCS projects, CCS R&D program, extensive characterised storage potential, an innovative and advanced oil and gas industry.

- **Well advanced:** Potentially a large-scale CCS project, or a pilot storage project, CCS R&D program, extensive characterised storage potential, and potentially a mature oil and gas industry.

- **Making progress:** A developing CCS R&D program and potentially a storage project, either well characterised storage, or extensive storage potential.

- **Just starting:** Not actively pursued any extensive storage studies locally, or explored CCS in detail.

- **Yet to make a start or very low potential:** Limited storage studies or potential for storage.

Download a full version of the [Global Storage Readiness Assessment](#).

**Legal and Regulatory Indicator**

The **CCS Legal and Regulatory Indicator** represents a detailed assessment of each countries’ legal and regulatory frameworks for CCS which were assessed against a number of individual criteria and scored accordingly between 0 and 87. For more information see Appendix 1.

From the scoring system, three broadly-defined bands have been used to categorise each country:

- **Band A:** CCS-specific laws or existing laws that are applicable across most parts of the CCS project cycle (Score 60-87)

- **Band B:** CCS-specific laws or existing laws that are applicable across parts of the CCS project cycle (Score 36-60)

- **Band C:** Very few CCS-specific or existing laws that are applicable across parts of the CCS project cycle (<36)

Download a full version of the [CCS Legal and Regulatory Indicator](#).

**CCS Policy Indicator**

The **CCS Policy Indicator** draws from an extensive Institute database of policy measures for a wide range of countries, including direct support for CCS as well as broader implicit support through measures such as carbon pricing. For more information see Appendix 1.

- **Upper Tier:** CCS Policy environment that are generally supportive of CCS activities.

- **Upper-Mid Tier:** CCS Policy environment that demonstrate a higher-order potential to support CCS activities.

- **Lower-Mid Tier:** Discrete but relatively limited policies that are supportive of CCS.

- **Lower Tier:** CCS Policy environments that reflect an early stage of technology demonstration.

Download a full version of [CCS Policy Indicator](#).
2.5 Projects

A pilot or commercial injection project is the ultimate step to storage readiness. It shows that a country has progressed to the point of enabling deployment of CCS projects. In order to progress to this point, the project has met technical, economic, social and regulatory hurdles through expertise and knowledge of CCS requirements. A project shows that CCS is possible in their nation and this is important for public perception. There are two categories in the Portfolio:

- **Large-scale integrated CCS projects (LSIPs)**: are defined as projects involving the capture, transport, and storage of CO\(_2\) at a scale of at least 800,000 tonnes of CO\(_2\) annually for a coal–based power plant; or at least 400,000 tonnes of CO\(_2\) annually for other emissions–intensive industrial facilities (including natural gas–based power generation).
- **Notable projects**: are projects that are not of a sufficient scale to be considered as large-scale projects or were not fully integrated. Notable projects provide valuable information to assist in the design and development of CCS projects and advance the understanding of the behaviour of CO\(_2\) in the subsurface. Projects with only capture or transport-focus are not reported here.

2.6 Prospective basins

Where possible prospective basins have been detailed for each nation. This list is derived from national basin storage assessments that have ranked basins or are from general basin prospectivity studies from independent studies. In general a prospective basin would meet the criteria detailed in 2.1 Storage assessments section. At the very least, a prospective basin has oil and gas fields.
3 ASIA-PACIFIC

3.1 Australia

3.1.1 Summary

Australia has a strong understanding of the storage resource potential because it has completed several national and basin-scale studies based on extensive knowledge of the subsurface geology. Significant storage potential occurs in both the onshore and offshore basins especially in the northwest, central and southeast basins. A mature oil and gas industry in many basins has associated storage potential in DGOF especially in the Gippsland Basin. There is limited opportunity for CO₂-EOR. There are dedicated CCS programs and projects, which work openly in the scientific community and have completed several R&D programs including pilot injection and monitoring, measurement and verification (MMV).

There is a reasonable match between large, point source emissions and storage opportunities only in the northwest and a moderate source-storage opportunities match in the south east.

The first national study, GEODISC estimated 740 GtCO₂ of effective storage resource within 48 of the most prospective basins (Bradshaw et al. 2000). The latest study estimated an effective storage resource of 227 to 702 GtCO₂ in 26 of the highest ranked or strategically important basins (e.g. adjacent to high emission sources) have (Carbon Storage Taskforce 2009).

At the state level detailed studies have been completed in Western Australia (3D-GEO Pty Ltd. 2013), Victoria (Goldie Divko et al. 2009) and Queensland (Bradshaw et al. 2009). Basin and site-scale studies, including dynamic simulations have focussed on the Gippsland, Otway, Bonaparte, Darling, Perth and Surat Basins.

3.1.2 National Resource Assessment Status

<table>
<thead>
<tr>
<th>Estimated resource (GtCO₂)</th>
<th>Resource level</th>
<th>Resource Calculation Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>227-702*</td>
<td>Effective</td>
<td>Volumetric using storage efficiency factor and probabilistic modelling.</td>
</tr>
</tbody>
</table>

*selected basins only

Carbon Storage Taskforce 2009
3.1.3 Prospective basins

**Gippsland** (offshore, southeast): Total basin estimate: 30-80 GtCO₂; effective resource based on national study (Carbon Storage Taskforce 2009). Site estimate example: Injection rates of 1-5 Mtpa CO₂ based on CO₂ injection simulations have been modelled for the nearshore region (Hoffman et al. 2015).

**Eromanga** (onshore, central): Total basin estimate: 12-53 GtCO₂; effective resource based on national study (Carbon Storage Taskforce 2009). 12 MtCO₂; effective storage resource based on comprehensive reservoir-seal study (Bradshaw et al. 2009).

**Northern Carnarvon** (offshore, northwest): Total basin estimate: 26-89 GtCO₂; effective resource based on national study (Carbon Storage Taskforce 2009). Gorgon Project plans to inject 3-4 Mtpa CO₂.

**Browse** (offshore, northwest): Total basin estimate: 7-16 GtCO₂; effective resource based on national study (Carbon Storage Taskforce 2009).

**Cooper** (onshore, central): Total basin estimate: 4-15 GtCO₂; effective resource based on national study (Carbon Storage Taskforce 2009). QLD portion of total basin estimate: 172 MtCO₂; effective storage resource based on comprehensive reservoir-seal study (Bradshaw et al. 2009).

3.1.4 Map
3.1.5 Projects

LSIP: Gorgon Carbon Dioxide Injection Project (Onshore, Northern Carnarvon Basin, central west): Execute; DSF.

LSIP: CarbonNet Project (offshore Gippsland Basin, southeast): Evaluate; DSF.

LSIP: South West Hub Project (onshore Perth Basin, southwest): Evaluate; DSF.

Notable: CO2CRC Otway Project (Onshore Otway Basin, southeast): Operate; DSF.

3.1.6 CCS Indicators

3.1.7 Key References

3D-GEO Pty Ltd. 2013. Western Australia carbon dioxide geological storage atlas: Geological Survey of Western Australia, Report 126.


3.2 Bangladesh

3.2.1 Summary

Bangladesh has only one published storage assessment. The Bengal Basin covers much of the country and is thought to have moderate potential on the eastern half of the basin, both onshore and offshore in DSF. IEAGHG (2008) identified a theoretical storage resource of 20 GtCO₂ in DSF. There is an established gas industry in the country with increasing opportunity for DGF storage in the east with over 1.1 GtCO₂ of theoretical storage; two gas fields being over 200 Mt each (based on ultimate recoverable resources (URR) with CO₂-replacement assumptions) (IEAGHG 2008).

There is a match between large point source emissions and storage opportunities (IEAGHG 2008). Bangladesh requires a national-scale DSF and DGF study to identify prospective areas for storage and effective storage resource potential.

3.2.2 National Resource Assessment Status

Status: Limited

<table>
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<th>Estimated resource (GtCO₂)</th>
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<tr>
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<td>Theoretical</td>
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</tr>
</tbody>
</table>

IEAGHG 2008

3.2.3 Prospective basin

Bengal (onshore/offshore): Total basin estimate: 20 GtCO₂; theoretical storage resource based on multi-national assessment (IEAGHG 2008).
3.2.4 Map

3.2.5 CCS Indicator

3.2.6 Key References

3.3 China

3.3.1 Summary

China has a strong understanding of storage resource because it has completed several national and basin studies, publishing 860 studies (CCOP 2014).

China has, volumetrically, some of the largest storage resources in the world both onshore and offshore, especially when considering the overlap between large point source emissions and storage opportunities. The majority of storage will be in DSF. China has a mature oil and gas industry in many basins across the country and the potential for DGOF and CO₂-EOR is highly likely. There are dedicated CCS programs and projects, which work openly in the scientific community and have completed several R&D programs including pilot injection projects.

A national assessment estimated a theoretical storage resource of 3,080 GtCO₂, with DSF accounting for 99% (Dahowski et al. 2009). A subsequent onshore national study using higher resolution detail and more data estimated an effective storage resource of 1573 GtCO₂ for all suitable, onshore basins (Wei et al. 2013). A national assessment on CO₂-EOR estimated around 7.7 billion barrels of oil could be recovered and with a practical storage resource of 2.2 GtCO₂ of CO₂ (Wei et al. 2015).

The majority of large point source emissions are within close proximity to potential storage resources (less than 100 km) (Li et al. 2009).

Most published work comprises basin-scale assessments, often as part of provincial-wide studies. Over the last decade, almost every prospective basin in China has been characterised, including high level large point source emissions -storage opportunities matching, and an effective resource estimate completed. Many basins have preferred sites selected and some have already completed pilot projects.

