Global Storage Portfolio

A global assessment of the geological CO_2 storage resource potential

Global CCS Institute

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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 (CO_2). 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 CO_2. 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 CO_2 (CO_2-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 CO_2 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 1 Resource Assessment Status

COUNTRY	ASSESSMENT STATUS[1]	ESTIMATED RESOURCE ($GTCO_2$)	RESOURCE LEVEL[2]
ASIA-PACIFIC			
Australia	Full	227-702	Effective
Bangladesh	Limited	20	Theoretical
China	Full	1573	Effective
India	Moderate	47-143	Theoretical
Indonesia	Moderate	1.4-2	Effective
Japan	Full	146	Effective
Korea	Full	100	Theoretical
Malaysia	Moderate	28	Effective
New Zealand	Moderate	16	Theoretical
Pakistan	Moderate	32	Theoretical
Philippines	Limited	23	Theoretical
Sri Lanka	Limited	6	Theoretical
Thailand	Limited	10	Theoretical
Vietnam	Limited	12	Theoretical
AMERICAS			
Brazil	Moderate	2,030	Theoretical
Canada	Full	198-671	Effective
Mexico	Moderate	100	Theoretical
USA	Full	2,367-21,200	Effective

[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			
Jordan	Limited	9	Theoretical
Saudi Arabia	Very Limited	5-30	Theoretical
UAE	Very Limited	5-25	Theoretical
EUROPE AND RUSSIA			
Europe excluding UK	Full	72	Theoretical
Norway	Full	86	Effective
Russia	Very Limited	6.8	Theoretical
UK	Full	78	Theoretical
AFRICA			
Algeria	Very Limited	10	Theoretical
Morocco	Limited	0.6	Theoretical
Mozambique	Moderate	2.7-229	Theoretical
South Africa	Moderate	162	Theoretical

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^{o} 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.

[3]International Energy Agency (IEA). 2015. Energy technology perspectives 2015.
[4]Intergovernmental Panel on Climate Change (IPCC). 2014. Climate change 2014: synthesis report.

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_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 (>35oC/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_2 (CO_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/fluid 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[5] is the most widely adopted in the storage literature, classifying the pore space available for CO_2 storage into a hierarchical (but not necessarily sequential) pyramid scheme (

Figure 1).

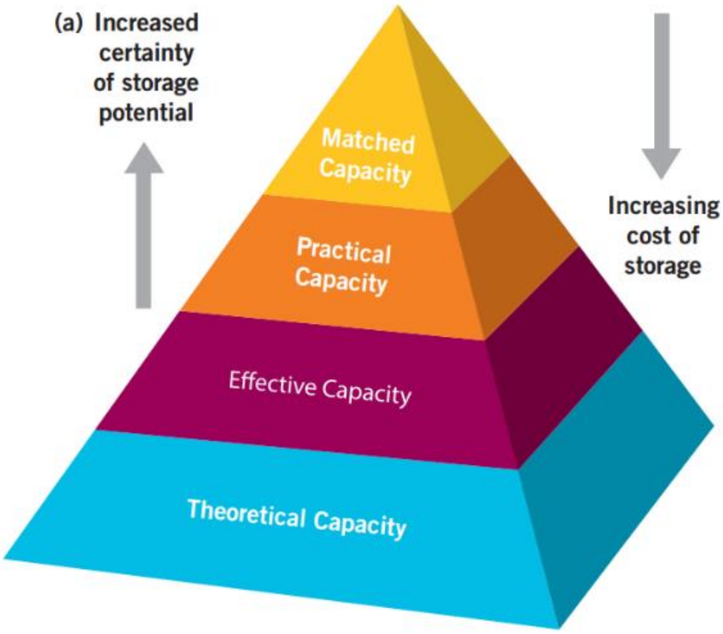

Figure 1 CSLF Techno-Economic Resource-Reserve pyramid[5]

- **Theoretical resource**: the maximum amount of CO_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_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.

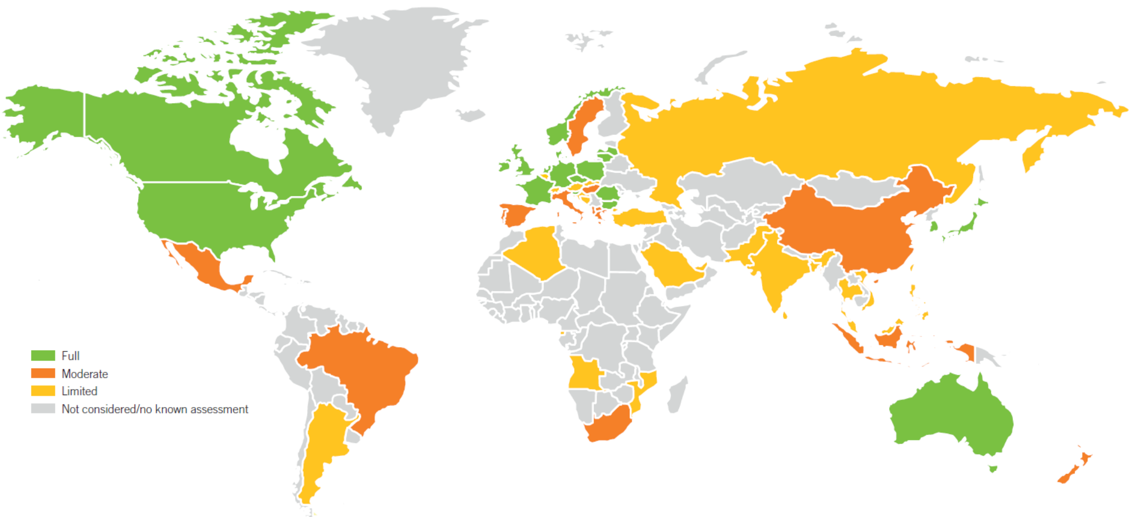


Figure 2 Geographical coverage of storage resources assessments

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:

- ***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 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 CO_2-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 $GtCO_2$ 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 $GtCO_2$ 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

Status: Full

Estimated resource ($GtCO_2$)	Resource level	Resource Calculation Method
227-702*	Effective	Volumetric using storage efficiency factor and probabilistic modelling.
*selected basins only		
Carbon Storage Taskforce 2009		

3.1.3 Prospective basins

Gippsland (offshore, southeast): Total basin estimate: 30-80 $GtCO_2$; effective resource based on national study (Carbon Storage Taskforce 2009). Site estimate example: Injection rates of 1-5 Mtpa CO_2 based on CO_2 injection simulations have been modelled for the nearshore region (Hoffman et al. 2015).

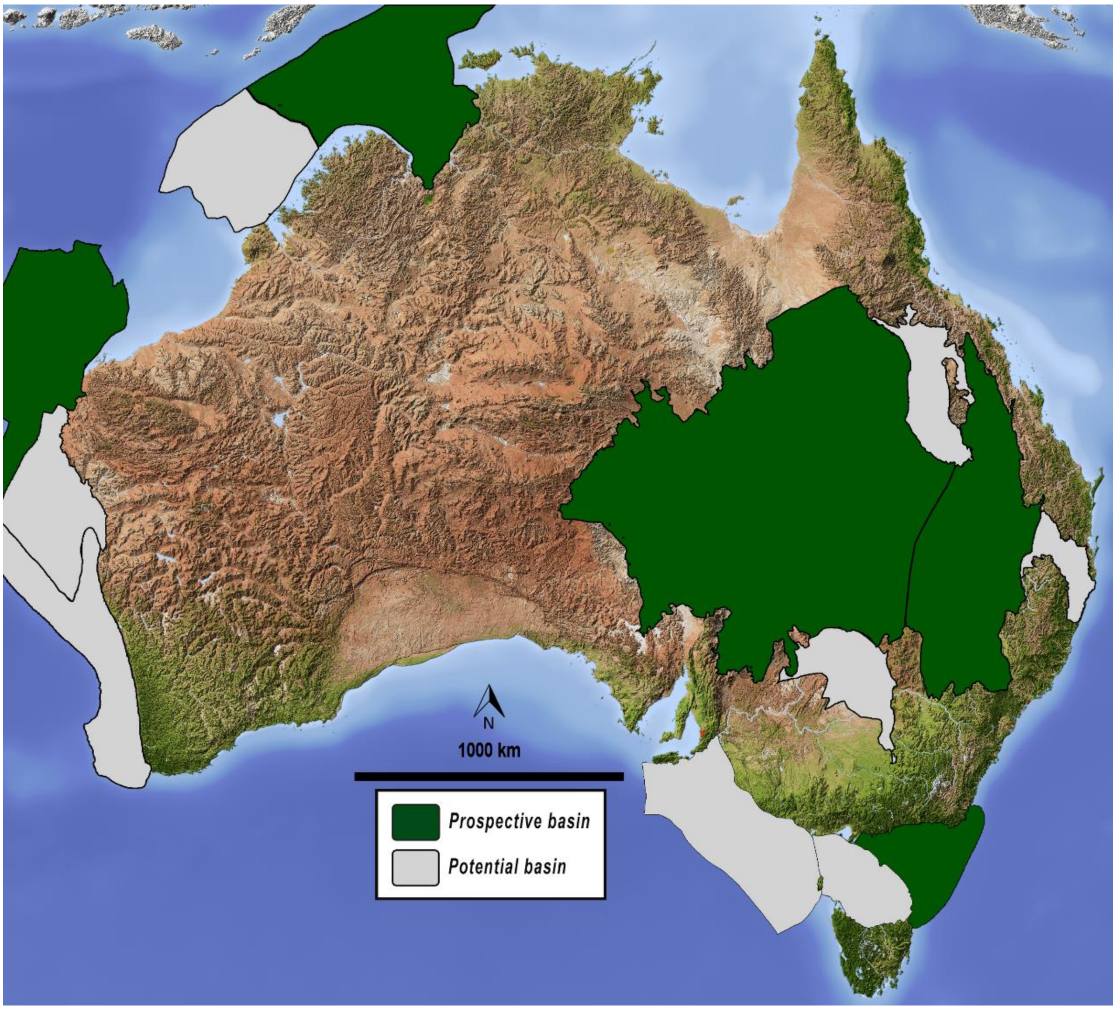
Eromanga (onshore, central): Total basin estimate: 12-53 $GtCO_2$; effective resource based on national study (Carbon Storage Taskforce 2009). 12 $MtCO_2$; effective storage resource based on comprehensive reservoir-seal study (Bradshaw et al. 2009).

Northern Carnarvon (offshore, northwest): Total basin estimate: 26-89 $GtCO_2$; effective resource based on national study (Carbon Storage Taskforce 2009). Gorgon Project plans to inject 3-4 Mtpa CO_2.

Browse (offshore, northwest): Total basin estimate: 7-16 $GtCO_2$; effective resource based on national study (Carbon Storage Taskforce 2009).

Cooper (onshore, central): Total basin estimate: 4-15 $GtCO_2$; effective resource based on national study (Carbon Storage Taskforce 2009). QLD portion of total basin estimate: 172 $MtCO_2$; effective storage resource based on comprehensive reservoir-seal study (Bradshaw et al. 2009).

3.1.4 Map



3.1.5 Projects

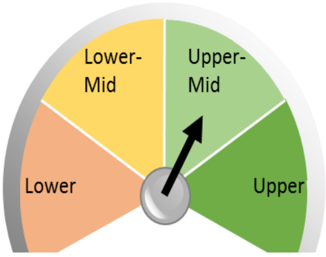
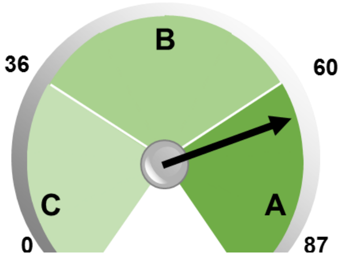
LSIP: Gorgon Carbon Dioxide Injection Project (Onshore, Northern Carnarvon Basin, central west): Execute; DSF.

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

Storage Readiness Indicator	Policy Indicator	Legal & Regulatory Indicator
		

3.1.7 Key References

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

Bradshaw et al. 2000. GEODISC: Project 1—Regional Analysis Stage 2 Basins.

Bradshaw et al. 2009. Queensland carbon dioxide geological storage atlas.

Carbon Storage Taskforce. 2009. National carbon mapping and infrastructure plan – Australia.

Goldie Divko et al. 2009. Geological Carbon Storage Potential of the Onshore Gippsland Basin, Victoria, Australia, report 2.

Hoffman et al. 2015. The CarbonNet Project: site characterisation for carbon storage in the near shore Gippsland Basin.

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 $GtCO_2$ in DSF. There is an established gas industry in the country with increasing opportunity for DGF storage in the east with over 1.1 $GtCO_2$ of theoretical storage; two gas fields being over 200 Mt each (based on ultimate recoverable resources (URR) with CO_2-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

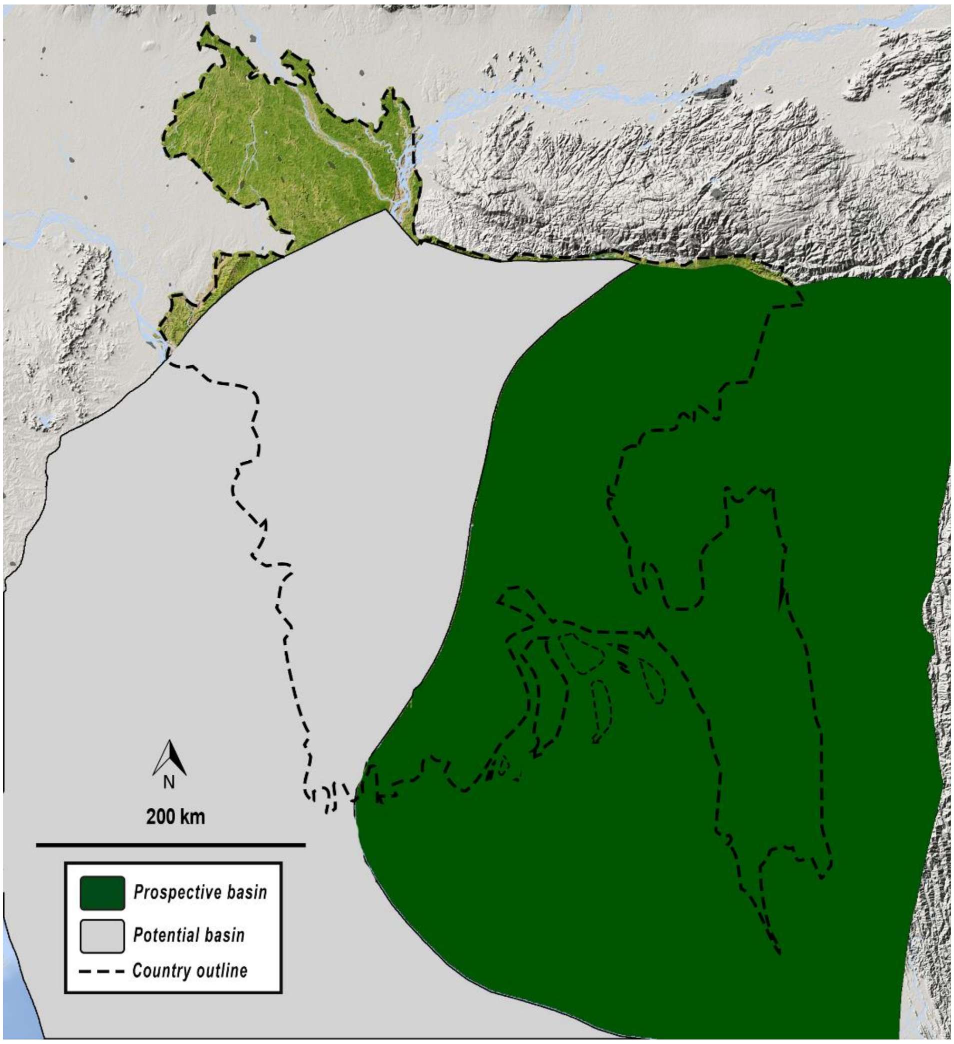
Status: Limited

Estimated resource ($GtCO_2$)	Resource level	Resource Calculation Method
20	Theoretical	Volumetric using generic storage efficiency and generalised basin assumptions
IEAGHG 2008		

3.2.3 Prospective basin

Bengal (onshore/offshore): Total basin estimate: 20 $GtCO_2$; theoretical storage resource based on multi-national assessment (IEAGHG 2008).