3.3.2 National Resource Assessment Status

**Status:** Full

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<td></td>
</tr>
<tr>
<td>Wei et al. 2013</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
3.3.3 Prospective basins

**Ordos** (onshore; central): Total basin estimate: 60-700 GtCO₂; effective resource based on detailed reservoir-seal analysis (Jiao et al. 2011); Site estimate example: Injection rates of up to 18 Mtpa based on CO₂ injection simulations (Jiao et al. 2011). LSIP Yanchang CCUS Project plans to inject over 1 Mtpa. Site of several pilot projects.

**Pearl River Mouth** (offshore, southeast): Total basin estimate: 110-443 GtCO₂; effective resource based on detailed reservoir-seal analysis (Zhou et al. 2013).

**Bohai** (onshore/offshore, northeast): Total basin estimate: 192 GtCO₂ effective resource based on detailed reservoir-seal analysis (Li et al. 2015).

**Songliao** (onshore, northeast): Total basin estimate: 20 GtCO₂ effective resource based on detailed reservoir-seal analysis (Su et al. 2013). Site estimate example: Injection rates of 15 Mtpa based on CO₂ injection simulations (Zhao et al. 2012).

**Tarim** (onshore, west): Total basin estimate: 745 GtCO₂; theoretical resource based on national study (Dahowski et al. 2009).

3.3.4 Map
3.3.5 Projects

LSIP: Sinopec Qilu Petrochemical CCS (Onshore, Bohai Basin, Shandong): Define; CO₂-EOR.
LSIP: Sinopec Shengli Power Plant CCS (Onshore, Bohai Basin, Shandong): Define; CO₂-EOR.
LSIP: Yanchang Integrated CCS Demonstration Project (Onshore, Ordos Basin, Shaanxi): Define; CO₂-EOR.
LSIP: PetroChina Jilin Oil Field EOR Project (Phase 2) (Onshore, Jilin): Define; CO₂-EOR.
LSIP: Huaneng GreenGen IGCC (Phase 3) (Onshore, Songliao/Yitong basins, Jilin): Evaluate; CO₂-EOR.
LSIP: Shenhua Ordos CTL (Phase 2) (Onshore, Tianjin): Evaluate; DSF.
LSIP: Shanxi International Energy Group CCUS Project (Onshore, Shanxi): Identify; CO₂-EOR.
LSIP: Shenhua Ningxia CTL (Onshore, Ningxia): Identify; CO₂-EOR.
LSIP: China Resources Power (Haifeng) Integrated Carbon Capture and Sequestration Demonstration (Offshore, Pearl River Basin, South China Sea): Identify; DSF.

Notable: Shenhua Group Ordos Carbon Capture and Storage (CCS) Demonstration Project (Onshore, Ordos Basin, Inner Mongolia): Operate; DSF.

Notable: Sinopec Shengli Oilfield Carbon Capture Utilization and Storage Pilot Project (Onshore, Bohai Basin, Shandong): Operate; CO₂-EOR.

3.3.6 CCS Indicators

<table>
<thead>
<tr>
<th>Storage Readiness Indicator</th>
<th>Policy Indicator</th>
<th>Legal &amp; Regulatory Indicator</th>
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<tr>
<td>Not to make a start</td>
<td>Prepared</td>
<td>C</td>
</tr>
</tbody>
</table>

3.3.7 Key References

CCOP Technical Secretariat. 2014. CCOP guideline on the methodologies for selecting geological carbon dioxide (CO₂) storage and estimation of storage capacities.

Dahowski et al. 2009. Regional opportunities for carbon dioxide capture and storage in China, a comprehensive CO₂ storage cost curve and analysis of the potential for large scale carbon dioxide capture and storage in the People’s Republic of China.


3.4 India

3.4.1 Summary

There is a basic understanding of storage potential in India. India has been the subject of two published storage assessments and one high-level large point source emissions to prospective storage basin matching study. The basins with the highest potential are found offshore, with most storage resources occurring in DSF with limited opportunities in DGF. Onshore, the majority of the country is dominated by basalt plains. The IEAGHG (2008) estimated a theoretical storage resource of 63 GtCO₂, mainly DSF. Viebahn et al. (2014) indicated that the potential for India was between 47-143 GtCO₂, but for ‘good quality’ storage, the theoretical estimate was 47-48 GtCO₂. The DGOF storage potential is low at around 4-6 GtCO₂ (Viebahn et al. 2014). India requires a national-scale DSF and DGF study to identify prospective areas for storage and effective storage resource potential.

3.4.2 National Resource Assessment Status

**Status:** Moderate

<table>
<thead>
<tr>
<th>Estimated resource (GtCO₂)</th>
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<td>Viebahn et al. 2014</td>
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<td></td>
</tr>
</tbody>
</table>

3.4.3 Prospective basins

**Cambay** (onshore, central west): Total basin estimate: 5.8 GtCO₂ DSF and DOF theoretical resource based on multinational study (IEAGHG 2008).

**Cauvery** (offshore, southeast, shared with Sri Lanka): Total basin estimate: 6 GtCO₂ DSF theoretical resource based on multinational study (IEAGHG 2008).

**Krishna-Godavari** (offshore/minor onshore, southeast): Total basin estimate: 4 GtCO₂ DSF theoretical resource based on multinational study (IEAGHG 2008).

**Mumbai** (offshore/ minor onshore, central west): Total basin estimate: 13 GtCO₂ DSF and DOF theoretical resource based on multinational study (IEAGHG 2008).
3.4.4 Map

3.4.5 CCS Indicators

3.4.6 References


3.5 Indonesia

3.5.1 Summary

Indonesia has a robust understanding of storage potential via a mature oil and gas industry in onshore and offshore basins with significant characterisation of subsurface geology. The oil and gas basins have been the focus of several studies, but a national assessment where individual basins have been studied has not been released. Planning for a small onshore pilot project in the Java Basin is underway. The large stationary emission sources are proximal to the hydrocarbon fields, including the potential for CO₂-EOR.

The first multinational study focussed on the South Sumatra Basin, which has an estimate 8 GtCO₂ of theoretical storage resource in DSF. 1 Gt in effective storage resource in DGOF was estimated including one gas field containing over 488 MtCO₂ resource alone (ADB 2013).

A second high-level multi-national study estimated over 557 Mt of effective storage resource in eight oil and gas basins (CCOP 2014); South and Central Sumatra may have a theoretical storage resources of over 10 GtCO₂ of storage. A later study focussed on South Sumatra and West Java basins and included CO₂-EOR, DGF, and DSF potential (World Bank 2015). The cumulative effective storage resources of that assessment was between 1.4 and 2 GtCO₂, with the majority coming from DGF. Storage associated with gas production is important because some of the gas fields in Indonesia contain high concentrations of CO₂ including the giant Natuna field with 70% CO₂. Indonesia is part of the CCOP CCS-M and will produce an East and Southeast Asia atlas of storage potential scheduled for 2018.

3.5.2 National Resource Assessment Status

**Status:** Moderate

<table>
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</tr>
<tr>
<td>World Bank 2015</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3.5.3 Prospective basins

**Java** (onshore/offshore; Java): 386 Mt effective storage resource estimate in DGF and 160-377 Mt effective storage resource in DSF (World Bank, 2015).

**Kutei** (onshore/offshore; East Kalimantan): 8 GtCO₂ effective storage resource estimate in DGF (IEAGHG 2009).

**Tarakan** (onshore/offshore; North Kalimantan): 0.13 GtCO₂ effective storage resource estimate in DGF (CCOP 2014).

**Central Sumatra** (onshore; Sumatra): 229 Mt effective storage resource estimate in DGF (CCOP 2014).

**South Sumatra** (onshore; Sumatra): 595 Mt effective storage resource estimate CO₂-EOR and DGF and 279-683 Mt effective storage resource in DSF (World Bank 2015).
3.5.4 Map

![Map of Global Storage Portfolio in Asia-Pacific region]

3.5.5 Projects

Pilot: Gundih Project (onshore east Java Basin, Java): Define; DSF.

3.5.6 CCS Indicators

<table>
<thead>
<tr>
<th>Storage Readiness Indicator</th>
<th>Policy Indicator</th>
<th>Legal &amp; Regulatory Indicator</th>
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<tr>
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<td>87</td>
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</tbody>
</table>

3.5.7 References


CCOP Technical Secretariat. 2014. CCOP guideline on the methodologies for selecting geological carbon dioxide (CO2) storage and estimation of storage capacities.


3.6 Japan

3.6.1 Summary

Japan has a comprehensive understanding of the storage resource potential due to a series of national studies. Significant storage potential occurs in both the onshore and offshore basins mainly in DSF, but there are minor DGF opportunities. Japan has progressed to the identification of specific storage sites. It has already completed one pilot injection project in onshore Niigata Prefecture. A second pilot project will focus on nearshore storage in the Hokkaido Prefecture, and is currently under construction.

The first assessment estimated a theoretical resource estimate of 92 GtCO₂ focussing on oil and gas fields and neighbouring DSF, as well as DSF in anticlinal structures (Tanaka et al. 1995). This was further refined to an effective storage resource of 101 GtCO₂ including additional DSF storage scenarios (RITE 2006; Suekane et al. 2008). The scope of a third study took into account a larger area of continental Japan including offshore DSF without trapping structures and a revised calculation method. These changes resulted in a revised effective storage resource of 146 GtCO₂ (Takahashi et al. 2009).

The final national assessment focussed on DSF close to large CO₂ emission sources. The storage resource value of 14 sites was not published, but the authors show that some sites have storage resource of between 5 and 7 GtCO₂ (Ogawa et al. 2011). A basin-scale dynamic simulation study of the Kanto Basin (Tokyo Bay), showed a total effective storage potential of 1 GtCO₂ with the injection of 1 Mtpa from 10 injection wells for 100 years (Yamamoto 2009).

3.6.2 National Resource Assessment Status

**Status:** Full

<table>
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<td>Takahashi et al. 2009</td>
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</tbody>
</table>

3.6.3 Prospective basins

The individual basin resource estimates have not been published.
3.6.4 Map

3.6.5 Project

Notable: Nagaoka CCS Pilot Project (Onshore, Niigata Basin, Niigata Prefecture): Complete; DSF.
Notable: Tomakomai CCS Demonstration Project (Nearshore, Hokkaido Prefecture): Execute; DSF.

3.6.6 CCS Indicators

<table>
<thead>
<tr>
<th>Storage Readiness Indicator</th>
<th>Policy Indicator</th>
<th>Legal &amp; Regulatory Indicator</th>
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</table>
3.6.7 References


3.7 Korea

3.7.1 Summary

Korea has a moderate understanding of the storage resource and has recently completed several national and basin studies. The total storage potential is still largely unknown, but is likely to occur in offshore DSF. Kim et al. (2014) details that almost 100 GtCO₂ of storage resource has been estimated from several Korean studies (MEST 2008; Egawa et al. 2009; Kim et al. 2011). The majority of this storage is derived from CO₂-EOR potential in the offshore Jeju (95 GtCO₂) and Ulleung (3 GtCO₂) basins (MEST 2008). Detailed studies are progressing, for example, a dynamic simulation in the Bukpyeong Basin estimated a storage injection rate of 1-12 Mtpa (Kihm and Kim, 2013).

The Korean CCS Roadmap ‘Practical use of CCS technology by 2020’ states a site selection and drilling, injection and monitoring program will run from 2015-2017 leading to a small-scale pilot test. Confidence in storage resource estimates are low due to sparse subsurface data, with the exception of the Ulleung Basin. This would mean that Korean basins would require an extensive data acquisition program before resource values could be better defined.

3.7.2 National Resource Assessment Status

Status: Full

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<td>Volumetric calculation</td>
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</table>

After MEST 2008; Egawa et al. 2009; Kim et al. 2011, as reported in Kim et al. 2014

3.7.3 Prospective basins

**Bukpyeong** (onshore/ offshore; northeast): Total basin estimate: 877 Mt; effective DSF resource based on basin study (Kim et al. 2011). Dynamic injection simulation gave an indicative injection rate of between 1 and 9 Mtpa were achieved into reservoirs in the basin (Kihm et al. 2013).

**Gyeongsang** (onshore; southeast): Total basin estimate: 1 GtCO₂; theoretical DSF resource based on basin study (Egawa et al. 2009). Dynamic simulations focusing on chemical reactivity studies achieved an injection rate of 0.5 Mtpa into reservoirs in the basin (Kihm et al. 2012).

**Ulleung** (offshore; southeast): Total basin estimate: 3 GtCO₂; theoretical resource based on national study (MEST, 2008).

**Jeju** (offshore; south): Total basin estimate: 95 GtCO₂; theoretical resource based on national study (MEST, 2008).
3.7.4 Map

3.7.5 Projects

LSIP: Korea CCS One (Offshore, Ulleung Basin): Evaluate; DSF.
LSIP: Korea CCS Two (Offshore, Ulleung Basin): Evaluate; DSF.

3.7.6 CCS Indicators
3.7.7 References


3.8 Malaysia

3.8.1 Summary

Malaysia has not produced a national basin assessment for storage. An extensive and mature oil and gas industry has enabled characterisation of the subsurface geology in oil and gas basins. It is highly likely the offshore basins of Malaysia have a high storage potential for both DGOF and CO₂-EOR, as well as DSF storage. The National Oil Company has undertaken several studies into CO₂-EOR and DSF in the Malay and Sarawak basins. The only published account estimated an effective storage resource of 28 GtCO₂ based on DGF in Sarawak, Malay, Brunei-Sabah basins (IEAGHG 2009). These basins would make up the majority of all storage potential and also host the majority of oil and gas fields in Malaysia. Storage potential closely linked to gas fields is important for the development of the gas industry as many fields have high (30-70%) CO₂ content in the reservoir.

Malaysia is part of the CCOP CCS-M and will produce an East and Southeast Asia atlas of storage potential scheduled for 2018.

3.8.2 National Resource Assessment Status

**Status:** Moderate

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<td>Gas fields in four basins: Sarawak, Malay, Brunei-Sabah</td>
<td></td>
<td>IEAGHG 2009</td>
</tr>
</tbody>
</table>

3.8.3 Prospective basins

**Greater Sarawak** (offshore; East Malaysia): 10 GtCO₂ effective storage resource estimate in DGF (IEAGHG 2009). Dynamic simulation study in the M4 reservoir indicates injection rates of between 2-3 Mtpa (Masoudi et al. 2011).

**Malay** (offshore, West Malaysia): 15 GtCO₂ effective storage resource estimate in DGF (IEAGHG 2009).

**Brunei-Sabah** (offshore; East Malaysia): 3 GtCO₂ effective storage resource estimate in gas fields (IEAGHG 2009).
3.8.4 Map

![Map of the Global Storage Portfolio in Asia-Pacific region.](image)

3.8.5 CCS Indicators

<table>
<thead>
<tr>
<th>Storage Readiness Indicator</th>
<th>Policy Indicator</th>
<th>Legal &amp; Regulatory Indicator</th>
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<tr>
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</table>

3.8.6 References

CCOP Technical Secretariat. 2014. CCOP guideline on the methodologies for selecting geological carbon dioxide (CO₂) storage and estimation of storage capacities.

IEAGHG. 2009. CO₂ storage in depleted oilfields: Global application criteria for carbon dioxide enhanced oil recovery report 2009/12.


Nadeson 2004. Water-Alternating-Gas (WAG) Pilot Implementation, a First EOR Development Project in Dulang Field, Offshore Peninsular Malaysia, SPE 88499-MS.
3.9 New Zealand

3.9.1 Summary

New Zealand has undertaken CO₂ storage studies both nationally and in prospective basins; assessments have been predominantly focussed onshore. A small oil and gas industry has yielded a significant knowledge base of subsurface geology. The onshore storage potential is around 16 GtCO₂, almost exclusively in DSF (Field et al. 2009). The Taranaki Basin is the only region with commercial hydrocarbon accumulations and the only potential for DGOF and CO₂-EOR. There is 300 MtCO₂ of effective storage resource estimate in the Maui field alone (Field et al. 2009). The DSF in the Taranaki has a conservative theoretical resource of around 5 GtCO₂ storage potential (Field et al. 2009).

3.9.2 National Resource Assessment Status

**Status:** Moderate

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<th>Estimated resource (GtCO₂)</th>
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<td>Volumetric using general storage efficiency factor</td>
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</tbody>
</table>

*Onshore basins only excluding Southland Basin

| Field et al. 2009 |

3.9.3 Prospective basin

**Taranaki** (onshore/offshore, western North Island): Total basin estimate: over 5 GtCO₂; theoretical resource based on national study. Dynamic simulation into the Maui Field suggests an injection rate of 5 Mtpa and 222 MtCO₂ stored (Archer et al. 2009).

**East Coast** (onshore, eastern North Island): Total basin estimate: over 5 GtCO₂; theoretical resource based on national study (Field et al. 2009).
3.9.4 Map

3.9.5 CCS Indicators

Storage Readiness Indicator | Policy Indicator | Legal & Regulatory Indicator
3.9.6 Key References


3.10 Pakistan

3.10.1 Summary

Pakistan has a limited understanding of storage potential and has been the subject of one published assessment. There is likely a storage resource potential in onshore DSF with minor offshore potential. The Potwar Basin (also known as Lower Indus) has the highest potential with a theoretical storage resource of 2 GtCO₂ in DGOF including four gas fields with resource capacity of over 200 MtCO₂ (IEAGHG 2008). No DSF estimate has been completed on the Potwar Basin. The only quantitative DSF assessment was completed on the Balochistan Basin in the east with over 30 GtCO₂ of theoretical storage resource (IEAGHG 2008). There is a reasonable match between large point source emissions and storage opportunities.

3.10.2 National Resource Assessment Status

**Status:** Moderate

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<tbody>
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<td>Theoretical</td>
<td>Volumetric using generic storage efficiency and generalised basin assumptions.</td>
</tr>
</tbody>
</table>

IEAGHG 2008

3.10.3 Prospective basins

**Potwar Basin** (Lower Indus): Total basin estimate: 1.7 GtCO₂ effective storage potential in DGF based on multinational (IEAGHG 2008).

**Balochistan** (offshore/onshore): Total basin estimate: 30 GtCO₂; DSF theoretical resource estimate based on multinational study (IEAGHG 2008).
3.10.4 Map

3.10.5 CCS Indicators

3.10.6 Key References

3.11 Philippines

3.11.1 Summary

The Philippines has a limited understanding of storage potential and has been the subject of one multinational resource assessment. A small oil and gas industry has enabled characterisation of the subsurface geology in the oil and gas basins. It is highly likely the offshore basins have a high storage potential for both DGOF DSF storage. A multinational study estimated a total of around 23 GtCO₂ theoretical storage resource potential (ADB 2013). DSF make up the majority of storage with 22.7 GtCO₂ theoretical storage resource, with oil and gas fields a low 0.3 GtCO₂ effective storage resource; a large gas field has 251 MtCO₂ of effective storage resource alone. Only 2 of 16 potential storage basins were assessed, which means there may be other storage opportunities (ADB 2013).

The Philippines is part of the CCOP CCS-M and will produce an East and Southeast Asia atlas of storage potential scheduled for 2018.