3.2.4 Map



3.2.5 CCS Indicator

Storage Readiness Indicator

3.2.6 Key References

IEAGHG. 2008. A regional assessment of the potential for CO_2 storage in the Indian Subcontinent Report 2008/2.

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 CO_2-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 $GtCO_2$, 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 $GtCO_2$ for all suitable, onshore basins (Wei et al. 2013). A national assessment on CO_2-EOR estimated around 7.7 billion barrels of oil could be recovered and with a practical storage resource of 2.2 $GtCO_2$ of CO_2 (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

Estimated resource ($GtCO_2$)	Resource level	Resource Calculation Method
1573*	Effective	Volumetric using storage efficiency factor.
*onshore basins only		
Wei et al. 2013		

3.3.3 Prospective basins

Ordos (onshore; central): Total basin estimate: 60-700 GtCO_2; effective resource based on detailed reservoir-seal analysis (Jiao et al. 2011); Site estimate example: Injection rates of up to 18 Mtpa based on CO_2 injection simulations (Jiao et al. 2011). LSIP Yanchang CCUS Project plans to inject over 1 Mtpa. Site of several pilot projects.

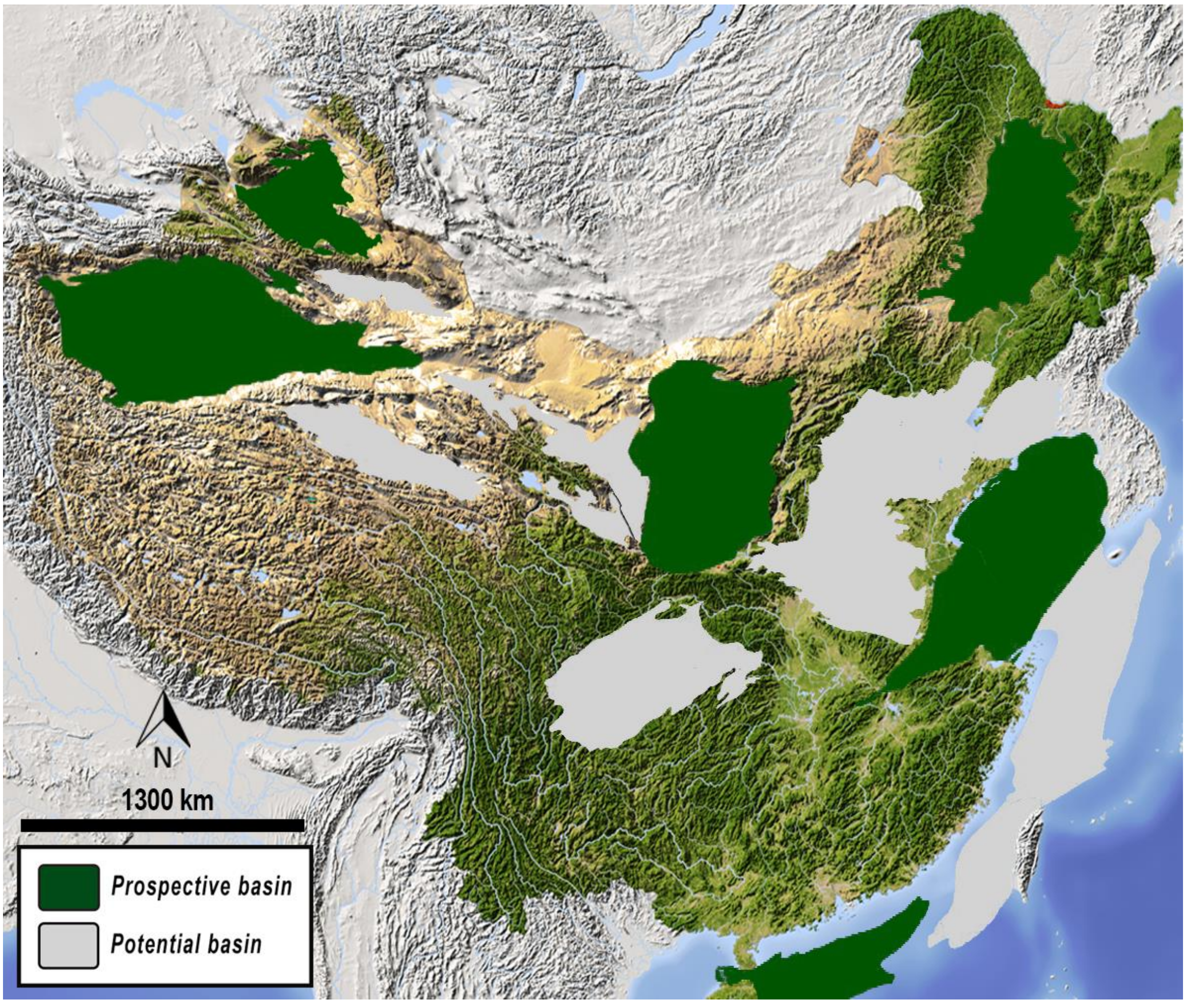
Pearl River Mouth (offshore, southeast): Total basin estimate: 110-443 GtCO_2; effective resource based on detailed reservoir-seal analysis (Zhou et al. 2013).

Bohai (onshore/offshore, northeast): Total basin estimate: 192 GtCO_2 effective resource based on detailed reservoir-seal analysis (Li et al. 2015).

Songliao (onshore, northeast): Total basin estimate: 20 GtCO_2 effective resource based on detailed reservoir-seal analysis (Su et al. 2013). Site estimate example: Injection rates of 15 Mtpa based on CO_2 injection simulations (Zhao et al. (2012).

Tarim (onshore, west): Total basin estimate: 745 GtCO_2; 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; CO_2-EOR.

LSIP: Sinopec Shengli Power Plant CCS (Onshore, Bohai Basin, Shandong): Define; CO_2-EOR.

LSIP: Yanchang Integrated CCS Demonstration Project (Onshore, Ordos Basin, Shaanxi): Define; CO_2-EOR.

LSIP PetroChina Jilin Oil Field EOR Project (Phase 2) (Onshore, Jilin): Define; CO_2-EOR.

LSIP: Huaneng GreenGen IGCC (Phase 3) (Onshore, Songliao/Yitong basins, Jilin): Evaluate; CO_2-EOR.

LSIP: Shenhua Ordos CTL (Phase 2) (Onshore, Tianjin): Evaluate; DSF.

LSIP: Shanxi International Energy Group CCUS Project (Onshore, Shanxi): Identify; CO_2-EOR.

LSIP: Shenhua Ningxia CTL (Onshore, Ningxia): Identify; CO_2-EOR.

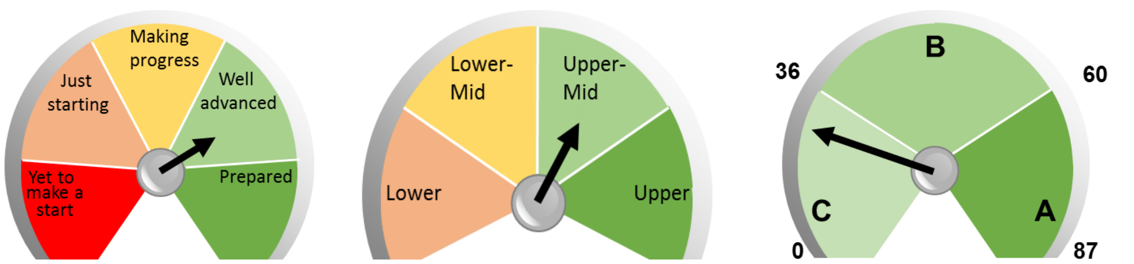
LSIP: China Resources Power (Haifeng) Integrated Carbon Capture and Sequestration Demonstration (Offshore, Pearl River Basin, South China Sea): Identify; DSF.

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; CO_2-EOR.

3.3.6 CCS Indicators

Storage Readiness Indicator	Policy Indicator	Legal & Regulatory Indicator



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Dahowski et al. 2009. Regional opportunities for carbon dioxide capture and storage in China, a comprehensive CO_2 storage cost curve and analysis of the potential for large scale carbon dioxide capture and storage in the People's Republic of China.

Jiao et al. 2011. A feasibility study of geological CO_2 sequestration in the Ordos Basin, China. Energy Procedia 4, 5982–5989.

Li et al. 2015. Assessment of the CO_2 Storage Potential in the Deep Saline Formation of Offshore Bohai Basin, China. Environ. Eng. Geosci. Advanced Copy.

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Zhou et al. 2013. Feasibility Study of CCS-Readiness in Guangdong Province, China (GDCCSR) Final Report: Part 2 Assessment of CO_2 Storage Potential for Guangdong Province, China.

Zhao et al. 2012. CO_2 Plume Evolution and Pressure Build-up of Large-scale CO_2 Injection into Saline Aquifers in Sanzhao Depression, Songliao Basin, China. Transport Porous Med., 95: 407–424

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 $GtCO_2$, mainly DSF. Viebahn et al. (2014) indicated that the potential for India was between 47-143 $GtCO_2$, but for 'good quality' storage, the theoretical estimate was 47-48 $GtCO_2$. The DGOF storage potential is low at around 4-6 $GtCO_2$ (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

Estimated resource ($GtCO_2$)	Resource level	Resource Calculation Method
47-143	Theoretical	Volumetric using generic storage efficiency and generalised basin assumptions
Viebahn et al. 2014		

3.4.3 Prospective basins

Cambay (onshore, central west): Total basin estimate: 5.8 $GtCO_2$ DSF and DOF theoretical resource based on multinational study (IEAGHG 2008).

Cauvery (offshore, southeast, shared with Sri Lanka): Total basin estimate: 6 $GtCO_2$ DSF theoretical resource based on multinational study (IEAGHG 2008).

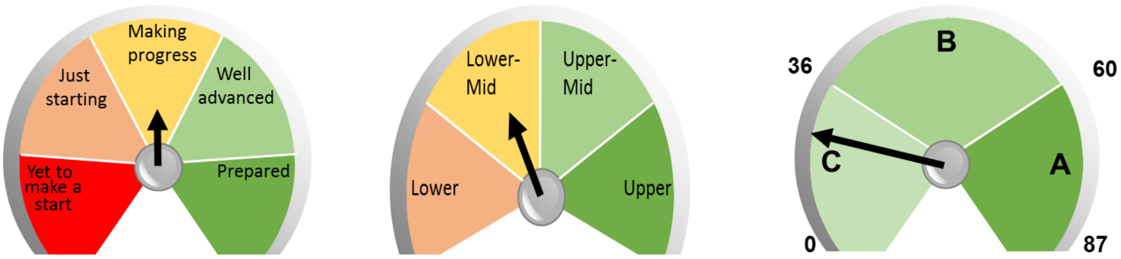
Krishna-Godavari (offshore/minor onshore, southeast): Total basin estimate: 4 $GtCO_2$ DSF theoretical resource based on multinational study (IEAGHG 2008).

Mumbai (offshore/ minor onshore, central west): Total basin estimate: 13 $GtCO_2$ DSF and DOF theoretical resource based on multinational study (IEAGHG 2008).

3.4.4 Map

3.4.5 CCS Indicators

Storage Readiness Indicator	Policy Indicator	Legal & Regulatory Indicator



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Viebahn et al. 2014. Prospects of carbon capture and storage (CCS) in India's power sector – An integrated assessment. Applied Energy, 117: 62-75.

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 CO_2-EOR.

The first multinational study focussed on the South Sumatra Basin, which has an estimate 8 $GtCO_2$ of theoretical storage resource in DSF. 1 Gt in effective storage resource in DGOF was estimated including one gas field containing over 488 $MtCO_2$ 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 $GtCO_2$ of storage. A later study focussed on South Sumatra and West Java basins and included CO_2-EOR, DGF, and DSF potential (World Bank 2015). The cumulative effective storage resources of that assessment was between 1.4 and 2 $GtCO_2$, 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 CO_2 including the giant Natuna field with 70% CO_2. 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

Estimated resource ($GtCO_2$)	Resource level	Resource Calculation Method
1.4-2	Effective	Volumetric calculation with generic storage efficiency.
* South Sumatra and West Java basins only		
World Bank 2015		

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).

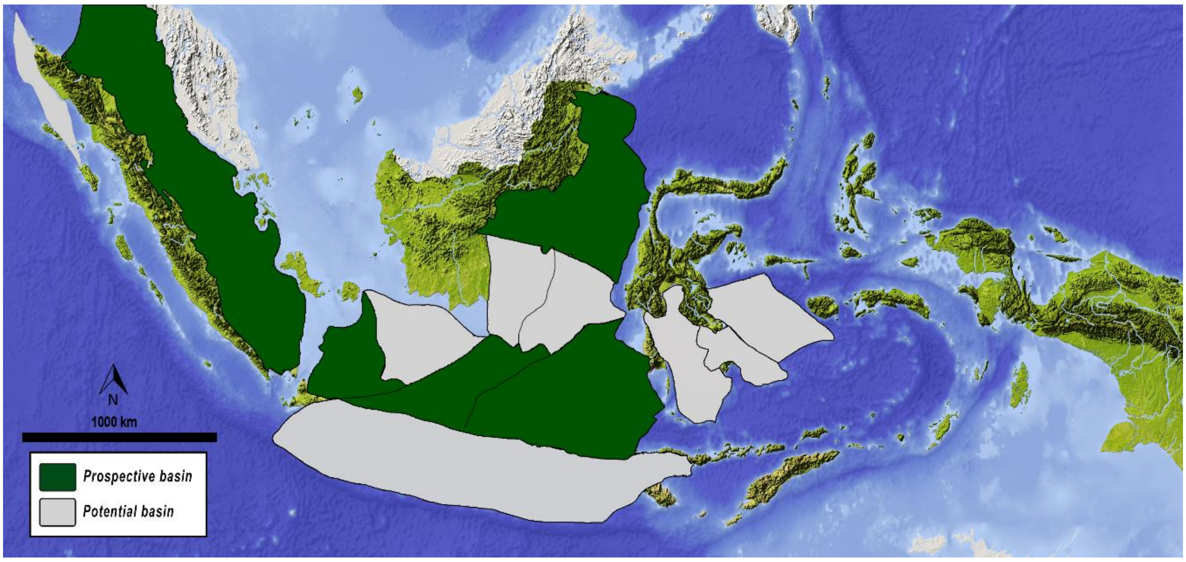
Kutei (onshore/offshore; East Kalimantan): 8 $GtCO_2$ effective storage resource estimate in DGF (IEAGHG 2009).

Tarakan (onshore/offshore; North Kalimantan): 0.13 $GtCO_2$ 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 CO_2-EOR and DGF and 279-683 Mt effective storage resource in DSF (World Bank 2015).

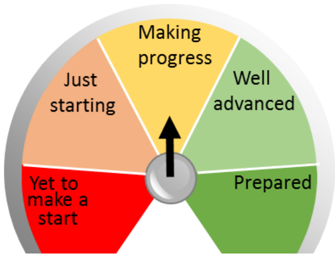
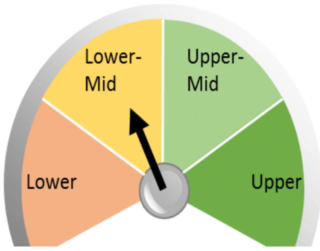
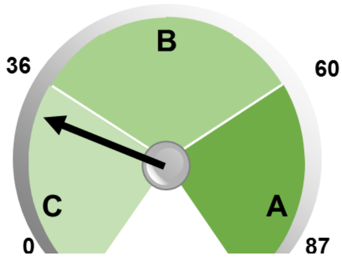
3.5.4 Map



3.5.5 Projects

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

3.5.6 CCS Indicators

Storage Readiness Indicator	Policy Indicator	Legal & Regulatory Indicator
		

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IEAGHG. 2009. CO_2 storage in depleted gas fields report 2009/01.

World Bank. 2015. Carbon Capture and Storage for Coal-Fired Power Plants in Indonesia.

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 $GtCO_2$ 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 $GtCO_2$ 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 $GtCO_2$ (Takahashi et al. 2009).