3.11.2 National Resource Assessment Status

Status: Limited

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<th>Estimated resource (GtCO₂)</th>
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<td>ADB 2013</td>
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</table>

3.11.3 Prospective basins

The basins of the Philippines have not been specifically assessed for their storage prospects and resource potential. Luzon, Northwest Palawan and Cagayan basins are cited as the most prospective of the basins (ADB 2013).
3.11.4 Map

3.11.5 CCS Indicators

3.11.6 Key References

3.12 Sri Lanka

3.12.1 Summary

Sri Lanka has a limited understanding of storage potential and has been the subject of one multinational resource assessment. There is possible storage resource potential in offshore DSF in the north, with no onshore storage potential onshore due to a lack of basins. The offshore Cauvery Basin, which Sri Lanka shares with India could potentially host a storage site with 6 GtCO₂ of theoretical storage resource (IEAGHG 2008). The oil and gas industry is new with one discovery in the Mannar Basin so there is limited subsurface data.

Sri Lanka requires a national basin-scale assessment study of the offshore DSF storage potential, but this would require acquiring subsurface data.

3.12.2 National Resource Assessment Status

Status: Limited

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<td>IEAGHG 2008</td>
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</table>

3.12.3 Prospective basins

**Cauvery** (offshore, southeast, shared with India): 6 GtCO₂ theoretical resource based on multinational study (IEAGHG 2008).
3.12.4 Map

3.12.5 CCS Indicator

3.12.6 References

3.13 Thailand

3.13.1 Summary

Thailand has a moderate understanding of storage potential with one multinational resource assessment (ADB 2013). It is likely to have substantial storage potential in DSF, predominantly in offshore basins of the Gulf of Thailand, which is also the location of mature oil and gas fields with DGOF storage potential. There is cumulative theoretical storage potential of over 10 GtCO₂; 8.9 GtCO₂ theoretical storage resource in DSF and 1.4 GtCO₂ effective storage resource in DGOF based on 10 of 94 sedimentary basins (ADB 2013). The majority of oil and gas fields are nearing depletion by 2020 and there is a large opportunity for CO₂-EOR. The top three ranked basins were estimated to have a combined effective storage resource of 350 MtCO₂ (ADB 2013).

Thailand is part of the CCOP CCS-M and will produce an East and Southeast Asia atlas of storage potential scheduled for 2018.

3.13.2 National Resource Assessment Status

**Status:** Limited

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</table>

ADB 2013

3.13.3 Prospective basins

Individual basin’s storage resource estimates have not been published. The most prospective basins are in the Gulf of Thailand due to the presence of known oil and gas fields and DSF (ADB 2013).
3.13.4 Map

3.13.5 CCS Indicators

<table>
<thead>
<tr>
<th>Storage Readiness Indicator</th>
<th>Legal &amp; Regulatory Indicator</th>
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<td>Making progress</td>
<td></td>
</tr>
<tr>
<td>Well advanced</td>
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</tr>
<tr>
<td>Prepared</td>
<td></td>
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</tbody>
</table>

- **Storage Readiness Indicator**
  - Just starting
  - Making progress
  - Well advanced
  - Prepared

- **Legal & Regulatory Indicator**
  - A: 87
  - B: 60
  - C: 36
3.13.6 Key References

3.14 Vietnam

3.14.1 Summary

Vietnam has a moderate understanding of storage potential with one multinational resource assessment. A small but mature oil and gas industry has enabled characterisation of the subsurface geology in oil and gas basins, including two pilot CO₂-EOR operations but elsewhere storage characterisation is limited. The majority of DSF storage potential is in offshore basins and there is potential for DGOF storage and CO₂-EOR.

The multinational assessment focused on storage that estimated a total theoretical storage potential of around 12 GtCO₂ theoretical storage resource (ADB 2013). The majority is located in DSF (10.4 GtCO₂), 1.4 GtCO₂ in DGOF, which includes the largest field estimated to have over 300 MtCO₂ of effective storage resource. The ADB assessment was based on the known hydrocarbon traps in 6 of 8 sedimentary basins of Vietnam. The assessment indicates that there is potentially 300 GtCO₂ if all storage basins were included and widened to DSF storage. It is important to note that some of the gas fields in Viet Nam contain high concentrations of CO₂ with many above 10% and some up to 80% (ADB 2013).

Vietnam is part of the CCOP CCS-M and will produce an East and Southeast Asia atlas of storage potential scheduled for 2018.

3.14.2 National Resource Assessment Status

**Status:** Limited

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3.14.3 Prospective basins

Individual basin’s storage resource estimate has not been published, but the most prospective basins includes the Cuu Long, Nam Con Son and Malay-Tho Chu due to the presence of known oil and gas fields and/or DSF (AD, 2013).
3.14.4 Map

3.14.5 Projects

Pilot: Bach Ho (White Tiger) Oil Field CO$_2$-EOR Pilot Project (offshore, Cuu Long Basin): Complete; CO$_2$-EOR.

Pilot: Rang Dong (Aurora) Oil Field CO$_2$-EOR Pilot Project (offshore, Cuu Long Basin): Complete; CO$_2$-EOR.
3.14.6 CCS Indicators

3.14.7 Key References


4 AMERICAS

4.1 Brazil

4.1.1 Summary

Brazil has produced a high-level national assessment for storage as part of the CARBMAP project and has assessed individual basins. A mature oil and gas industry has enabled characterisation of the subsurface geology in oil and gas basins, but elsewhere storage characterisation is limited. A high level CCS Atlas identified several prospective basins, but did not undertake resource estimates (Ketzer et al. 2014). The Atlas found that it is highly likely DSF, DGOF and CO₂-EOR storage could be undertaken in the prospective basins, especially the Santos and Campos basins. There is a close match between large point source emissions and storage opportunities.

The national assessment gave a theoretical storage resource of over 2,000 GtCO₂, predominantly in onshore and offshore DSF (Rockett et al. 2011). In addition 4 GtCO₂ effective storage resource in DGOF, 1.7 GtCO₂ in the Campos Basin alone (Rockett et al. 2011).

The completion of a national assessment with detailed basin-scale assessments and effective storage resource, or potentially progressing to the identification of specific storage sites, could increase storage opportunities for CCS.

4.1.2 Projects

LSIP: Petrobras Lula Oil Field CCS Project (Offshore, Santos Basin)
Notable: Miranga CO₂ Injection Project (Onshore, Recôncavo Basin, Bahia)
Pilot: Ressacada Pilot CCS Project (Onshore, Florianópolis Island)

4.1.3 National Resource Assessment Status

Status: Moderate

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</table>

Rockett et al. 2011

4.1.4 Prospective basins

Individual basin’s storage resource estimate has not been published, but the Campos, Paraná, Potiguar, Recôncavo, and Santos basins have been identified as the most prospective basins (Ketzer et al. 2014).
4.1.5 Map

4.1.6 Projects

LSIP: Petrobras Lula Oil Field CCS Project (Offshore, Santos Basin): Operate; CO$_2$-EOR.

Notable: Petrobras Miranga CO$_2$ Injection Project (Offshore, Reconcavo Basin): Completed; CO$_2$-EOR.

4.1.7 CCS Indicators
4.1.8 Key References


Ketzer et al. 2007. Opportunities for CO$_2$ capture and geological storage in Brazil: The CARBMAP Project.

Ketzer et al. 2014. Brazilian atlas of CO$_2$ capture and geological storage.


4.2 Canada

4.2.1 Summary

Canada has a strong understanding of the storage resource potential because it has completed several national, basin, and site-scale studies and has extensive and detailed knowledge of the subsurface geology. Significant storage is already being achieved and it is highly likely that DSF, DGOF and CO$_2$-EOR storage could be extensively deployed in the prospective basins further. It has a mature oil and gas industry with detailed subsurface data across many basins. The onshore basins are typically located over emission sources and are typically centred in Alberta and Saskatchewan. There are three operating LSIP in Canada including the Great Plains Synfuel Plant and Weyburn Midale Project, Boundary Dam Carbon Capture and Storage Project and Quest Project. There are dedicated CCS programs and projects which work openly in the scientific community and have completed several R&D programs including pilot injection and MMV.

The latest North American Atlas estimates of total onshore and offshore DSF and DGOF effective storage resource of 198-671 GtCO$_2$ across Canada. The majority of this resource is located in Alberta and Saskatchewan. Basin and site-scale studies, including dynamic simulations have focused on the Province of Québec, Williston Basin and Alberta Basin, primarily the Basal Cambrian Sandstone.

4.2.2 National Resource Assessment Status

Status: Full

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<td>Volumetric using storage efficiency factor and probabilistic modelling.</td>
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</tbody>
</table>

US DOE/NETL 2015

4.2.3 Prospective basins

**Alberta** (Onshore, Alberta): 38-148 GtCO$_2$ effective resource estimate of DSF and DGOF based on a North American Atlas (US DOE/NETL 2015). Basin and site scale assessments have targeted numerous different storage sites, including dynamic simulation and test injection projects. Quest Project aims to inject 1 Mtpa into the Basal Cambrian DSF.

**Williston** (Canadian part only) (Onshore, Saskatchewan/Manitoba): 150-497 GtCO$_2$ effective resource estimate of DSF and DGOF based on a North American Atlas (US DOE/NETL 2015). Basin and site scale assessments have targeted numerous different storage complexes, including dynamic simulation and test injection projects. Weyburn-Project has injected over 22 Mt since 2000.

**Michigan and Appalachian** basins (Onshore, Ontario): 731 Mt effective resource of two areas of the basins within DSF based on study of Ontario CCS potential (Shafeen et al. 2004).
4.2.4 Map

4.2.5 Projects

LSIP: Great Plains Synfuel Plant and Weyburn Midale Project (Onshore, Williston Basin, Saskatchewan): Operate; CO₂-EOR.
LSIP: Boundary Dam Carbon Capture and Storage Project (Onshore, Williston Basin, central, Saskatchewan): Operate; Primarily CO₂-EOR, secondary DSF.
LSIP: Quest (Onshore, Alberta Basin, Alberta): Execute; DSF.
LSIP: Alberta Carbon Trunk Line ACTL with Agrium CO₂ Stream (Onshore, Alberta Basin, Alberta): Execute; CO₂-EOR.
LSIP: Alberta Carbon Trunk Line ACTL with North West Sturgeon Refinery CO₂ Stream (Onshore, Alberta Basin, Alberta): Execute; CO₂-EOR.
LSIP: Spectra Energy’s Fort Nelson CCS Project (Onshore, Alberta Basin, British Columbia): Define; DSF.

Notable: Zama Field Validation Test (Onshore, Alberta Basin, Alberta): Completed; CO₂-EOR.

4.2.6 CCS Indicators
4.2.7 Key References


Petroleum Technology Research Centre. 2015. Aquistore Project summary report.


4.3 Mexico

4.3.1 Summary

Mexico has produced a high-level national assessment for storage as part of a multinational study and one national study. An oil and gas industry has enabled characterisation of the subsurface geology in oil and gas basins, but elsewhere storage characterisation is limited. It is likely that storage in DSF, DGOF and CO₂-EOR could be achieved in the prospective basins (Dávila et al. 2010). The DSF theoretical storage resource for prospective basins was estimated to be 100 GtCO₂ (NACSA 2012). An assessment of storage resources associated with DGOF was not included in that publication, although the National Oil Company is undertaking investigations of CO₂-EOR potential.

The completion of a national assessment with detailed basin-scale assessments and effective storage resource would advance CCS prospects in the country. The identification of suitable sites for storage is currently progressing (SENER 2014).

4.3.2 National Resource Assessment Status

**Status:** Moderate

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<td>NACSA 2012</td>
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4.3.3 Prospective Province

**Gulf of Mexico (Burgos Sub-basin):** Total basin estimate: 17 GtCO₂; theoretical resource based on multi-national study (NACSA 2012).

**Veracruz:** Total basin estimate: 15 GtCO₂; theoretical resource based on multi-national study (NACSA 2012).

**Southeastern:** Total basin estimate: 24 GtCO₂; theoretical resource based on multi-national study (NACSA 2012).

**Yucatan:** Total basin estimate: 14 GtCO₂; theoretical resource based on multi-national study (NACSA 2012).
4.3.4 Map

4.3.5 CCS Indicators

<table>
<thead>
<tr>
<th>Storage Readiness Indicator</th>
<th>Policy Indicator</th>
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<td>87</td>
</tr>
</tbody>
</table>

4.3.6 Key References


SENER. 2014. CCUS Technology Roadmap in Mexico.
4.4 Trinidad and Tobago

4.4.1 Summary

There is a moderate understanding of storage potential with one multinational resource assessment. It is likely that Trinidad and Tobago could undertake storage in CO₂-EOR and DGF and it is highly likely that DSF storage would be achievable. An oil and gas industry has enabled characterisation of the subsurface geology in the two main basins, but elsewhere storage characterisation is limited. The offshore oil fields have hosted four onshore pilot CO₂-EOR operations between the 1970s and 1990.

Only one dedicated storage study is available to this author and the information is based on that unpublished CCS Scoping Study prepared for the Government of Trinidad and Tobago. The study estimated an effective storage resource based on screening of oil and gas fields. However, this analysis was impacted by a lack of data in most of the oil and gas fields.

4.4.2 National Resource Assessment Status

Status: Very Limited

4.4.3 Prospective basins

Individual basin’s storage resource estimate has not been published. The only unpublished study focussed on oil and gas fields and estimated that fields in the East Coast (Venezuelan Eastern Basin) and North Coast (Tobago Trough) had the highest potential for CCS. DGF and EOR could provide early opportunities in those basins listed above.
4.4.4 Map

![Map Image]

4.4.5 CCS Indicators

<table>
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<td>87</td>
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</table>

4.4.6 Key References

No publically available reports on CO₂ storage available.

4.5 US

4.5.1 Summary

The US has a strong understanding of the storage resource potential because it has completed several national, basin, and site-scale studies and extensive characterisation of subsurface geology. Significant storage is already being achieved and it is highly likely that storage in DSF, DGOF and CO₂-EOR will be further deployed. It has a mature oil and gas industry with detailed subsurface data across many basins.

There are seven LSIP in operation and all utilise the CO₂ for EOR operations. The National Energy Technology Laboratory’s Regional Carbon Sequestration Partnership (RCSP) have led to the exploration, appraisal and validation of key basins, including 19 injection tests. The next phase of RCSP will see eight large scale (over 1 Mtpa) injection projects operating or under development. As well as the RCSP, there have been many other dedicated CCS programs and projects, which work openly in the scientific community and have completed several R&D programs including pilot injection and MMV.

The latest North American Atlas details a conservative estimate of total onshore and offshore DSF and DGOF effective storage resource of 2,367-21,200 GtCO₂ across the US. It did not detail the storage potential of individual basins, rather by state/province. An earlier study by the US Geological Survey completed a national, basin-scale assessments but identified individual storage sites within the basins and estimated a cumulative effective storage resource of between 2,134-4,013 GtCO₂ in DSF and DGOF storage (USGS 2013).

There is significant opportunity for CO₂-EOR. The 2015 Atlas estimated a potential for 9 GtCO₂ of CO₂ storage for economically feasible CO₂-EOR operations, but this could increase to 17 GtCO₂ under a next generation scenario (US DOE NETL 2015), including injection into residual oil zones (ROZs).

4.5.2 National Resource Assessment Status

Status: Full

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<td>US DOE NETL 2015</td>
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</table>

4.5.3 Prospective basins

**Anadarko and Southern Oklahoma** (onshore, Oklahoma, Texas, Kansas, and Colorado): Total basin estimate: 36-69 GtCO₂; effective storage resource estimate (USGS 2013). The Farnsworth Project will inject 1 Mt between 2013 and 2018 (US DOE NETL 2015).

**Gulf of Mexico** (offshore, US Only, Gulf Coast): Total basin estimate: 1,300-2,400 GtCO₂; effective storage resource estimate (USGS 2013).

**Illinois** (onshore, Illinois, Indiana): Total basin estimate: 110-210 GtCO₂; effective storage resource estimate (USGS 2013). Illinois Industrial Carbon Capture and Storage Project will inject around 1 Mtpa.
Permian (onshore, Texas): Total basin estimate: 37-89 GtCO₂; effective storage resource estimate (USGS 2013). The majority of CO₂-EOR operations focus on the fields of the basin injecting around 570 Mt to date (Tenaska 2011).

San Joaquin (offshore, California): Total basin estimate: 36-69 GtCO₂; effective storage resource estimate (USGS 2013).


4.5.4 Map

4.5.5 Projects

LSIP: Lost Cabin Gas Plant (Onshore, Powder River Basin, Montana): Operate; CO₂-EOR.
LSIP: Val Verde Natural Gas Plants (Onshore, Permian Basin, Texas): Operate; CO₂-EOR.
LSIP: Air Products Steam Methane Reformer EOR Project (Onshore, Permian Basin, Texas): Operate; CO₂-EOR.
LSIP: Century Plant (Onshore, Permian Basin, Texas): Operate; CO₂-EOR.
LSIP: Shute Creek Gas Processing Facility (Onshore, Wyoming, Colorado): Operate; CO₂-EOR.
LSIP: Coffeyville Gasification Plant (Onshore, Oklahoma): Operate; CO₂-EOR.
LSIP: Enid Fertilizer CO₂-EOR Project (Onshore, Oklahoma): Operate; CO₂-EOR.
LSIP: Kemper County Energy Facility (Onshore, Mississippi): Execute; CO₂-EOR.
LSIP: Petra Nova Carbon Capture Project (Onshore, Texas): Execute; CO₂-EOR.
LSIP: Hydrogen Energy California Project (HECA) (Onshore, California): Define; CO₂-EOR.
LSIP: Riley Ridge Gas Plant (HECA) (Onshore, Wyoming): Evaluate; CO₂-EOR.

4.5.6 CCS Indicators

4.5.7 References


Tenaska, 2011. Bridging the commercial gap for carbon capture and storage.

USGS Carbon Dioxide Storage Resources Assessment Team. 2013. National assessment of geologic carbon dioxide storage resources—Results.

5  MIDDLE EAST

5.1  Jordan

5.1.1  Summary

The World Bank has completed a study on the potential for CCS in Jordan which included storage resource potential (World Bank 2012). The vast majority of storage potential in Jordan is in DSF underlying large parts of Jordan, including the Hamad Basin in the northeast and Wadi Sirhan Basin in central east. The study estimated a theoretical storage resource of around 9 GtCO₂.

5.1.2  National Resource Assessment Status

**Status:** Limited

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</table>

5.1.3  Prospective basins

**Wadi Sirhan** (onshore, east central): Total basin estimate 2.7 GtCO₂; theoretical storage resource based on national study (World Bank 2012).

**Hamad** (onshore, northeast): Total basin estimate 7 GtCO₂; theoretical storage resource based on national study (World Bank 2012).
5.1.4 Map

5.1.5 CCS Indicator

5.1.6 Key References

5.2 Saudi Arabia

5.2.1 Summary

Saudi Arabia has not published a national storage assessment. A mature and expansive oil and gas industry has resulted in extensive and detailed understanding of the geological characteristics and detailed data of the subsurface. It does have substantial potential in DGOF and in CO₂-EOR operations. CO₂-EOR potential in the Mesopotamian Foreddeep Basin, which hosts significant fields could hold an effective storage resource of 27 GtCO₂ and Greater Ghawar Uplift, which hosts the world’s largest oil field has an effective storage resource of 13 GtCO₂ (IEAGHG 2009). This is supported by a recent study that estimated up to 30 GtCO₂ effective storage capacity during CO₂-EOR operations (IEA 2015).