The final national assessment focussed on DSF close to large CO_2 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 $GtCO_2$ (Ogawa et al. 2011). A basin-scale dynamic simulation study of the Kanto Basin (Tokyo Bay), showed a total effective storage potential of 1 $GtCO_2$ with the injection of 1 Mtpa from 10 injection wells for 100 years (Yamamoto 2009).

3.6.2 National Resource Assessment Status

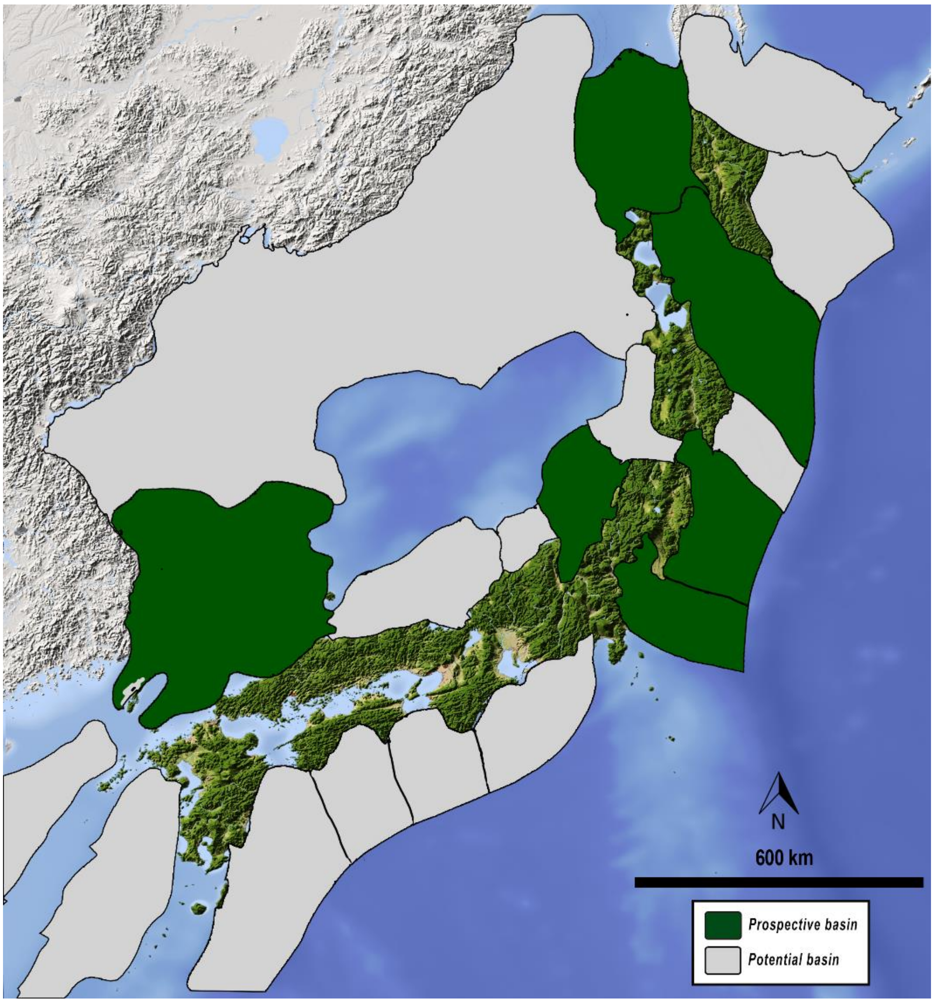
Status: Full

Estimated resource ($GtCO_2$)	Resource level	Resource Calculation Method
146	Effective	Volumetric using storage efficiency factor.
Takahashi et al. 2009		

3.6.3 Prospective basins

The individual basin resource estimates have not been published.

3.6.4 Map



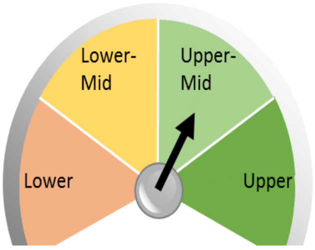
3.6.5 Project

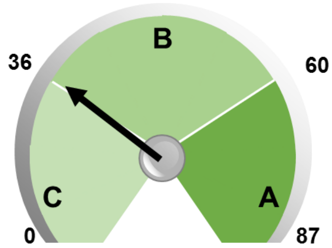
Notable: Nagaoka CCS Pilot Project (Onshore, Niigata Basin, Niigata Prefecture): Complete; DSF.

Notable: Tomakomai CCS Demonstration Project (Nearshore, Hokkaido Prefecture): Execute; DSF.

3.6.6 CCS Indicators

Storage Readiness Indicator	Policy Indicator	Legal & Regulatory Indicator





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RITE (The Research Institute of Innovative Technology for the Earth). 2006. Report on Research and development of underground storage technologies.

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Yamamoto et al. 2009. Large-scale numerical simulation of CO_2 geologic storage and its impact on regional groundwater flow: A hypothetical case study at Tokyo Bay, Japan. Energy Proc., 1: 1871-1878.

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 GtCO_2 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 CO_2-EOR potential in the offshore Jeju (95 GtCO_2) and Ulleung (3 GtCO_2) 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

Estimated resource (GtCO_2)	Resource level	Resource Calculation Method
100	Theoretical	Volumetric calculation
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 GtCO_2; 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 GtCO_2; theoretical resource based on national study (MEST, 2008).

Jeju (offshore; south): Total basin estimate: 95 GtCO_2; theoretical resource based on national study (MEST, 2008).

3.7.4 Map

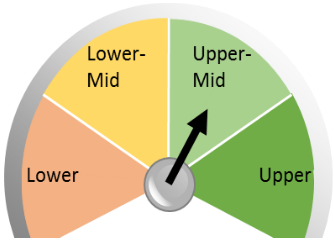
3.7.5 Projects

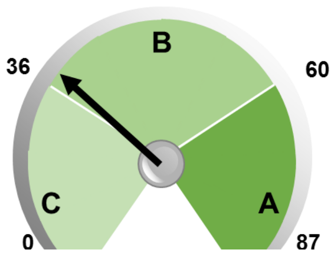
LSIP: Korea CCS One (Offshore, Ulleung Basin): Evaluate; DSF.

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

3.7.6 CCS Indicators

Storage Readiness Indicator	Policy Indicator	Legal & Regulatory Indicator





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Egawa et al. 2009. Preliminary evaluation of geological storage capacity of carbon dioxide in sandstones of the Sindong Group, Gyeongsang Basin (Cretaceous). J. Geol. Soc. Korea, 45, 463–472.

Kihm et al. 2012. Hydrogeochemical numerical simulation of impacts of mineralogical compositions and convective fluid flow on trapping mechanisms and efficiency of carbon dioxide injected into deep saline sandstone aquifers, J. Geophys. Res., 117: B06204.

Kim et al. 2011, Evaluation of CO_2 storage capacity of Bukpyeong Basin using three-dimensional modelling and thermal-hydrological numerical modelling. The 1st Korea CCS Conference (Abstract), Jeju, April 13–15. [Korean].

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Ministry of Educational Science and Technology (MEST). 2008. Characterization and evaluation of geologic formation for geological sequestration of carbon dioxide. 21st Century Frontier R&D Program. [Korean].

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 CO_2-EOR, as well as DSF storage. The National Oil Company has undertaken several studies into CO_2-EOR and DSF in the Malay and Sarawak basins. The only published account estimated an effective storage resource of 28 $GtCO_2$ 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%) CO_2 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

Estimated resource ($GtCO_2$)	Resource level	Resource Calculation Method
28*	Effective	DGOF, standard CO_2 replacement volume.
Gas fields in four basins: Sarawak, Malay, Brunei-Sabah		
IEAGHG 2009		

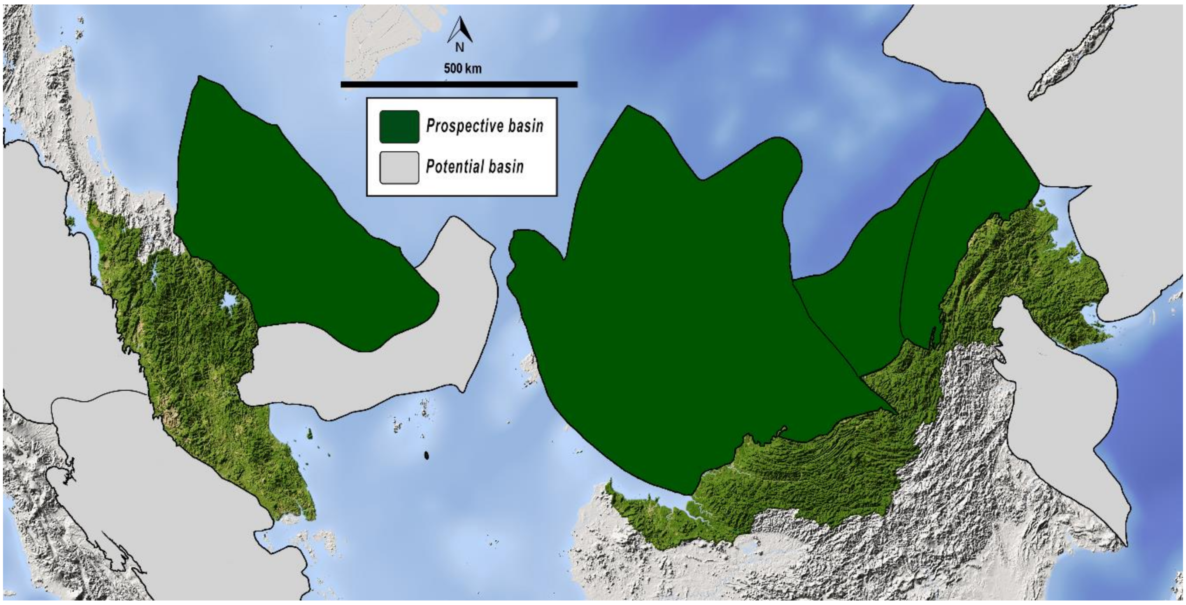
3.8.3 Prospective basins

Greater Sarawak (offshore; East Malaysia): 10 $GtCO_2$ 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 $GtCO_2$ effective storage resource estimate in DGF (IEAGHG 2009).

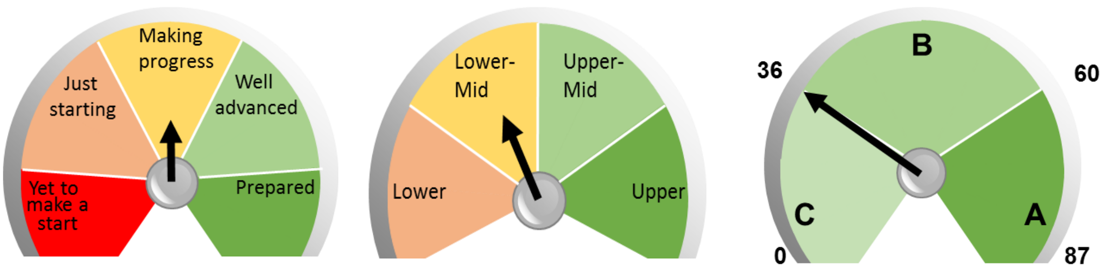
Brunei-Sabah (offshore; East Malaysia): 3 $GtCO_2$ effective storage resource estimate in gas fields (IEAGHG 2009).

3.8.4 Map



3.8.5 CCS Indicators

Storage Readiness Indicator	Policy Indicator	Legal & Regulatory Indicator



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Loo. 2012, Current Status on Carbon Capture and Storage Initiatives in Malaysia, 4th IEA international CCS Regulatory Network Meeting, 9-10 May 2012, Paris, France.

Masoudi et al. 2011. An integrated reservoir simulation-geomechanical study on feasibility of CO_2 storage in M4 carbonate reservoir, Malaysia. IPTC 15029.

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 CO_2 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 $GtCO_2$, 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 CO_2-EOR. There is 300 $MtCO_2$ 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 $GtCO_2$ storage potential (Field et al. 2009).

3.9.2 National Resource Assessment Status

Status: Moderate

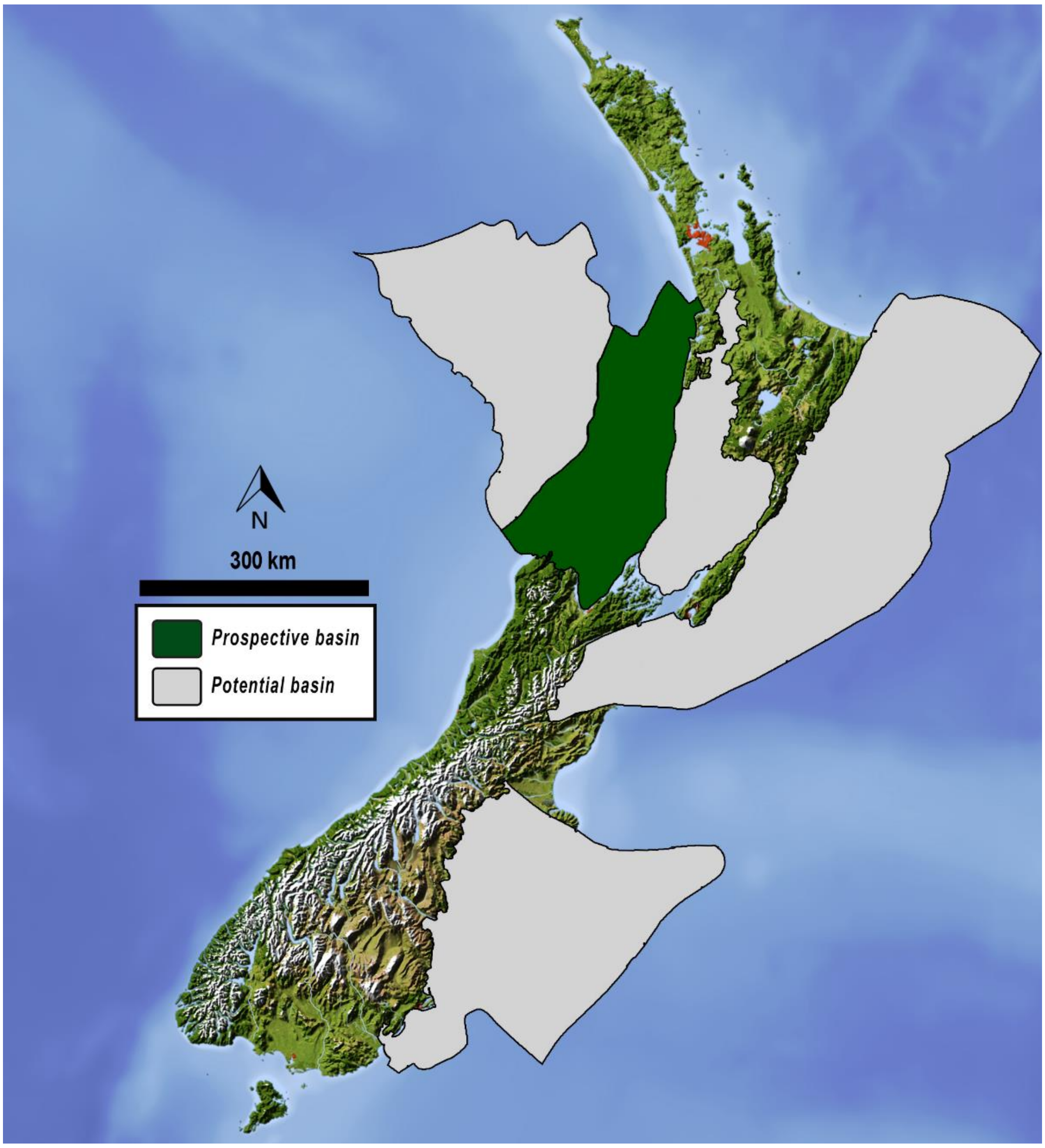
Estimated resource ($GtCO_2$)	Resource level	Resource Calculation Method
16*	Theoretical	Volumetric using general storage efficiency factor
*Onshore basins only excluding Southland Basin		
Field et al. 2009		

3.9.3 Prospective basin

Taranaki (onshore/offshore, western North Island): Total basin estimate: over 5 $GtCO_2$; theoretical resource based on national study. Dynamic simulation into the Maui Field suggests an injection rate of 5 Mtpa and 222 $MtCO_2$ stored (Archer et al. 2009).