5.2.2 National Resource Assessment Status

**Status:** Very Limited

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5.2.3 Prospective basins

The individual basin resources have not been published for storage potential.
5.2.4 Map

5.2.5 Projects

LSIP: Uthmaniyah CO₂ EOR Demonstration Project (Onshore, Ghawar Field, Eastern Province): Operate; CO₂-EOR.

5.2.6 CCS Indicators

<table>
<thead>
<tr>
<th>Storage Readiness Indicator</th>
<th>Policy Indicator</th>
<th>Legal &amp; Regulatory Indicator</th>
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</tbody>
</table>

5.2.7 Key References

IEAGHG. 2009. CO₂ storage in depleted oilfields: Global application criteria for carbon dioxide enhanced oil recovery report 2009/12.

5.3 United Arab Emirates

5.3.1 Summary

The UAE has not published a national storage assessment. A mature and expansive oil and gas industry has resulted in extensive and detailed understanding of the geological characteristics and detailed data of the subsurface. It does have substantial potential in DGOF and CO₂-EOR. The Rub Al Khali Basin was estimated to have an effective storage resource of 8.8 GtCO₂ (IEAGHG 2009). A recent study estimated a potential effective storage capacity of up to 25 GtCO₂ for CO₂-EOR operations (IEA 2015).

5.3.2 National Resource Assessment Status

**Status:** Very Limited

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<tbody>
<tr>
<td>5-25*</td>
<td>Theoretical</td>
<td>OOIP; assumes standardised CO₂ replacement value</td>
</tr>
<tr>
<td>*CO₂-EOR</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IEA 2015</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

5.3.3 Prospective basins

The individual basin resources have not been published for storage potential.
5.3.4 Map

5.3.5 Projects

LSIP: Abu Dhabi CCS Project (Onshore, Rumaitha Field): Execute; CO₂-EOR.

5.3.6 CCS Indicators

5.3.7 Key References

IEAGHG. 2009. CO₂ storage in depleted oilfields: Global application criteria for carbon dioxide enhanced oil recovery report 2009/12.

6 EUROPE AND RUSSIA

6.1 Europe excluding UK

6.1.1 Summary

The EU was one of the early movers on CO₂ storage assessments. Collectively, the majority of the countries, especially Western Europe, have a very strong understanding of the storage resource potential because it has completed several European-wide studies, as well as individual national assessments. Several countries have also completed basin and site-scale studies. Collectively, Europe has extensive knowledge of the subsurface geology with extensive data. The prospects for storage in DSF, DGOF and CO₂-EOR is highly likely in the North Sea where storage is already underway. Beyond the North Sea, there are still strong prospects for DSF and DGOF across Europe, with additional minor CO₂-EOR in Eastern Europe. The majority of countries in the EU have an open oil and gas industry with detailed subsurface data across many basins. There are dedicated CCS programs and projects in the EU, which work openly in the scientific community and have completed several R&D programs including pilot injection and MMV.

GeoCapacity analysed 23 European countries including most EU nations and surrounding nations such as Norway. The assessment included the majority of onshore and offshore sedimentary basins. The cumulative theoretical storage estimate for most EU nations was 72 GtCO₂ (Vangklide-Pedersen 2009). For the purposes of this Portfolio, the UK has not been added to this estimate and appears separately. DSF make up the majority of storage at 62 GtCO₂ and 10 GtCO₂ in DGOF. In key EU nations the study estimated a theoretical storage resource in DSF and DGOF in Germany (17 GtCO₂), Spain (14 GtCO₂), France (8 GtCO₂) and Italy (6 GtCO₂).

GeoCapacity was followed by the CO₂ StoP (CO₂ Storage Potential in Europe Project) study which reviewed 27 EU nations (including Norway and UK). However, no cumulative figures was given due to a lack of uniform data in some of the nations (Poulsen, et al. 2014). The authors did identify over 400 individual sites including DSF or DGOF storage with resource estimates.

The EU should focus on detailed basin and site-scale assessments especially in eastern and southern (Spain and Portugal) Europe. Numerous specific storage sites have already been identified.

6.1.2 National Resource Assessment Status

<table>
<thead>
<tr>
<th>Estimated resource (GtCO₂)</th>
<th>Resource level</th>
<th>Resource Calculation Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>72*</td>
<td>Theoretical</td>
<td>Volumetric calculation using storage efficiency factor.</td>
</tr>
</tbody>
</table>

*Belgium, Bulgaria, Croatia, Czech Republic, Denmark, Estonia, France, Germany, Greece, Hungary, Italy, Latvia, Lithuania, Luxemburg, Netherlands, Poland, Romania, Slovakia, Slovenia, Spain.

Vangklide-Pedersen 2009
6.1.3 Prospective basins/regions

**Baltic Sea Basin** (offshore/onshore; Sweden, Poland, Lithuania, Latvia, Estonia, Russia): Total basin estimate: 18 GtCO₂; effective storage resource was identified in DSF and DGOF (Elforsk 2014).

**Netherlands North Sea** (Offshore): Total basin estimate: 2.1 Gt; total effective storage resource in highly prospective DSF and DGF only (Neele et al. 2012). K12-B pilot project involves the re-injection of CO₂ into a DGF.

**Poland** (Onshore): The majority of storage will focus on onshore DSF with 82 GtCO₂ of total, including several individual sites each having over 200 MtCO₂ theoretical storage resource (Radoslaw et al. 2009).

**North German Basin** (Onshore, Germany): Total basin estimate: 9.3 GtCO₂; effective storage resource based on basin assessment. Dynamic simulation indicates an injection rate of 2.5 Mtpa (Schäfer et al. 2012).

**Portugal** (Majority offshore DSF, minor onshore DSF): Total country estimate: 3.8-7.6 GtCO₂; theoretical storage resource; Lusitanian Basin (Offshore DSF) (Martinez et al. 2013.): 2.2 GtCO₂; theoretical storage resource (CCS-PT, 2015).

6.1.4 Map
6.1.5 Projects

LSIP: ROAD Rotterdam Opslag en Afvang Demonstratieproject (Offshore, North Sea): Define; DSF.
Notable: Lacq CCS Pilot Project (Onshore, Paris Basin, France): Complete; DGF.
Notable: Ketzin Pilot Project (Onshore, northeast German Basin, Germany): Ongoing; DSF.
Notable: CO$_2$ Capture, Transport & Storage Technology Development Plant (TDP) (Onshore, Basque-Cantabrian Basin Spain): Ongoing; DSF.
Notable: K12-B CO$_2$ Injection Project (Offshore, North Sea Basin, Netherlands): Ongoing; DGF.

6.1.6 CCS Indicators

<table>
<thead>
<tr>
<th>Storage Readiness Indicator (Average)</th>
<th>Policy Indicator (Average)</th>
<th>Legal &amp; Regulatory Indicator (Average)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Making progress</td>
<td>Well advanced</td>
<td></td>
</tr>
<tr>
<td>Just starting</td>
<td>Prepared</td>
<td></td>
</tr>
<tr>
<td>Net to</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The majority lie in Making Progress, Netherlands and Germany are Well advanced.
All EU nations assessed lie in Lower-Mid to Upper Mid categories.
The majority lie in Band B with A for Denmark.

6.1.7 References

CCS-PT. 2015. CCS-PT: Perspectives for capture and sequestration of CO$_2$ in Portugal.
Elforsk. 2014. CCS in the Baltic Sea region – Bastor 2 final summary report.
Neele et al. 2012. Independent assessment of high-capacity offshore CO2 storage options [Netherlands].
Poulseren et al. 2014. CO$_2$StoP final report: assessment of CO$_2$ storage potential in Europe.
6.2 Norway

6.2.1 Summary

Norway has a strong understanding of storage resource potential because it has completed several national, basin, and site-scale studies and has extensive and detailed knowledge of the subsurface geology. The offshore North Sea has prospects for storage in DSF, DGOF and CO₂-EOR and storage is currently underway. It has an open and mature oil and gas industry with detailed subsurface data across many basins. Sleipner CO₂ Storage Project operated by Statoil in the North Sea Basin has been running since 1996 injecting up to 0.85 Mtpa. The Snøhvit CO₂ Storage Project in the Hammerfest Basin, operating since 2008, has an injection rate of around 0.7 Mtpa. There are dedicated CCS programs and projects in Norway, which work openly in the scientific community and have completed several R&D programs including pilot injection and MMV.

Norwegian storage opportunities are all located offshore and include DSF, DGOF and CO₂-EOR opportunities.

In 2014, the CO₂ Storage Atlas of the Norwegian Continental Shelf Project collated the data from three previous studies in the Norwegian Sea, North Sea and Barents Sea and estimated an effective storage resource of around 86 GtCO₂ total; 57 GtCO₂ in DSF and 25 GtCO₂ in producing fields. The majority of storage potential is in the Norwegian sector of the North Sea at 45 GtCO₂ effective storage resource (Halland et al. 2014).

6.2.2 National Resource Assessment Status

Status: Full

<table>
<thead>
<tr>
<th>Estimated resource (GtCO₂)</th>
<th>Resource level</th>
<th>Resource Calculation Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>86</td>
<td>Effective</td>
<td>Dynamic simulation or volumetric using storage efficiency factor</td>
</tr>
</tbody>
</table>

Halland et al. 2014.

6.2.3 Prospective region

North Sea (offshore, Norway): 45 GtCO₂; effective storage resource in DSF. Sleipner CO₂ Storage Project currently injecting up to 0.85 Mtpa.
6.2.4 Map

6.2.5 Projects

LSIP: Sleipner CO₂ Storage (Offshore, Central North Sea Basin, Norway): Operate; DSF.
LSIP: Snøhvit CO₂ Storage (Offshore, Hammerfest Basin, Norway): Operate; DSF.
6.2.6 CCS Indicators

6.2.7 References

Halland et al. 2014. CO₂ storage atlas: Norwegian continental shelf.
6.3 Russia

6.3.1 Summary

Russia has not published a national storage assessment. The oil and gas industry in Russia is mature and expansive and has extensive understanding of the geological characteristics including detailed data of the subsurface in prospective oil and gas basins. Based on the substantial oil and gas fields located across Russia, it is highly likely that there will be abundant DGOF and CO₂-EOR storage.

Storage in DSF is currently unknown. DGOF and CO₂-EOR hold large potential, especially in Timan-Pechar Basin and the Western Siberia and Kaliningrad regions. According to Shogenova et al. (2011) around 50% of hydrocarbon fields in northwest Russia are depleted. This area also has the highest potential for CO₂-EOR with 4.6 Gt in theoretical storage resource. A second study over much of Russia calculated 6.8 GtCO₂ effective storage resource in 322 oil fields, which includes 645 MtCO₂ in CO₂-EOR storage (Sidorova 2014). This study also identified the most prospective basins for CO₂-EOR and DOF and included factors such as economics, emission sources and location, injection and capacity of the oil fields.

6.3.2 National Resource Assessment Status

**Status:** Very Limited

<table>
<thead>
<tr>
<th>Estimated resource (GtCO₂)</th>
<th>Resource level</th>
<th>Resource Calculation Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.8*</td>
<td>Effective</td>
<td>OO/GIP with standard CO₂ reservoir conditions and recovery factor.</td>
</tr>
<tr>
<td>*CO₂-EOR/DOF</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sidorova 2014</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
6.3.3 Map

6.3.4 Prospective basins

No individual basin assessments have been published.

6.3.5 CCS Indicators

6.3.6 Key References


Sidorova. 2014. Economic assessment of the whole CCS technology cycle.
6.4 UK

6.4.1 Summary

The UK has a very strong understanding of storage resource potential because it has completed several national, basin, and site-scale studies and has extensive and detailed knowledge of the subsurface geology. It has an open and mature oil and gas industry with detailed subsurface data across many basins. In the North Sea, the prospects for storage in DSF, DGOF and CO₂-EOR are highly likely and significant storage is already being planned. There is also potential for storage in the Irish Sea in several basins. There are dedicated CCS programs and projects, which work openly in the scientific community and have completed several R&D programs including MMV.

For the UK, the North Sea is the primary target with abundant DGOF storage potential and additional DSF storage resource. The latest, UK Offshore Storage Atlas/CO₂ Storage Evaluation Database is an online database of over 500 potential offshore storage sites. UK theoretical storage resources have been estimated at 78 GtCO₂, mainly in DSF with an estimated potential to store 8 GtCO₂ in DGOF (Bentham et al. 2014).

6.4.2 National Resource Assessment Status

**Status:** Full

<table>
<thead>
<tr>
<th>Estimated resource (GtCO₂)</th>
<th>Resource level</th>
<th>Resource Calculation Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>78</td>
<td>Theoretical</td>
<td>Volumetric using storage efficiency factor and probabilistic modelling.</td>
</tr>
</tbody>
</table>

Bentham et al. 2014
6.4.3 Prospective basins

**Central North Sea** (offshore, UK Sector North Sea): Total basin estimate: 40 GtCO₂; theoretical storage resource based on national study (Bentham et al. 2014).

**Northern North Sea** (offshore, UK Sector North Sea): Total basin estimate: 14 GtCO₂; theoretical storage resource based on national study (Bentham et al. 2014).

**Southern North Sea** (offshore, UK Sector North Sea): Total basin estimate: 15 GtCO₂; theoretical storage resource based on national study (Bentham et al. 2014).

**East Irish Sea** (offshore, East Irish Sea): Total basin estimate: 6 GtCO₂; effective storage resource based on basin study (Bentham et al. 2014). DGOF effective storage resource: 1.1 GtCO₂ (Coulthurst et al. 2011).

6.4.4 Map
6.4.5 Projects

LSIP: Don Valley Power Project (Offshore, Central North Sea): Define; DSF.
LSIP: White Rose CCS Project (Offshore, Southern North Sea): Define; DSF.
LSIP: Teesside Collective Project (Offshore, Southern North Sea): Evaluate; DSF.
LSIP: Caledonia Clean Energy Project (Offshore, Central North Sea): Evaluate; DSF and CO₂-EOR.

6.4.6 CCS Indicators

6.4.7 Key References


Senior. 2010. CO₂ storage in UK- Industry Potential. Senior CCS Solutions.

7 AFRICA

7.1 Algeria

7.1.1 Summary

Algeria has not completed a national assessments for storage potential. However, due to the oil and gas industry in the country, there is a moderate geology and data coverage of the subsurface, limited to active oil and gas basins. It is the site of one of the longest running LSIP BP operated In Salah Project located in the Ahnet-Timimoun Basin, Central Sahara. The potential for DGOF, CO₂-EOR and DSF storage, when considering the geological characteristics of the basins is likely. The Grand Erg/Ahnet Basin has an effective storage resource of 10 GtCO₂ in DGF (IEAGHG 2009).

7.1.2 National Resource Assessment Status

**Status:** Very Limited

<table>
<thead>
<tr>
<th>Estimated resource (GtCO₂)</th>
<th>Resource level</th>
<th>Resource Calculation Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>10*</td>
<td>Theoretical</td>
<td>Standard CO₂ replacement volume.</td>
</tr>
<tr>
<td>*DGF only</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IEAGHG 2009</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

7.1.3 Prospective basins

The individual basin resources have not been published.
7.1.4 Map

7.1.5 Projects

LSIP: In Salah CO₂ Storage Project (Onshore, Ahnet-Timimoun Basin, Central Sahara): In Operate stage: CO₂ injection was temporarily suspended in June 2011; DSF.

7.1.6 CCS Indicators
7.1.7 References


IEAGHG. 2009. CO₂ storage in depleted gas fields, IEAGHG Report 2009/01.

7.2 Morocco

7.2.1 Summary

Morocco was the focus of COMET (Integrated infrastructure for CO₂ transport and storage in the west Mediterranean). The onshore basins, and most likely, the offshore basins have potential for DSF and DGOF storage. The regional assessment estimated an onshore theoretical storage resource of 0.6 GtCO₂ across five basins (Martinez et al. 2013; COMET 2015). The Essaouira, Doukkala, and the Gharb basins are the most promising onshore basins. Offshore storage, as well as the eastern and southern basins have not been assessed.

Morocco requires a national basin-scale assessment of the onshore and offshore DSF, DGOF and CO₂-EOR storage potential.

7.2.2 National Resource Assessment Status

**Status:** Limited

<table>
<thead>
<tr>
<th>Estimated resource (GtCO₂)</th>
<th>Resource level</th>
<th>Resource Calculation Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.6*</td>
<td>Theoretical</td>
<td>Volumetric</td>
</tr>
</tbody>
</table>

*onshore basins only

Martinez et al. 2013.

7.2.3 Prospective basins

**Essaouira** (onshore, westernmost High Atlas region): Total basin estimate: 298 MtCO₂; effective storage resource based on reservoir-scale assessment (COMET 2015).
7.2.4 Map

7.2.5 CCS Indicator

7.2.6 References


7.3 Mozambique

7.3.1 Summary

Mozambique has been the focus of one multinational assessment and two basin-scale studies. The storage potential of Mozambique covers DSF and DGF both onshore and offshore. The offshore Mozambique and Rovuma basins have suitable reservoirs and proven hydrocarbon discoveries. Each basin has multiple storage opportunities with a cumulative theoretical storage resource of 2.7-229 GtCO₂ (Carneiro et al. 2014; Solomon et al. 2014). The DGF in these basins are generally small or early in production life and therefore there is limited opportunities for depleted field storage in the coming decades.

7.3.2 National Resource Assessment Status

**Status:** Moderate

<table>
<thead>
<tr>
<th>Estimated resource (GtCO₂)</th>
<th>Resource level</th>
<th>Resource Calculation Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.7-229</td>
<td>Theoretical</td>
<td>Volumetric using storage efficiency factor</td>
</tr>
</tbody>
</table>

(Carneiro et al. 2014 ; Solomon et al. 2014)

7.3.3 Prospective basins

**Mozambique** (onshore, east coast): Total basin estimate: 2.4-228 GtCO₂; theoretical resource based on basin study (Solomon et al. 2014).

**Rovuma** (onshore, east coast): Total basin estimate: 235 – 470 MtCO₂; theoretical resource based on basin study (Carneiro et al. 2014).
7.3.4 Map

7.3.5 Key References


7.4 South Africa

7.4.1 Summary

South Africa has been proactive in characterising the storage potential and has published one national assessment and a dynamic-simulation basin-scale assessment. The majority of storage is found in DSF in offshore basins. There are dedicated CCS programs and projects, which work openly in the scientific community and have completed several R&D programs. There is current planning to undertake a pilot injection project.

The 2010 Atlas estimated 160 GtCO$_2$ of theoretical storage resource potential with 98% located in DSF three offshore basins; 1.8 GtCO$_2$ in DGOF storage resource potential (Viljoen et al. 2010). The Outeniqua Basin is the most characterised with oil and gas industry infrastructure and subsurface data. The Durban/Zululand Basin has limited data but is nearest to the major industrial CO$_2$ point sources. The Orange Basin has the greatest storage resource potential. Additional dynamic modelling studies have been completed on 12 basins which supported the findings that only the offshore basins have the potential to host a LSIP.