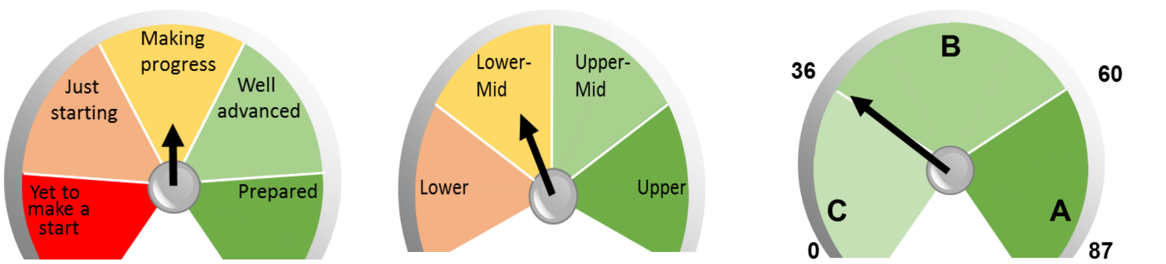
East Coast (onshore, eastern North Island): Total basin estimate: over 5 $GtCO_2$; theoretical resource based on national study (Field et al. 2009).

3.9.4 Map



3.9.5 CCS Indicators

Storage Readiness Indicator	Policy Indicator	Legal & Regulatory Indicator



3.9.6 Key References

Archer et al. 2009. Opportunities for underground geological storage of CO_2 in New Zealand - Report CCS-08/8 - Taranaki petroleum fields. GNS Science Report 2009/61.

Edbrooke et al. 2009. New Zealand Carbon Dioxide Storage Site Assessment: Phase 1. CO_2CRC, Canberra, Australia. RPT08-1410.

Field et al. 2009. New Zealand carbon dioxide storage site assessment: Phase 2. CO_2CRC Publication Number RPT09-1579.

Funnell et al. 2009, Opportunities for underground geological storage of CO_2 in New Zealand Report CCS-08/1: Waikato and onshore Taranaki overview, GNS Science Report 2009/53.

Stagpoole et al. 2009. Opportunities for underground geological storage of CO_2 in New Zealand - Report CCS- 08/4 - Offshore Waikato Region. GNS Science Report 2009/57.

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 $GtCO_2$ in DGOF including four gas fields with resource capacity of over 200 $MtCO_2$ (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 $GtCO_2$ 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

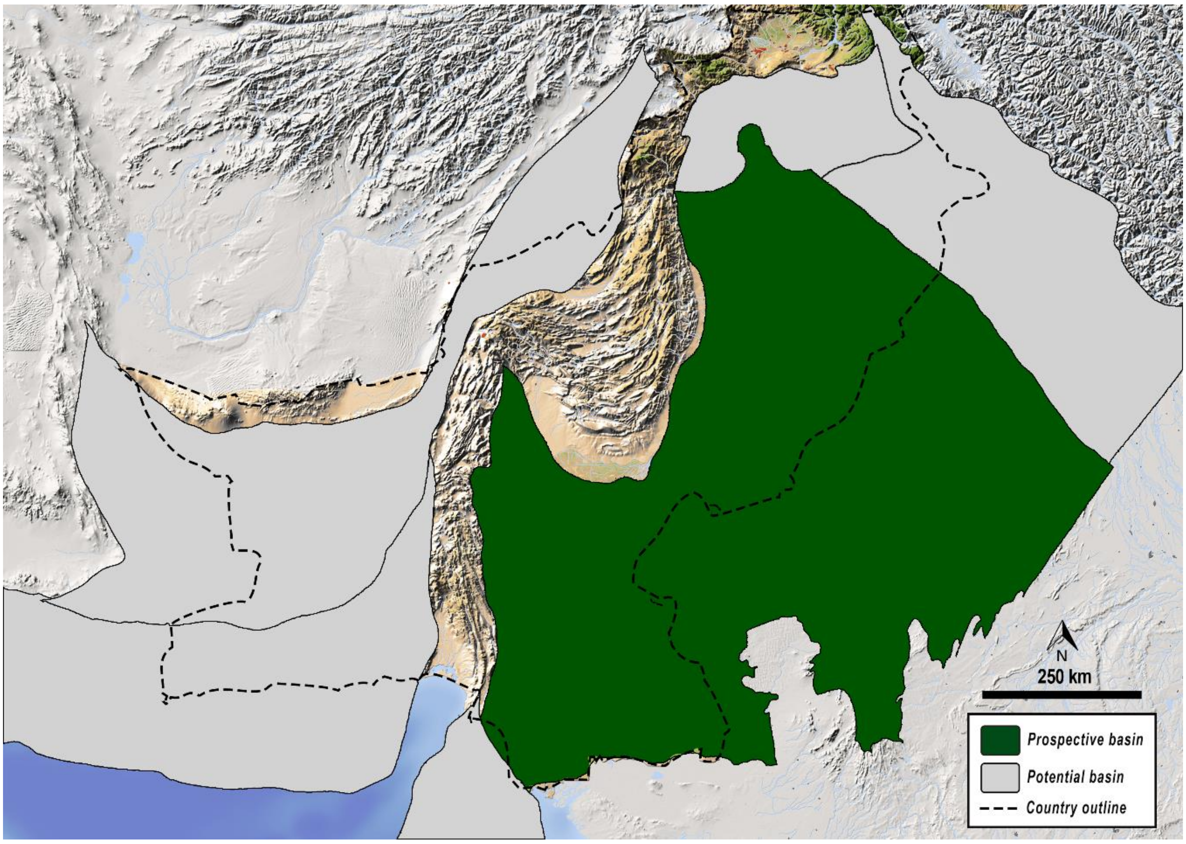
Estimated resource ($GtCO_2$)	Resource level	Resource Calculation Method
32	Theoretical	Volumetric using generic storage efficiency and generalised basin assumptions.
IEAGHG 2008		

3.10.3 Prospective basins

Potwar Basin (Lower Indus): Total basin estimate: 1.7 $GtCO_2$ effective storage potential in DGF based on multinational (IEAGHG 2008).

Balochistan (offshore/onshore): Total basin estimate: 30 $GtCO_2$; DSF theoretical resource estimate based on multinational study (IEAGHG 2008).

3.10.4 Map



3.10.5 CCS Indicators

Storage Readiness Indicator

3.10.6 Key References

IEAGHG. 2008. A regional assessment of the potential for CO_2 storage in the Indian Subcontinent Report 2008/2.

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 $GtCO_2$ theoretical storage resource potential (ADB 2013). DSF make up the majority of storage with 22.7 $GtCO_2$ theoretical storage resource, with oil and gas fields a low 0.3 $GtCO_2$ effective storage resource; a large gas field has 251 $MtCO_2$ 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

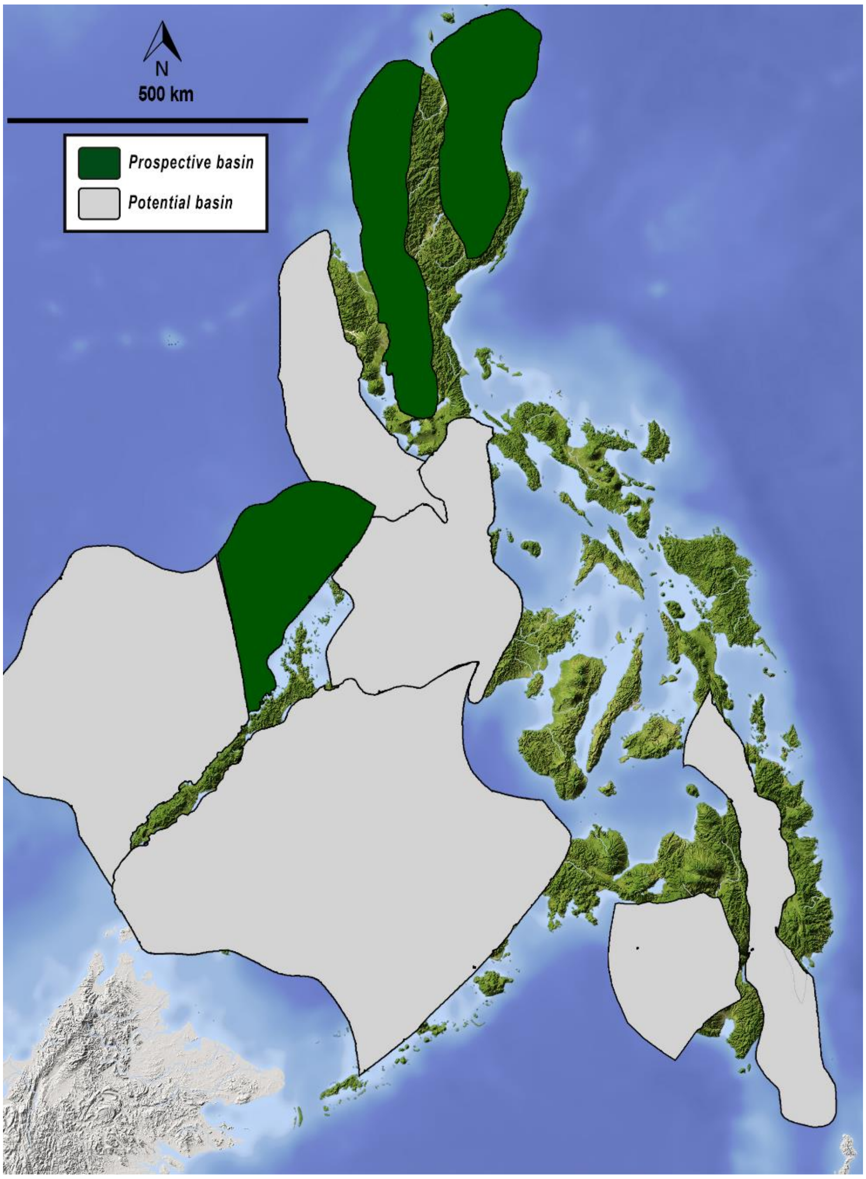
Status: Limited

Estimated resource ($GtCO_2$)	Resource level	Resource Calculation Method
23*	Theoretical	Volumetric calculation.
***Only 2 of 16 basins		
ADB 2013		

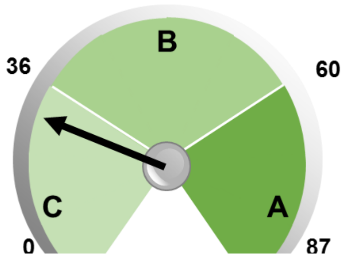
3.11.3 Prospective basins

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

Storage Readiness Indicator	Legal and Regulatory Indicator
	

3.11.6 Key References

Asian Development Bank. 2013. Prospects for carbon capture and storage in Southeast Asia.

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 $GtCO_2$ 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

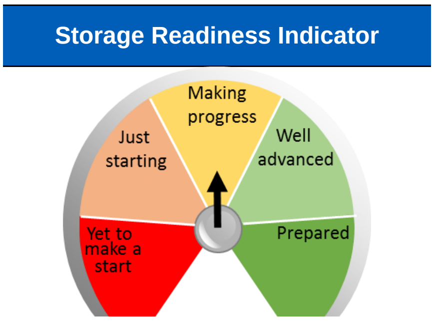
Estimated resource ($GtCO_2$)	Resource level	Resource Calculation Method
6*	Theoretical	Volumetric using generic storage efficiency and generalised basin assumptions.
*Large part of basin shared with India		
IEAGHG 2008		

3.12.3 Prospective basins

Cauvery (offshore, southeast, shared with India): 6 $GtCO_2$ theoretical resource based on multinational study (IEAGHG 2008).

3.12.4 Map

3.12.5 CCS Indicator



3.12.6 References

IEAGHG. 2008. A regional assessment of the potential for CO_2 storage in the Indian Subcontinent Report 2008/2.

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 $GtCO_2$; 8.9 $GtCO_2$ theoretical storage resource in DSF and 1.4 $GtCO_2$ 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 CO_2-EOR. The top three ranked basins were estimated to have a combined effective storage resource of 350 $MtCO_2$ (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

Estimated resource ($GtCO_2$)	Resource level	Resource Calculation Method
>10	Theoretical	Volumetric calculation.
ADB 2013		

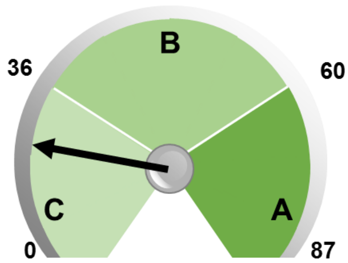
3.13.3 Prospective basins

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

Storage Readiness Indicator	Legal & Regulatory Indicator



3.13.6 Key References

Asian Development Bank. 2013. Prospects for carbon capture and storage in Southeast Asia.

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 CO_2-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 CO_2-EOR.

The multinational assessment focused on storage that estimated a total theoretical storage potential of around 12 $GtCO_2$ theoretical storage resource (ADB 2013). The majority is located in DSF (10.4 $GtCO_2$), 1.4 $GtCO_2$ in DGOF, which includes the largest field estimated to have over 300 $MtCO_2$ 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 $GtCO_2$ 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 CO_2 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

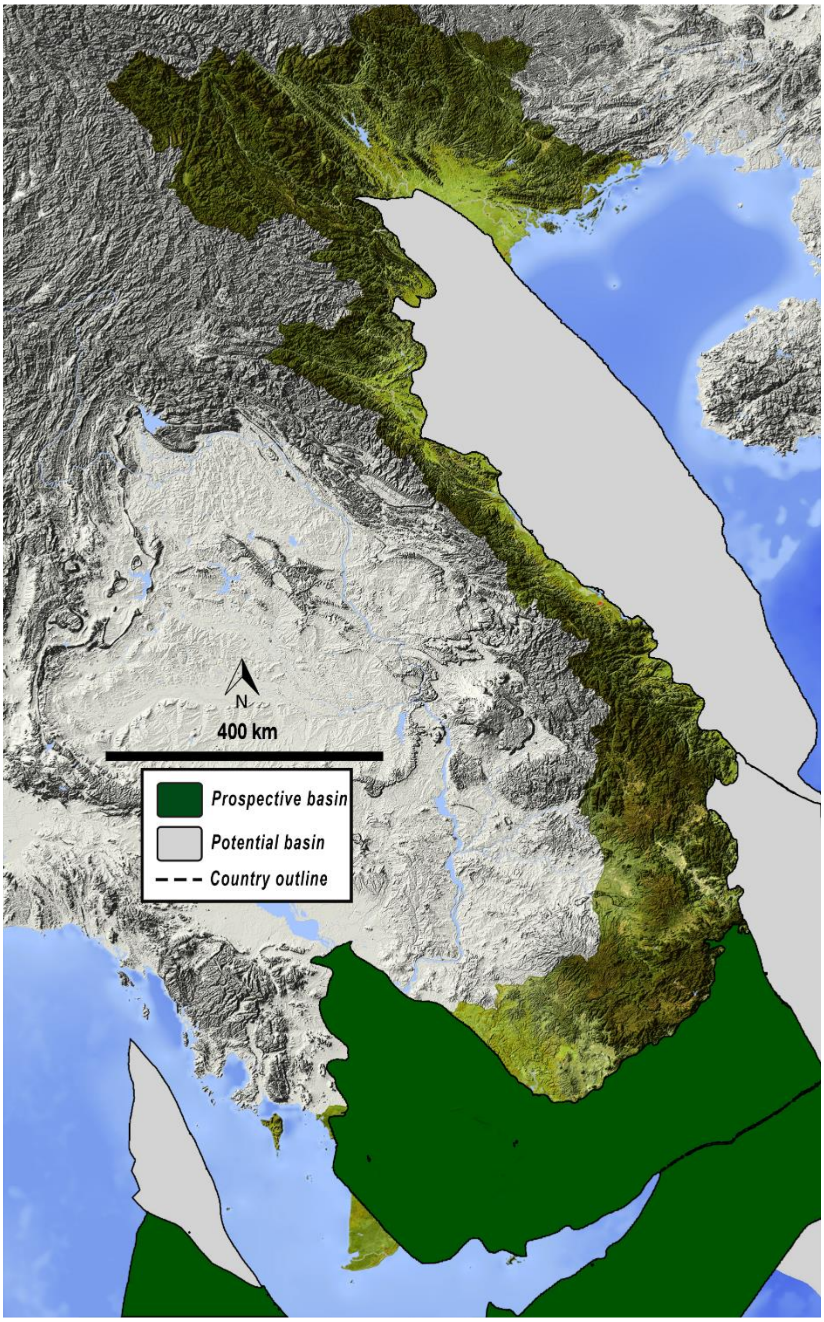
Status: Limited

Estimated resource ($GtCO_2$)	Resource level	Resource Calculation Method
12	Theoretical	Volumetric calculation.
ADB 2013		

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

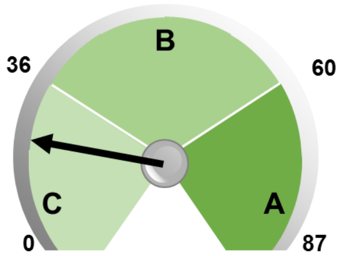


3.14.5 Projects

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

Storage Readiness Indicator	Legal & Regulatory Indicator
	

3.14.7 Key References

Asian Development Bank. 2013. Prospects for carbon capture and storage in Southeast Asia.

CCOP Technical Secretariat, 2014. CCOP Guideline on the Methodologies for Selecting Geological Carbon Dioxide (CO_2) Storage and Estimation of Storage Capacities.

Nguyen et al. 2015. Perspective of CO_2 Capture & Storage (CCS) development in Viet Nam: Results from expert interviews. Int. J. Greenh. Gas Con., 37: 220-227.

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 CO_2-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 $GtCO_2$, predominantly in onshore and offshore DSF (Rockett et al. 2011). In addition 4 $GtCO_2$ effective storage resource in DGOF, 1.7 $GtCO_2$ 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 CO_2 Injection Project (Onshore, Recôncavo Basin, Bahia)

Pilot: Ressacada Pilot CCS Project (Onshore, Florianópolis Island)

4.1.3 National Resource Assessment Status

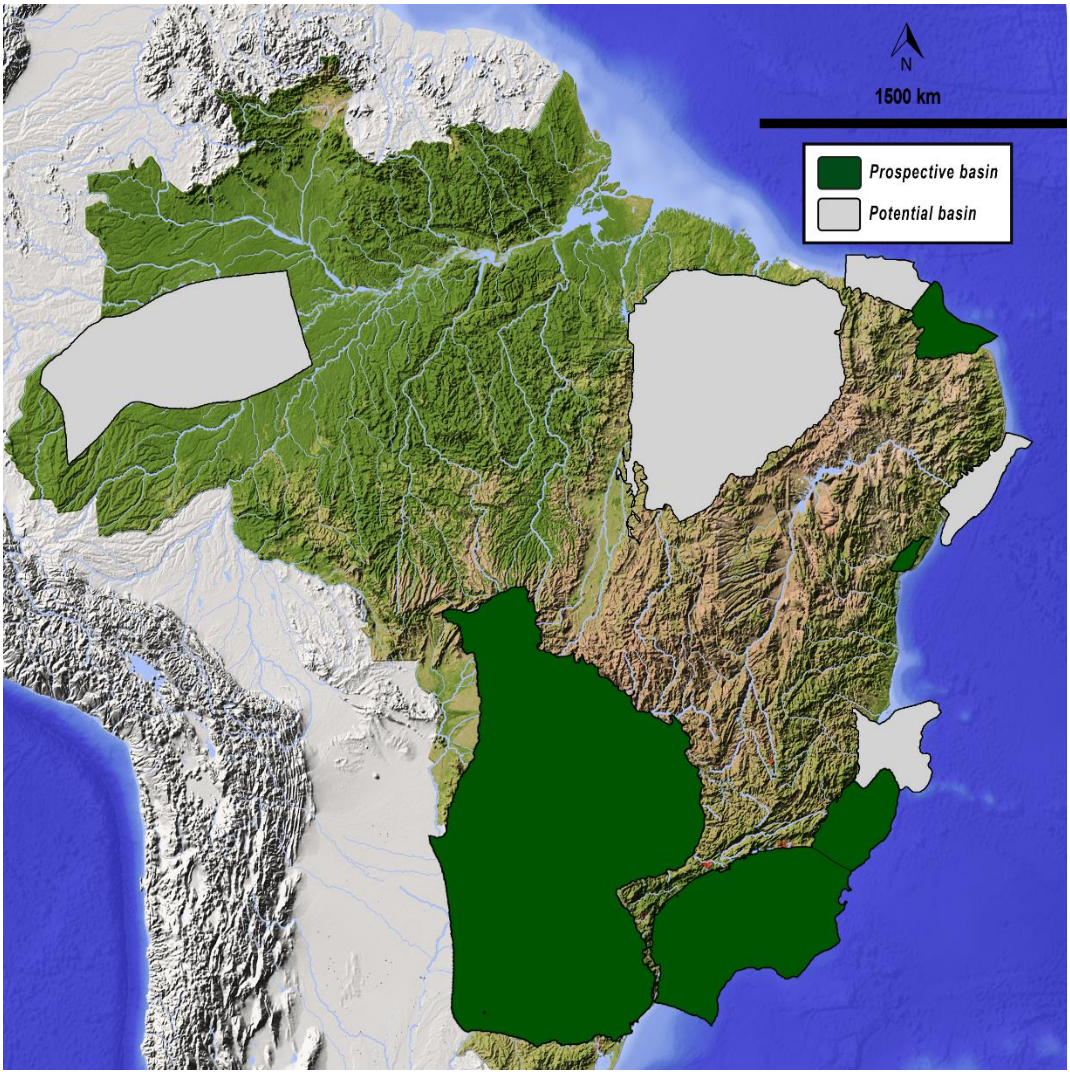
Status: Moderate

Estimated resource ($GtCO_2$)	Resource level	Resource Calculation Method
2,030	Theoretical	Volumetric using storage efficiency factor.
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



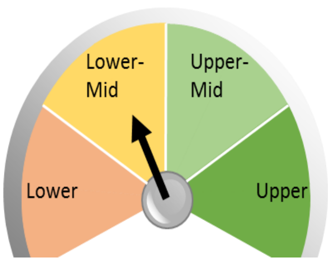
4.1.6 Projects

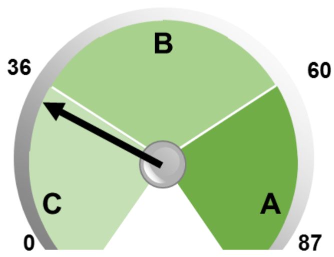
LSIP: Petrobras Lula Oil Field CCS Project (Offshore, Santos Basin): Operate; CO_2-EOR.

Notable: Petrobras Miranga CO_2 Injection Project (Offshore, Reconcavo Basin): Completed; CO_2-EOR.

4.1.7 CCS Indicators

Storage Readiness Indicator	Policy Indicator	Legal & Regulatory Indicator





4.1.8 Key References

Dino et al. 2009. CCS project in Recôncavo Basin. Energy Proc., 1: 2005–2011.

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.

Rockett et al. 2013. CO_2 Storage Capacity of Campos Basin's Oil Fields, Brazil. Energy Proc., 37: 1–10.

Rockett et al. 2011. The CARBMAP project: Matching CO_2 sources and geological sinks in Brazil using geographic information system. Energy Proc., 4: 2764-2771.

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 focussed on the Province of Québec, Williston Basin and Alberta Basin, primarily the Basal Cambrian Sandstone.

4.2.2 National Resource Assessment Status

Status: Full

Estimated resource ($GtCO_2$)	Resource level	Resource Calculation Method
198-671	Effective	Volumetric using storage efficiency factor and probabilistic modelling.
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).

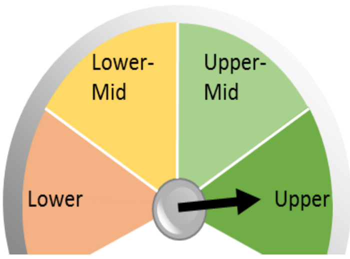
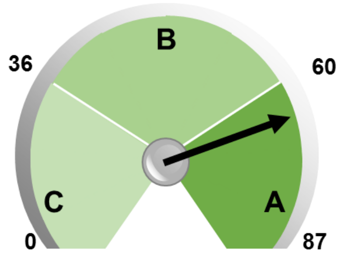
4.2.4 Map

4.2.5 Projects

LSIP: Great Plains Synfuel Plant and Weyburn Midale Project (Onshore, Williston Basin, Saskatchewan): Operate; CO_2-EOR.
LSIP: Boundary Dam Carbon Capture and Storage Project (Onshore, Williston Basin, central, Saskatchewan): Operate; Primarily CO_2-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; CO_2-EOR.
LSIP: Alberta Carbon Trunk Line ACTL with North West Sturgeon Refinery CO_2 Stream (Onshore, Alberta Basin, Alberta): Execute; CO_2-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; CO_2-EOR.

4.2.6 CCS Indicators

Storage Readiness Indicator	Policy Indicator	Legal & Regulatory Indicator
		

4.2.7 Key References

Bachu. 2003. Screening and ranking of sedimentary basins for sequestration of CO_2 in geological media in response to climate change. Environ. Geol., 44: 277–289.

Bédard et al. 2013. CO_2 Geological Storage in the Province of Québec, Canada Capacity Evaluation of the St. Lawrence Lowlands basin. Energy Proc., 37: 5093-5100.

IEAGHG Weyburn-Midale CO_2 Monitoring and Storage Project. http://ptrc.ca/projects/weyburn-midale. Accessed November 2015.

North American Carbon Atlas Partnership (NACSA). 2012. The North American carbon storage atlas (1st Ed.).

Peck et al. 2013. CO_2 storage resource potential of the Cambro-Ordovician saline system in the western interior of North America. Energy Proc., 37: 5230-39.

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

Shafeen et al. 2004. CO_2 sequestration in Ontario, Canada. Part I: storage evaluation of potential reservoirs. Ener. Conv. Management, 45: 3207-3217.

Shell Canada Limited. 2015. Quest Carbon Capture and storage project annual summary report - Alberta Department of Energy: 2014.

US Department of Energy (US DOE), National Energy Technology Laboratory (NETL). 2015. The United States 2015 carbon storage atlas (5th Ed.)

Wildgust et al (Eds.). 2013. The IEAGHG Weyburn-Midale CO_2 Monitoring and Storage Project. Int. J. Greenh. Gas Con., 16: S1-S308.

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 CO_2-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 $GtCO_2$ (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 CO_2-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

Estimated resource ($GtCO_2$)	Resource level	Resource Calculation Method
100	Theoretical	Volumetric using storage efficiency factor
NACSA 2012		

4.3.3 Prospective Province

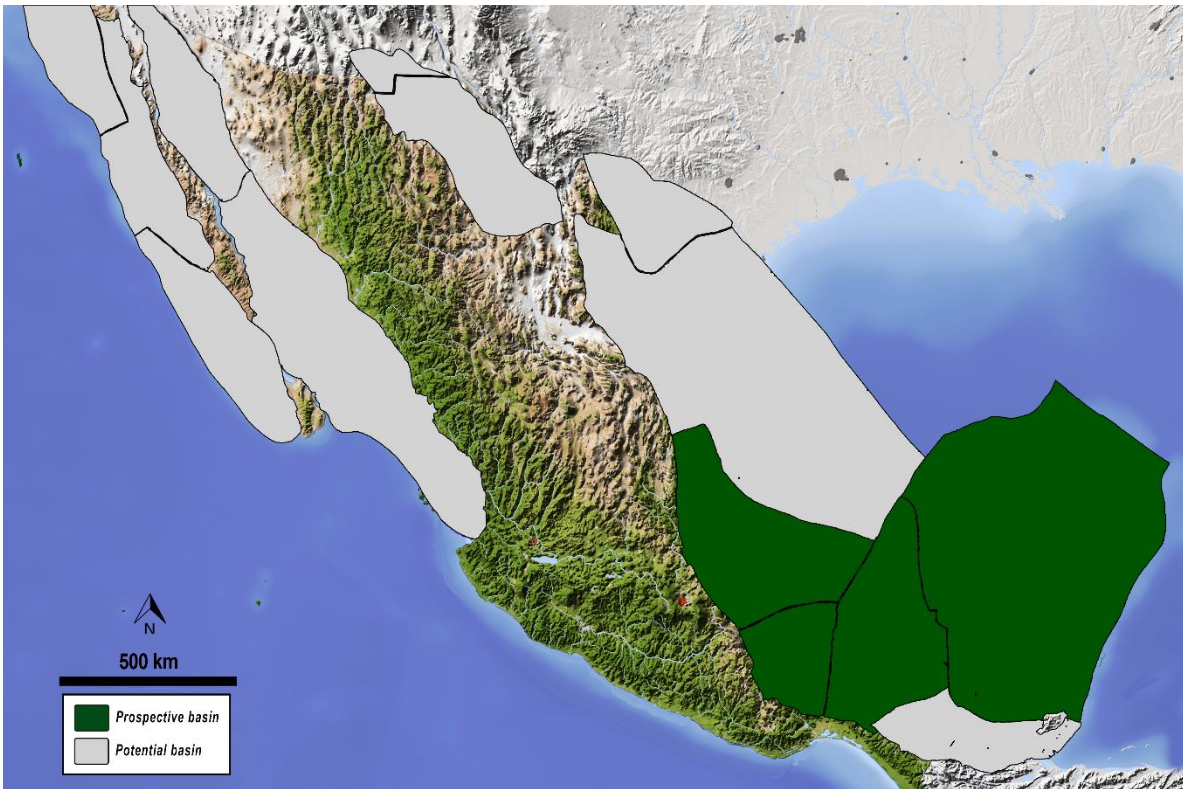
Gulf of Mexico (Burgos Sub-basin): Total basin estimate: 17 $GtCO_2$; theoretical resource based on multi-national study (NACSA 2012).

Veracruz: Total basin estimate: 15 $GtCO_2$; theoretical resource based on multi-national study (NACSA 2012).

Southeastern: Total basin estimate: 24 $GtCO_2$; theoretical resource based on multi-national study (NACSA 2012).

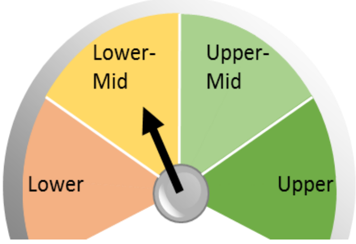
Yucatan: Total basin estimate: 14 $GtCO_2$; theoretical resource based on multi-national study (NACSA 2012).

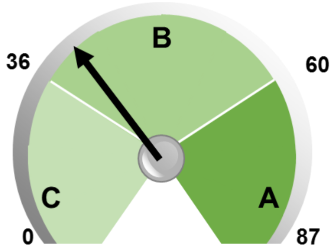
4.3.4 Map



4.3.5 CCS Indicators

Storage Readiness Indicator	Policy Indicator	Legal & Regulatory Indicator





4.3.6 Key References

North American Carbon Atlas Partnership (NACSA). 2012. The North American carbon storage atlas (1st Ed.).

Dávila et al. 2010. A preliminary selections of regions in Mexico with potential for geological carbon storage. J. Phys.Sci., 5: 408-414.

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 CO_2-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 CO_2-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.