South Africa should focus on further individual basin-scale assessments and identifying specific storage sites. The completion of a pilot injection project will advance CCS in the country.

7.4.2 National Resource Assessment Status

**Status:** Moderate

<table>
<thead>
<tr>
<th>Estimated resource (GtCO$_2$)</th>
<th>Resource level</th>
<th>Resource Calculation Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>162</td>
<td>Theoretical</td>
<td>Volumetric using storage efficiency factor and probabilistic modelling.</td>
</tr>
<tr>
<td>Viljoen et al. 2010</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

7.4.3 Prospective basins

**Orange** (offshore, west): Total basin estimate: 56 GtCO$_2$; theoretical resource based on national study, including 741 MtCO$_2$ in DGOF (Viljoen et al. 2010). Dynamic simulation models an effective storage resource of over 6.2 GtCO$_2$ based on injectivity rate of 1 Mtpa (Alderson et al. 2013).

**Durban and Zululand** (offshore, east): Total basin estimate: 42 GtCO$_2$; theoretical resource based on national study, including 117 Mt in DGOF (Viljoen et al. 2010). Dynamic simulation models an effective storage resource of over 3.2 GtCO$_2$ based on injectivity rate of 0.25 Mtpa (Alderson et al. 2013).

**Outeniqua** (offshore, south): Total basin estimate: 48 GtCO$_2$; theoretical resource based on national study, including 206 Mt in DGOF (Viljoen et al. 2010). Dynamic simulation models storage resource of greater than 150 Mt with injection rates between 0.25-1.0 Mtpa (Alderson et al. 2013).
7.4.4 Map

7.4.5 Projects
Pilot Injection Project: Inject up to 50,000 t CO₂ potentially in Zululand or Algoa Basin (onshore): Define; DSF.

7.4.6 CCS Indicators

<table>
<thead>
<tr>
<th>Storage Readiness Indicator</th>
<th>Policy Indicator</th>
<th>Legal &amp; Regulatory Indicator</th>
</tr>
</thead>
<tbody>
<tr>
<td>Just starting</td>
<td>Lower-</td>
<td>36</td>
</tr>
<tr>
<td>Not to make a start</td>
<td>Mid</td>
<td></td>
</tr>
<tr>
<td>Making progress</td>
<td>Upper-Mid</td>
<td>60</td>
</tr>
<tr>
<td>Well advanced</td>
<td>Upper</td>
<td></td>
</tr>
<tr>
<td>Prepared</td>
<td>Lower</td>
<td></td>
</tr>
</tbody>
</table>

87
7.4.7 References


8 Appendix 1

8.1 Storage Readiness Indicator

The *Global Storage Readiness Assessment* assessed countries for their potential to deploy CCS in their jurisdictional boundaries. The assessment criteria are detailed in Table 2.

1. A first screening criteria determines if a country has significant storage potential. Only nations with ‘Yes’ proceed.
2. Thereafter, each criterion grades from A to E, where A is high or advanced and E is low or poor.
3. The graded criterion is then converted to a numerical score and weighting applied. The weighting is based on the criteria’s importance, as judged by the authors in consultation with the storage community.
4. The final score groups countries across five categories from ‘Yet to make a start’ through to ‘Ready for large-scale deployment’ (Table 3).
### Table 2 Criteria for grading for the Storage Readiness Indicator

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Grades</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>E</td>
</tr>
<tr>
<td>Low</td>
<td>High</td>
</tr>
</tbody>
</table>

1. Has the country any conventional storage potential? Yes/No

#### Standard of country storage assessment

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Grades</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 Regional potential</td>
<td>Extremely limited</td>
</tr>
<tr>
<td>3 Regional assessment</td>
<td>None</td>
</tr>
<tr>
<td>4 Dataset</td>
<td>None</td>
</tr>
</tbody>
</table>

#### Maturity of science

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Grades</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 Assessment maturity</td>
<td>Regional, Country-scale/Theoretical capacity</td>
</tr>
<tr>
<td>6 Pilot project</td>
<td>No</td>
</tr>
<tr>
<td>7 Commercial project</td>
<td>No</td>
</tr>
</tbody>
</table>

#### Outreach

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Grades</th>
</tr>
</thead>
<tbody>
<tr>
<td>8 Knowledge dissemination</td>
<td>Does not engage in any known dissemination activities</td>
</tr>
</tbody>
</table>
## Table 3 Description and scores for the five status levels for the Storage Readiness Indicator

<table>
<thead>
<tr>
<th>Level</th>
<th>Description</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prepared for wide-scale storage</td>
<td>Operating large-scale CCS projects, CCS research and development program, characterised storage, extensive storage potential, an innovative and advanced oil and gas industry.</td>
<td>Over 90</td>
</tr>
<tr>
<td>Well advanced</td>
<td>Potentially a large-scale CCS project, or storage project, CCS research and development program, characterised storage, extensive storage potential, an innovative and advanced oil and gas industry.</td>
<td>70-90</td>
</tr>
<tr>
<td>Making progress</td>
<td>Developing CCS research and development program and potentially a storage project, either well characterised storage, or extensive storage potential.</td>
<td>30-70</td>
</tr>
<tr>
<td>Just starting</td>
<td>Not pursued any extensive storage studies, or explored CCS in detail.</td>
<td>10-30</td>
</tr>
<tr>
<td>Yet to make a start or very low potential</td>
<td>Limited storage studies or potential for storage.</td>
<td>&lt;10</td>
</tr>
</tbody>
</table>
8.2 CCS Policy Indicator

The *Carbon Capture and Storage Policy Indicator (CCS-PI): 2015 Update* draws from an extensive Institute database of policy measures for a wide range of countries, including direct support for CCS as well as broader implicit support through measures such as carbon pricing. These measures are weighted and aggregated to derive relative levels of support for CCS demonstrations and deployment. Policies are captured in the Policy Index where they have been implemented but also under development (with the degree of development affects a policy’s weighting). Countries are categorised into: Lower Tier, Lower-Mid Tier, Upper-Mid Tier and Upper Tier (Table 4).

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper Tier</td>
<td>CCS Policy environment that are generally supportive of CCS activities.</td>
</tr>
<tr>
<td>Upper-Mid Tier</td>
<td>CCS Policy environment that demonstrate a higher-order potential to support CCS activities.</td>
</tr>
<tr>
<td>Lower-Mid Tier</td>
<td>Discrete but relatively limited policies that are supportive of CCS.</td>
</tr>
<tr>
<td>Lower Tier</td>
<td>CCS Policy environment that reflect an early stage of technology demonstration.</td>
</tr>
</tbody>
</table>

Download a full version of the *CCS Policy Indicator*.

8.3 Legal and Regulatory Indicator

The *CCS Legal and Regulatory Indicator* represents a detailed assessment of each countries’ legal and regulatory frameworks for CCS which were assessed against a number of individual criteria (Table 5). These criteria were designed to reflect the core elements of a comprehensive legal and regulatory model for CCS. The criteria address issues which are likely to be of significance throughout the project lifecycle and include administrative arrangements and potential permitting pathways for CCS projects, as well as allied issues such as environmental impact assessment and public consultation provisions. Five overarching primary criteria provide the foundation of this assessment.

<table>
<thead>
<tr>
<th>Table 5 Primary Assessment Criteria for <em>CCS Legal and Regulatory Indicator</em></th>
</tr>
</thead>
<tbody>
<tr>
<td>The clarity and efficiency of the administrative process under the CCS legal framework to apply for, and obtain, regulatory approval for CCS projects</td>
</tr>
<tr>
<td>The comprehensiveness of the legal framework in providing for all aspects of a CCS project, including siting, design, capture, transport, storage, closure and monitoring for potential releases of stored CO₂.</td>
</tr>
<tr>
<td>The extent to which the CCS legal and regulatory framework provides for the appropriate siting of projects and adequate environmental impact assessment processes.</td>
</tr>
<tr>
<td>The extent to which the CCS legal and regulatory framework provides for and incorporates meaningful and effective stakeholder and public consultation.</td>
</tr>
<tr>
<td>The way in which laws and regulations deal with long-term liability for closure, monitoring and accidental releases of CO₂.</td>
</tr>
</tbody>
</table>
In addition to each of the five primary criteria, several further sub-criteria were developed. A scoring system, was then used to score a jurisdiction against each of the individual criteria and sub-criteria. Scores awarded across all of the assessment criteria which have resulted in a composite score to provide the basis for each country’s total score in the Indicator (Table 6 and Table 7).

### Table 6 Scoring scale for CCS Legal and Regulatory Indicator

<table>
<thead>
<tr>
<th>Score</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>Clearly and unequivocally capable of satisfying the criterion</td>
</tr>
<tr>
<td>2</td>
<td>Moderately capable of satisfying the criterion, subject to conditions or limitations</td>
</tr>
<tr>
<td>1</td>
<td>Capable of satisfying the criterion only in some minor respects</td>
</tr>
<tr>
<td>0</td>
<td>Largely incapable of satisfying the criterion</td>
</tr>
</tbody>
</table>

From the scoring system, three broadly-defined bands have been used to categorise each country:

### Table 7 Descriptions and scores for the CCS Legal and Regulatory Indicator

<table>
<thead>
<tr>
<th>Band</th>
<th>Description</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>CCS-specific laws or existing laws that are applicable across most parts of the CCS project cycle</td>
<td>60-87</td>
</tr>
<tr>
<td>B</td>
<td>CCS-specific laws or existing laws that are applicable across parts of the CCS project cycle</td>
<td>36-60</td>
</tr>
<tr>
<td>C</td>
<td>Very few CCS-specific or existing laws that are applicable across parts of the CCS project cycle</td>
<td>&lt;36</td>
</tr>
</tbody>
</table>

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