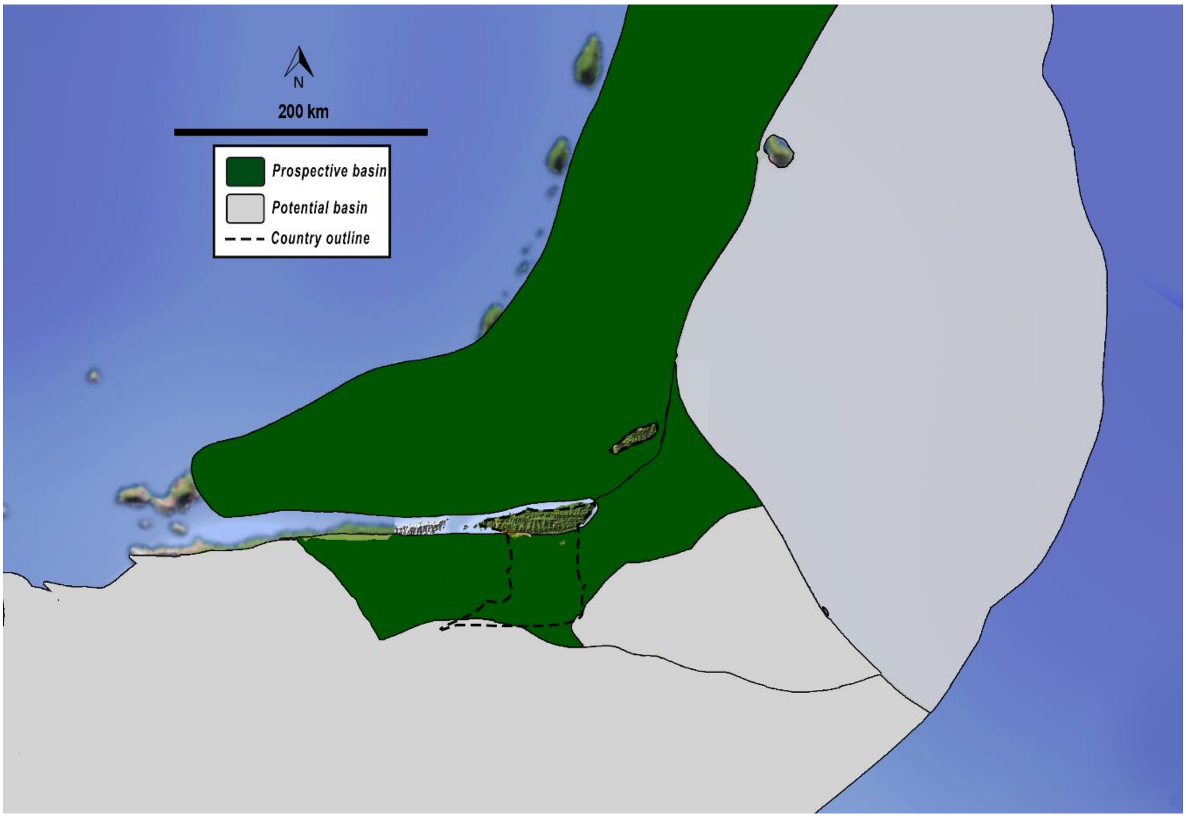
4.4.2 National Resource Assessment Status

Status: Very Limited

4.4.3 Prospective basins

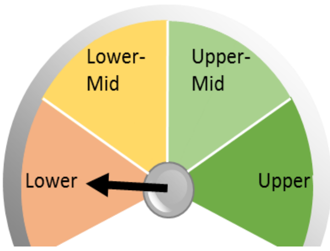
Individual basin's storage resource estimate has not been published. The only unpublished study focussed on oil and gas fields and estimated that fields in the East Coast (Venezuelan Eastern Basin) and North Coast (Tobago Trough) had the highest potential for CCS. DGF and EOR could provide early opportunities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

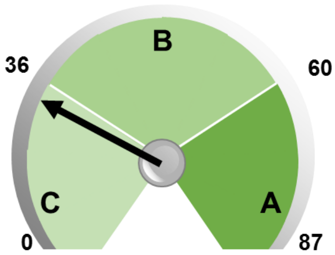
4.4.4 Map



4.4.5 CCS Indicators

Storage Readiness Indicator	Policy Indicator	Legal & Regulatory Indicator





4.4.6 Key References

No publically available reports on CO_2 storage available.

Mohammed-Singh et al. 2004. Lessons from Trinidad's CO_2 Immiscible Pilot Projects. Paper No. SPE 89364, SPE Reservoir Evaluation and Engineering, Oct. 2004, pp. 397-403

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 CO_2-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 CO_2 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 $GtCO_2$ 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 $GtCO_2$ in DSF and DGOF storage (USGS 2013).

There is significant opportunity for CO_2-EOR. The 2015 Atlas estimated a potential for 9 $GtCO_2$ of CO_2 storage for economically feasible CO_2-EOR operations, but this could increase to 17 $GtCO_2$ 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

Estimated resource ($GtCO_2$)	Resource level	Resource Calculation Method
2,367-21,200	Effective	Volumetric using storage efficiency factor and probabilistic modelling.
US DOE NETL 2015		

4.5.3 Prospective basins

Anadarko and Southern Oklahoma (onshore, Oklahoma, Texas, Kansas, and Colorado): Total basin estimate: 36-69 $GtCO_2$; 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 $GtCO_2$; effective storage resource estimate (USGS 2013).

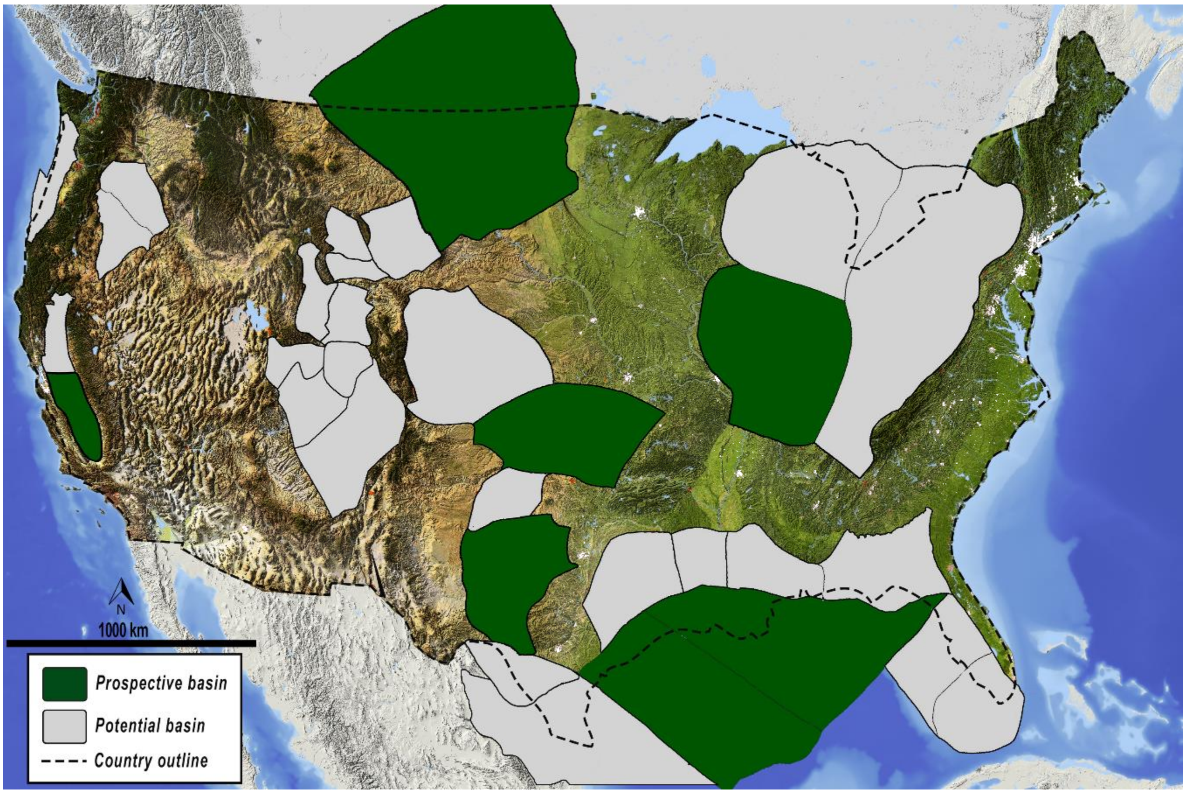
Illinois (onshore, Illinois, Indiana): Total basin estimate: 110-210 $GtCO_2$; effective storage resource estimate (USGS 2013). Illinois Industrial Carbon Capture and Storage Project will inject around 1 Mtpa.

Permian (onshore, Texas): Total basin estimate: 37-89 $GtCO_2$; effective storage resource estimate (USGS 2013). The majority of CO_2-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 $GtCO_2$; effective storage resource estimate (USGS 2013).

Williston Basin (onshore, US Only, North Dakota, South Dakota, and Montana): Total basin estimate: 110-190 $GtCO_2$; 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; CO_2-EOR.

LSIP: Val Verde Natural Gas Plants (Onshore, Permian Basin, Texas): Operate; CO_2-EOR.

LSIP: Air Products Steam Methane Reformer EOR Project (Onshore, Permian Basin, Texas): Operate; CO_2-EOR.

LSIP: Century Plant (Onshore, Permian Basin, Texas): Operate; CO_2-EOR.

LSIP: Shute Creek Gas Processing Facility (Onshore, Wyoming, Colorado): Operate; CO_2-EOR.

LSIP: Coffeyville Gasification Plant (Onshore, Oklahoma): Operate; CO_2-EOR.

LSIP: Enid Fertilizer CO_2-EOR Project (Onshore, Oklahoma): Operate; CO_2-EOR.

LSIP: Illinois Industrial Carbon Capture and Storage Project (Onshore, Illinois Basin, Illinois): Execute; DSF.

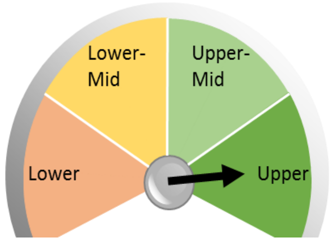
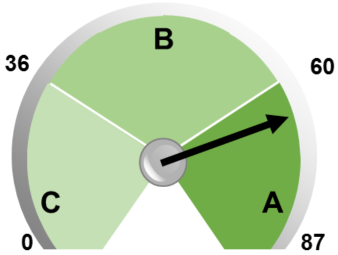
LSIP: Kemper County Energy Facility (Onshore, Mississippi): Execute; CO_2-EOR.

LSIP: Petra Nova Carbon Capture Project (Onshore, Texas): Execute; CO_2-EOR.

LSIP: Hydrogen Energy California Project (HECA) (Onshore, California): Define; CO_2-EOR.

LSIP: Riley Ridge Gas Plant (HECA) (Onshore, Wyoming): Evaluate; CO_2-EOR.

4.5.6 CCS Indicators

Storage Readiness Indicator	Policy Indicator	Legal & Regulatory Indicator
		

4.5.7 References

National Energy Technology Laboratory (NETL). 2011. Improving Domestic Energy Security and Lowering CO_2 Emissions with “Next Generation” CO_2-Enhanced Oil Recovery (CO_2-EOR). DOE/NETL-2011/1504.

North American Carbon Atlas Partnership (NACSA). 2012. The North American carbon storage atlas (1st Ed.).

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.

US Department of Energy (US DOE), National Energy Technology Laboratory (NETL). 2015. The United States 2015 carbon storage atlas (5th Ed.).

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 $GtCO_2$.

5.1.2 National Resource Assessment Status

Status: Limited

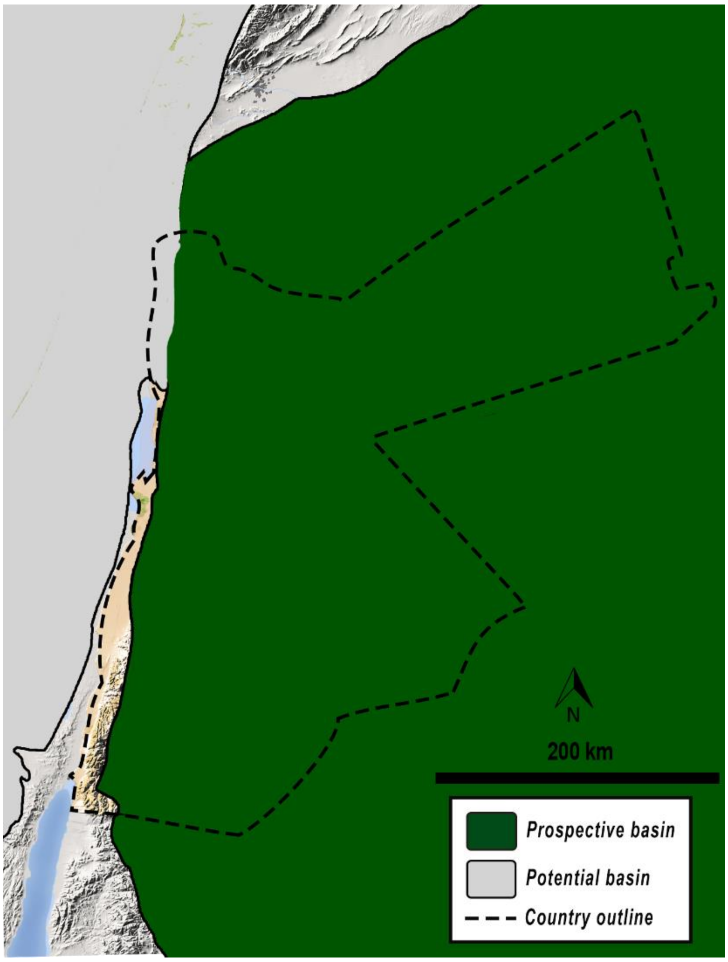
Estimated resource ($GtCO_2$)	Resource level	Resource Calculation Method
9	Theoretical	Volumetric using storage efficiency factor
World Bank 2012		

5.1.3 Prospective basins

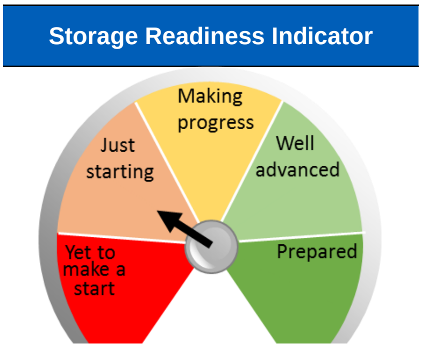
Wadi Sirhan (onshore, east central): Total basin estimate 2.7 $GtCO_2$; theoretical storage resource based on national study (World Bank 2012).

Hamad (onshore, northeast): Total basin estimate 7 $GtCO_2$; theoretical storage resource based on national study (World Bank 2012).

5.1.4 Map



5.1.5 CCS Indicator



5.1.6 Key References

World Bank CCS. 2012. Hashemite Kingdom of Jordan Carbon Capture and Storage (CCS) Capacity Building Technical Assistance, Final Report.

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 CO_2-EOR operations. CO_2-EOR potential in the Mesopotamian Foredeep Basin, which hosts significant fields could hold an effective storage resource of 27 $GtCO_2$ and Greater Ghawar Uplift, which hosts the world's largest oil field has an effective storage resource of 13 $GtCO_2$ (IEAGHG 2009). This is supported by a recent study that estimated up to 30 $GtCO_2$ effective storage capacity during CO_2-EOR operations (IEA 2015).

5.2.2 National Resource Assessment Status

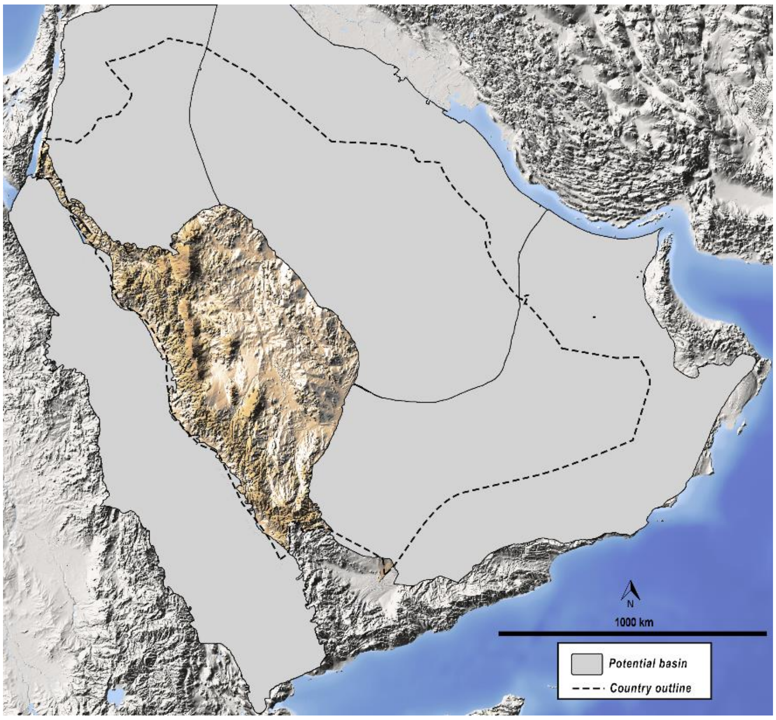
Status: Very Limited

Estimated resource ($GtCO_2$)	Resource level	Resource Calculation Method
5-30*	Theoretical	OOIP; assumes generalised standardised CO_2 replacement value.
*CO_2-EOR only		
IEA 2015		

5.2.3 Prospective basins

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

5.2.4 Map

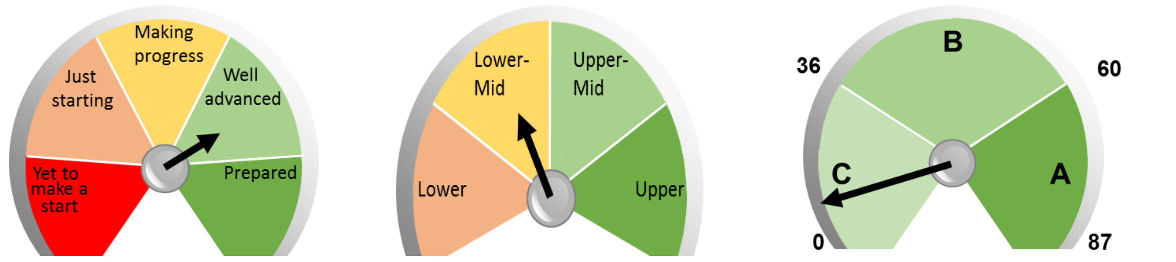


5.2.5 Projects

LSIP: Uthmaniyah CO_2 EOR Demonstration Project (Onshore, Ghawar Field, Eastern Province): Operate; CO_2-EOR.

5.2.6 CCS Indicators

Storage Readiness Indicator	Policy Indicator	Legal & Regulatory Indicator



5.2.7 Key References

IEAGHG. 2009. CO_2 storage in depleted oilfields: Global application criteria for carbon dioxide enhanced oil recovery report 2009/12.

IEA. 2015. Storing CO_2 through enhanced oil recovery. Insights Series 2015.

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 CO_2-EOR. The Rub Al Khali Basin was estimated to have an effective storage resource of 8.8 $GtCO_2$ (IEAGHG 2009). A recent study estimated a potential effective storage capacity of up to 25 $GtCO_2$ for CO_2-EOR operations (IEA 2015).

5.3.2 National Resource Assessment Status

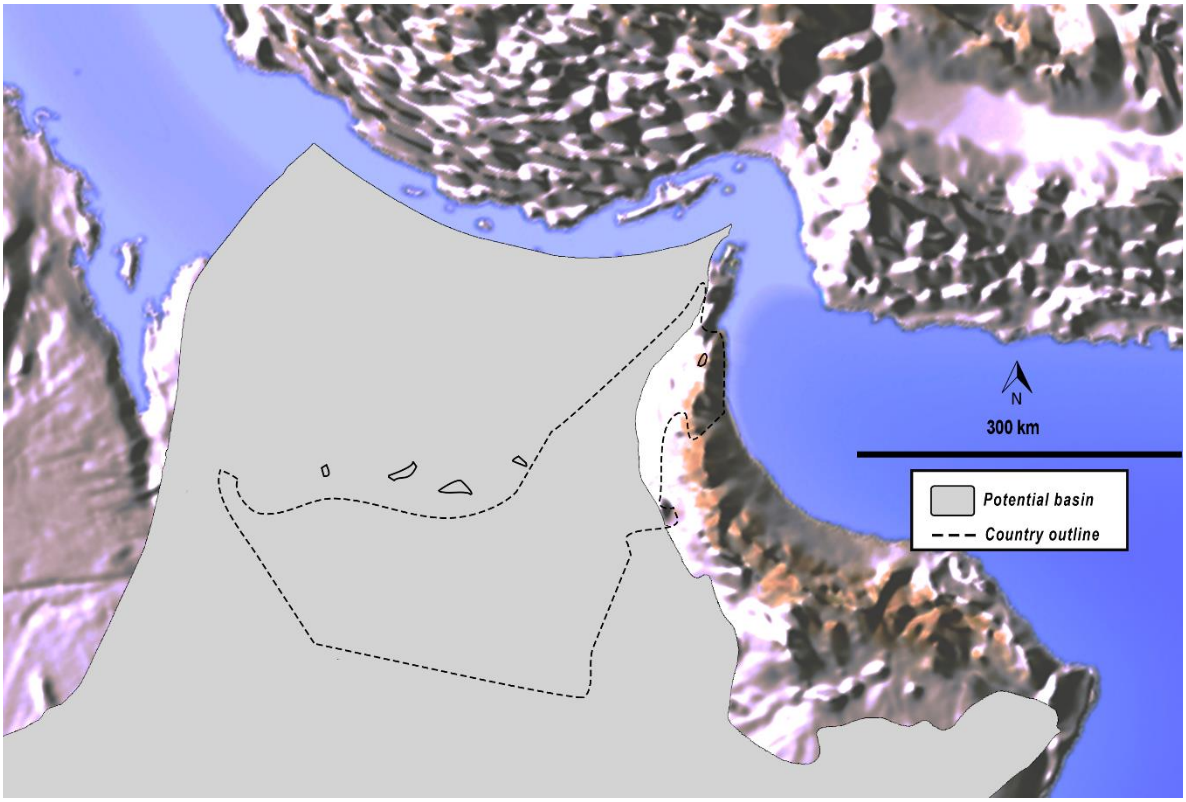
Status: Very Limited

Estimated resource ($GtCO_2$)	Resource level	Resource Calculation Method
5-25*	Theoretical	OOIP; assumes standardised CO_2 replacement value
*CO_2-EOR		
IEA 2015		

5.3.3 Prospective basins

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

5.3.4 Map

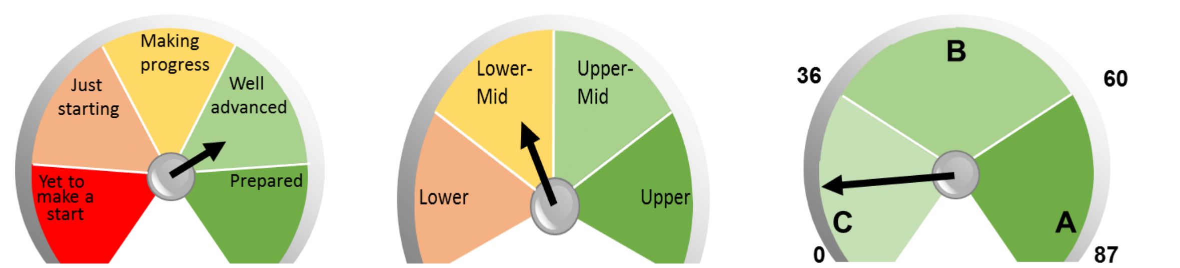


5.3.5 Projects

LSIP: Abu Dhabi CCS Project (Onshore, Rumaitha Field): Execute; CO_2-EOR.

5.3.6 CCS Indicators

Storage Readiness Indicator	Policy Indicator	Legal & Regulatory Indicator



5.3.7 Key References

IEAGHG. 2009. CO_2 storage in depleted oilfields: Global application criteria for carbon dioxide enhanced oil recovery report 2009/12.

IEA. 2015. Storing CO_2 through enhanced oil recovery. Insights Series 2015.

6 EUROPE AND RUSSIA

6.1 Europe excluding UK

6.1.1 Summary

The EU was one of the early movers on CO_2 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 CO_2-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 CO_2-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 $GtCO_2$ (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 $GtCO_2$ and 10 $GtCO_2$ in DGOF. In key EU nations the study estimated a theoretical storage resource in DSF and DGOF in Germany (17 $GtCO_2$) Spain (14 $GtCO_2$), France (8 $GtCO_2$) and Italy (6 $GtCO_2$).

GeoCapacity was followed by the CO_2 StoP (CO_2 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

Status: Full

Estimated resource ($GtCO_2$)	Resource level	Resource Calculation Method
72*	Theoretical	Volumetric calculation using storage efficiency factor.
*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 $GtCO_2$; effective storage resource was identified in DSF and DGOF (Elforsk 2014).

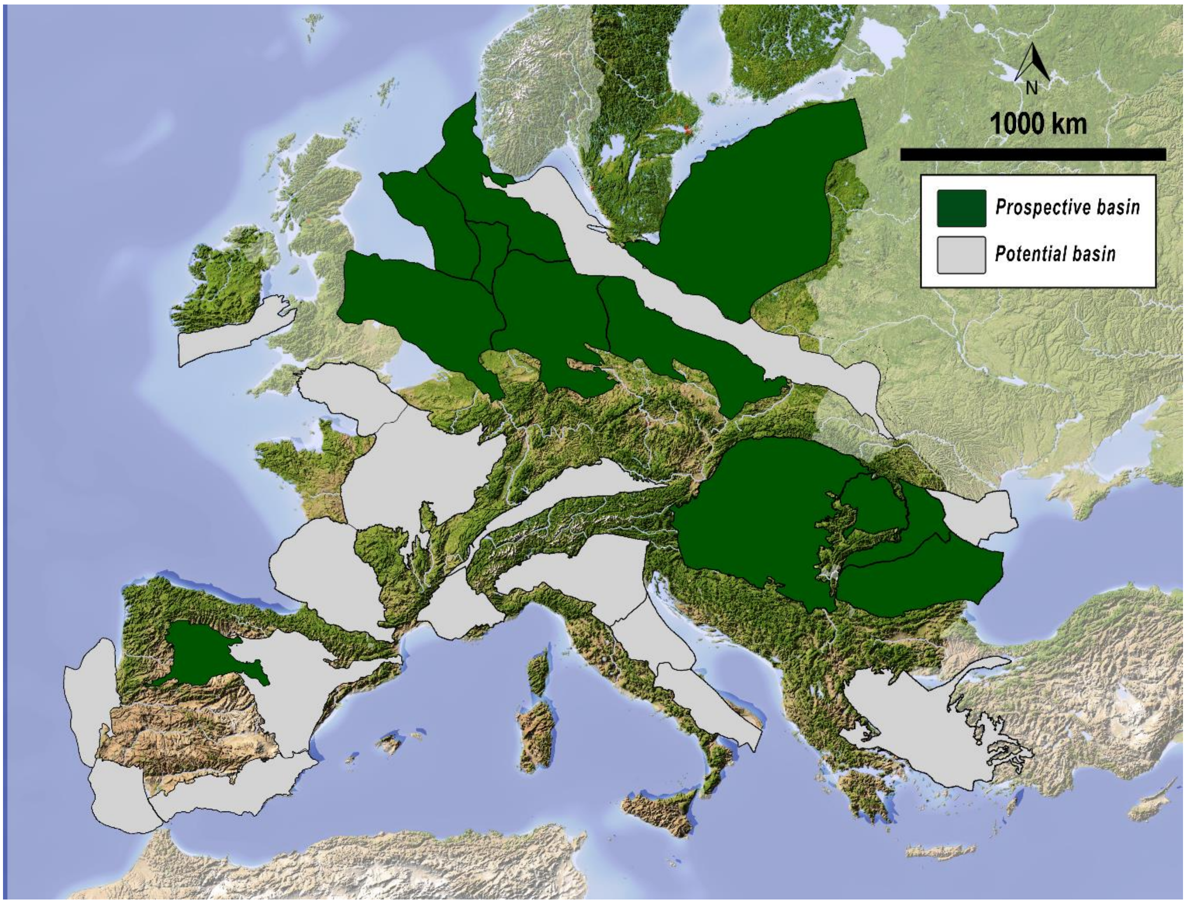
Netherlands North Sea (Offshore): Total basin estimate: 2.1 Gt; total effective storage resource in highly prospective DSF and DGF only (Neele et al. 2012). K12-B pilot project involves the re-injection of CO_2 into a DGF.

Poland (Onshore): The majority of storage will focus on onshore DSF with 82 $GtCO_2$ of total, including several individual sites each having over 200 $MtCO_2$ theoretical storage resource (Radoslaw et al. 2009).

North German Basin (Onshore, Germany): Total basin estimate: 9.3 $GtCO_2$; 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 $GtCO_2$; theoretical storage resource; Lusitanian Basin (Offshore DSF) (Martinez et al. 2013.): 2.2 $GtCO_2$; 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.

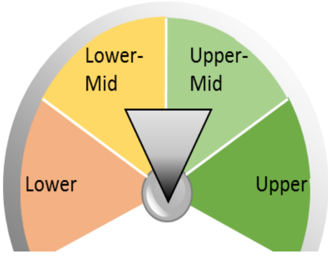
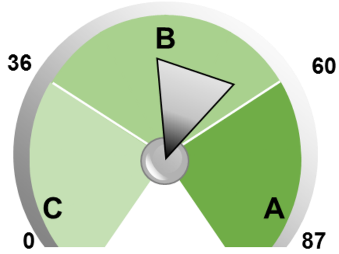
Notable: Lacq CCS Pilot Project (Onshore, Paris Basin, France): Complete DGF.

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

Storage Readiness Indicator (Average)	Policy Indicator (Average)	Legal & Regulatory Indicator (Average)
		
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

Anthonsen et al. 2013. CO_2 storage potential in the Nordic region. Energy Proc., 37: 5080-5092.

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.

GEUS GeoCapacity. 2009. Assessing European Capacity for Geological Storage of Carbon Dioxide - D42. GeoCapacity Final Report.

Martinez et al. 2013. Storage capacity evaluation for development of CO2 infrastructure in the west Mediterranean. Energy Proc., 37: 5209 – 5219.

Neele et al. 2012. Independent assessment of high-capacity offshore CO2 storage options [Netherlands].

Poulsen et al. 2014. CO_2StoP final report: assessment of CO_2 storage potential in Europe.

Rotterdam Climate Initiative. 2009. CO_2 capture, transport and storage in Rotterdam - report 2009, Executive summary.

Radoslaw et al. 2009. CO_2 Storage Capacity of Deep Aquifers and Hydrocarbon Fields in Poland – EU GeoCapacity Project Results. Energy Proc., 1: 2671- 2677

Rütters et al. 2013. State of play on CO_2 geological storage in 28 European countries. CGS Europe report No. D2.10: 89p.

Schäfer et al. 2012. The regional pressure impact of CO_2 storage: a showcase study from the North German Basin. Environ Earth Sci., 65: 2037–2049.

Vangklide-Pedersen (Ed.). 2009. EU GeoCapacity assessing European capacity for geological storage of carbon dioxide. Final report: D16 storage capacity.

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 CO_2-EOR and storage is currently underway. It has an open and mature oil and gas industry with detailed subsurface data across many basins. Sleipner CO_2 Storage Project operated by Statoil in the North Sea Basin has been running since 1996 injecting up to 0.85 Mtpa. The Snøhvit CO_2 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 CO_2-EOR opportunities.

In 2014, the CO_2 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 $GtCO_2$ total; 57 $GtCO_2$ in DSF and 25 $GtCO_2$ in producing fields. The majority of storage potential is in the Norwegian sector of the North Sea at 45 $GtCO_2$ effective storage resource (Halland et al. 2014).

6.2.2 National Resource Assessment Status

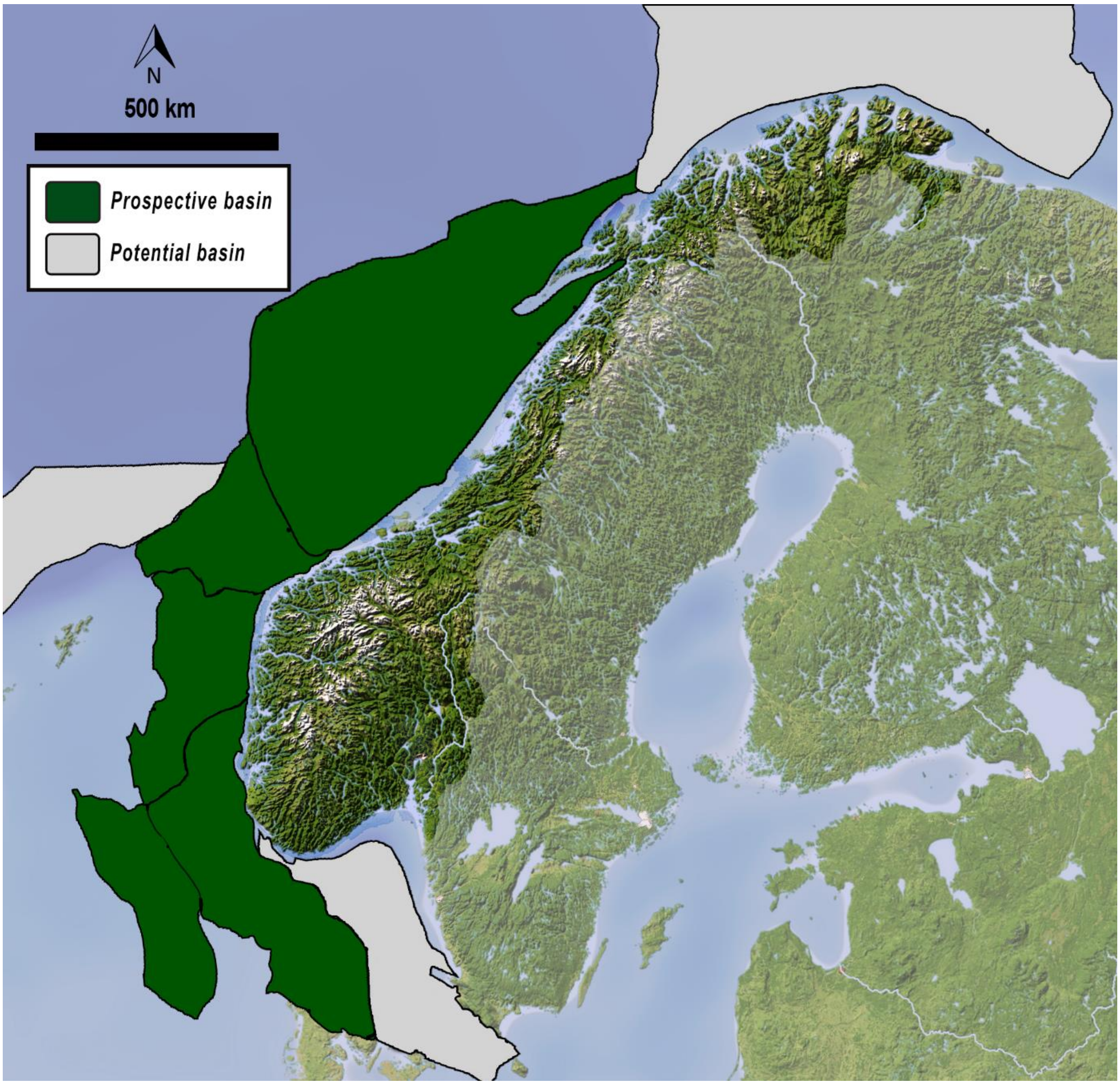
Status: Full

Estimated resource ($GtCO_2$)	Resource level	Resource Calculation Method
86	Effective	Dynamic simulation or volumetric using storage efficiency factor
Halland et al. 2014.		

6.2.3 Prospective region

North Sea (offshore, Norway): 45 $GtCO_2$; effective storage resource in DSF. Sleipner CO_2 Storage Project currently injecting up to 0.85 Mtpa.

6.2.4 Map



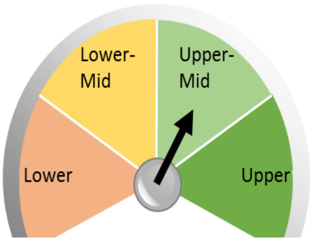
6.2.5 Projects

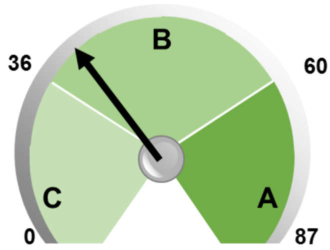
LSIP: Sleipner CO_2 Storage (Offshore, Central North Sea Basin, Norway): Operate; DSF.

LSIP: Snøhvit CO_2 Storage (Offshore, Hammerfest Basin, Norway): Operate; DSF.

6.2.6 CCS Indicators

Storage Readiness Indicator	Policy Indicator	Legal & Regulatory Indicator





6.2.7 References

Halland et al. 2011. CO_2 storage atlas: Norwegian North Sea, Norway.

Halland et al. 2014. CO_2 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 CO_2-EOR storage.

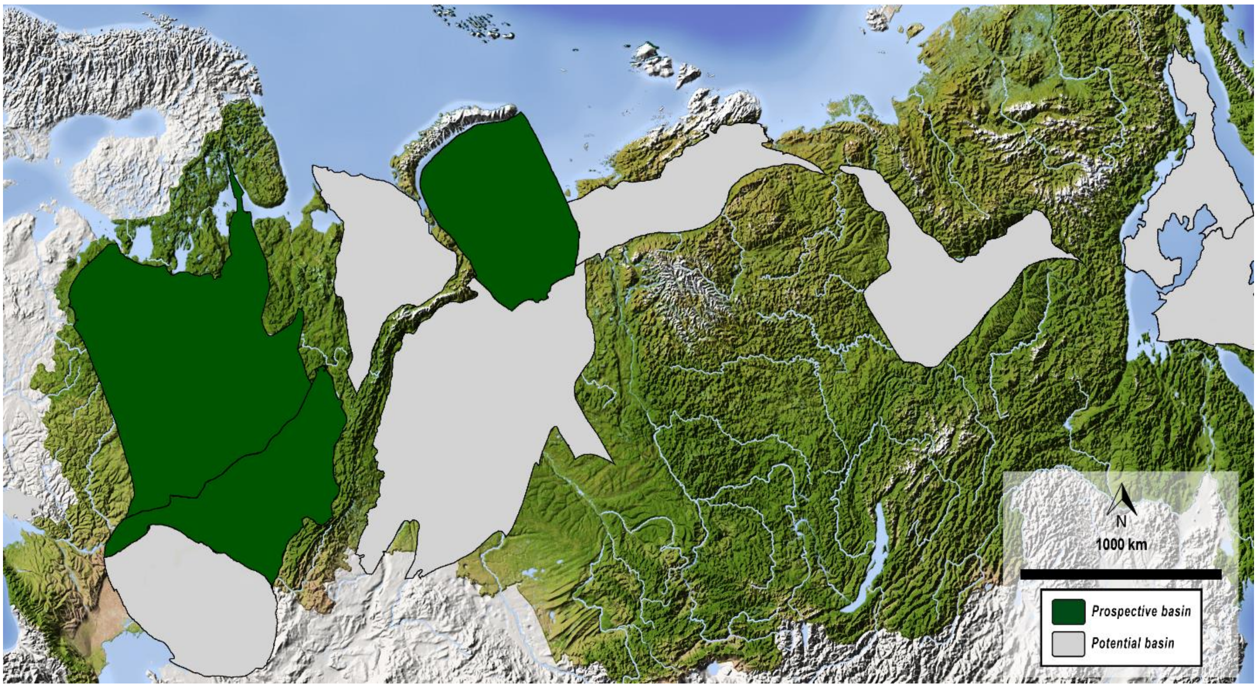
Storage in DSF is currently unknown. DGOF and CO_2-EOR hold large potential, especially in Timan-Pecharo Basin and the Western Siberia and Kaliningrad regions. According to Shogenova et al. (2011) around 50% of hydrocarbon fields in northwest Russia are depleted. This area also has the highest potential for CO_2-EOR with 4.6 Gt in theoretical storage resource. A second study over much of Russia calculated 6.8 $GtCO_2$ effective storage resource in 322 oil fields, which includes 645 $MtCO_2$ in CO_2-EOR storage (Sidorova 2014). This study also identified the most prospective basins for CO_2-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

Estimated resource ($GtCO_2$)	Resource level	Resource Calculation Method
6.8*	Effective	OO/GIP with standard CO_2 reservoir conditions and recovery factor.
*CO_2-EOR/DOF		
Sidorova 2014		

6.3.3 Map

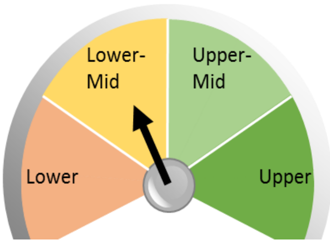


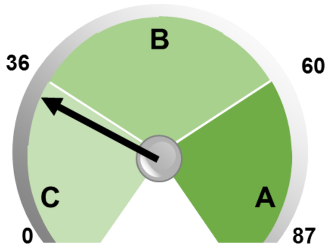
6.3.4 Prospective basins

No individual basin assessments have been published.

6.3.5 CCS Indicators

Storage Readiness Indicator	Policy Indicator	Legal & Regulatory Indicator





6.3.6 Key References

Global CCS Institute. 2009. Strategic Analysis of the Global status of Carbon Capture and Storage Report 3: Country Studies Russia.

Shogenova et al. 2011. CO_2 geological storage capacity analysis in Estonia and neighbouring regions. Energy Proc., 4: 2785-2792.

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 CO_2-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/CO_2 Storage Evaluation Database is an online database of over 500 potential offshore storage sites. UK theoretical storage resources have been estimated at 78 $GtCO_2$, mainly in DSF with an estimated potential to store 8 $GtCO_2$ in DGOF (Bentham et al. 2014).

6.4.2 National Resource Assessment Status

Status: Full

Estimated resource ($GtCO_2$)	Resource level	Resource Calculation Method
78	Theoretical	Volumetric using storage efficiency factor and probabilistic modelling.
Bentham et al. 2014		

6.4.3 Prospective basins

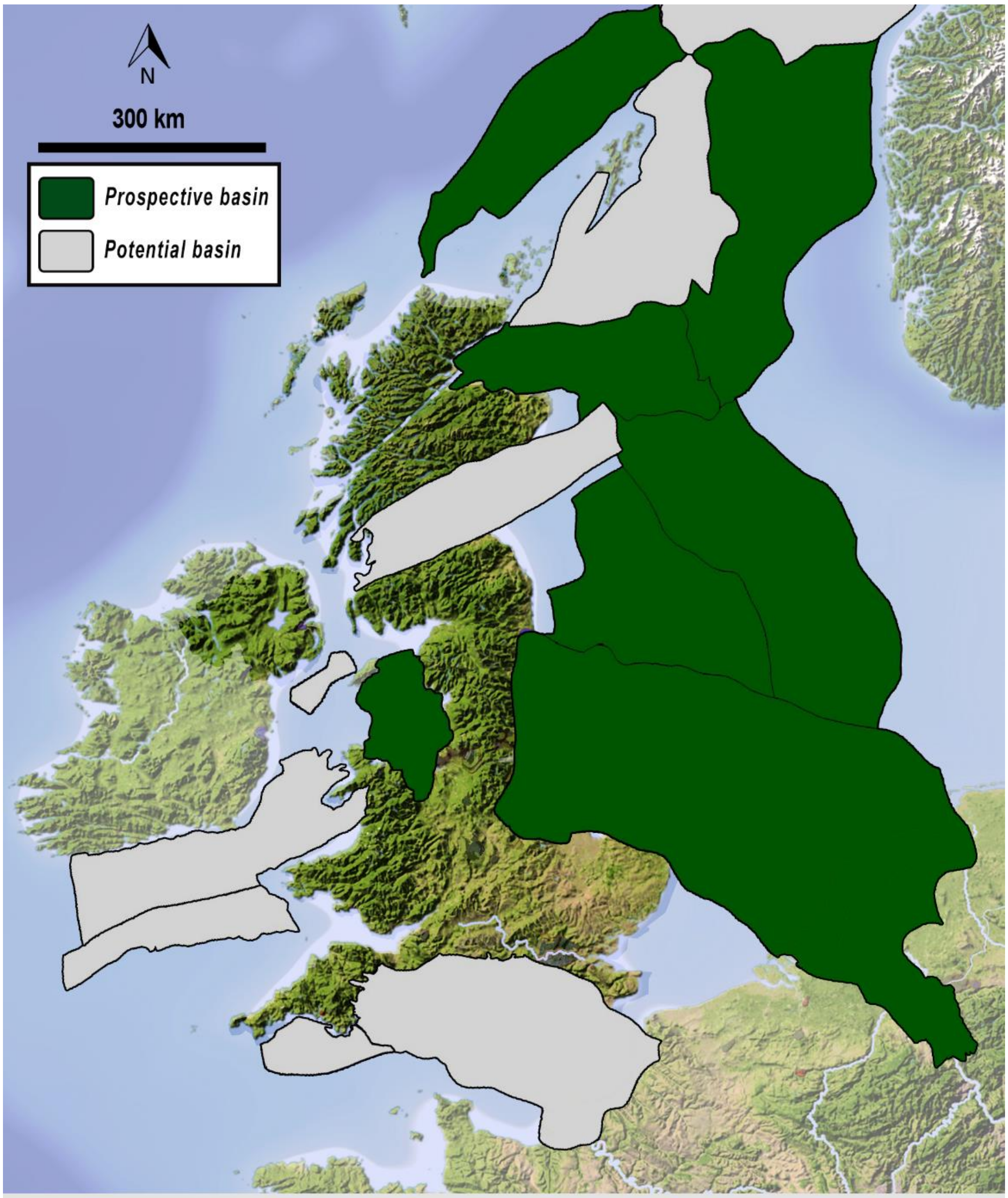
Central North Sea (offshore, UK Sector North Sea): Total basin estimate: 40 $GtCO_2$; theoretical storage resource based on national study (Bentham et al. 2014).

Northern North Sea (offshore, UK Sector North Sea): Total basin estimate: 14 $GtCO_2$; theoretical storage resource based on national study (Bentham et al. 2014).

Southern North Sea (offshore, UK Sector North Sea): Total basin estimate: 15 $GtCO_2$; theoretical storage resource based on national study (Bentham et al. 2014).

East Irish Sea (offshore, East Irish Sea): Total basin estimate: 6 $GtCO_2$; effective storage resource based on basin study (Bentham et al. 2014). DGOF effective storage resource: 1.1 $GtCO_2$ (Coulthurst et al. 2011).

6.4.4 Map



6.4.5 Projects

LSIP: Don Valley Power Project (Offshore, Central North Sea): Define; DSF.

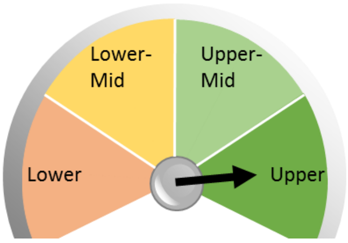
LSIP: White Rose CCS Project (Offshore, Southern North Sea): Define; DSF.

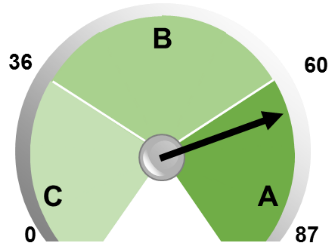
LSIP: Teesside Collective Project (Offshore, Southern North Sea): Evaluate; DSF.

LSIP: Caledonia Clean Energy Project (Offshore, Central North Sea): Evaluate; DSF and CO_2-EOR.

6.4.6 CCS Indicators

Storage Readiness Indicator	Policy Indicator	Legal & Regulatory Indicator





6.4.7 Key References

Bentham et al. 2014. CO_2 STORage Evaluation Database (CO_2 Stored). The UK's online storage atlas. *Energy Proc.,* 63: 5103-5113.

Coulthurst et al. 2011. The East Irish Sea CCS Cluster: A Conceptual Design – Technical Report.

Gammer et al. 2011. *The Energy Technologies Institute's UK* CO_2 *Storage Appraisal Project (UKSAP)*. SPE 148426.

Ó Cléirigh et al. 2008. Assessment of the Potential for Geological Storage of Carbon Dioxide for the Island of Ireland.

Senior. 2010. CO_2 storage in UK- Industry Potential. Senior CCS Solutions.

Vangklide-Pedersen (Ed.). 2009. EU GeoCapacity assessing European capacity for geological storage of carbon dioxide. Final report: D16 storage capacity.

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, CO_2-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 $GtCO_2$ in DGF (IEAGHG 2009).

7.1.2 National Resource Assessment Status

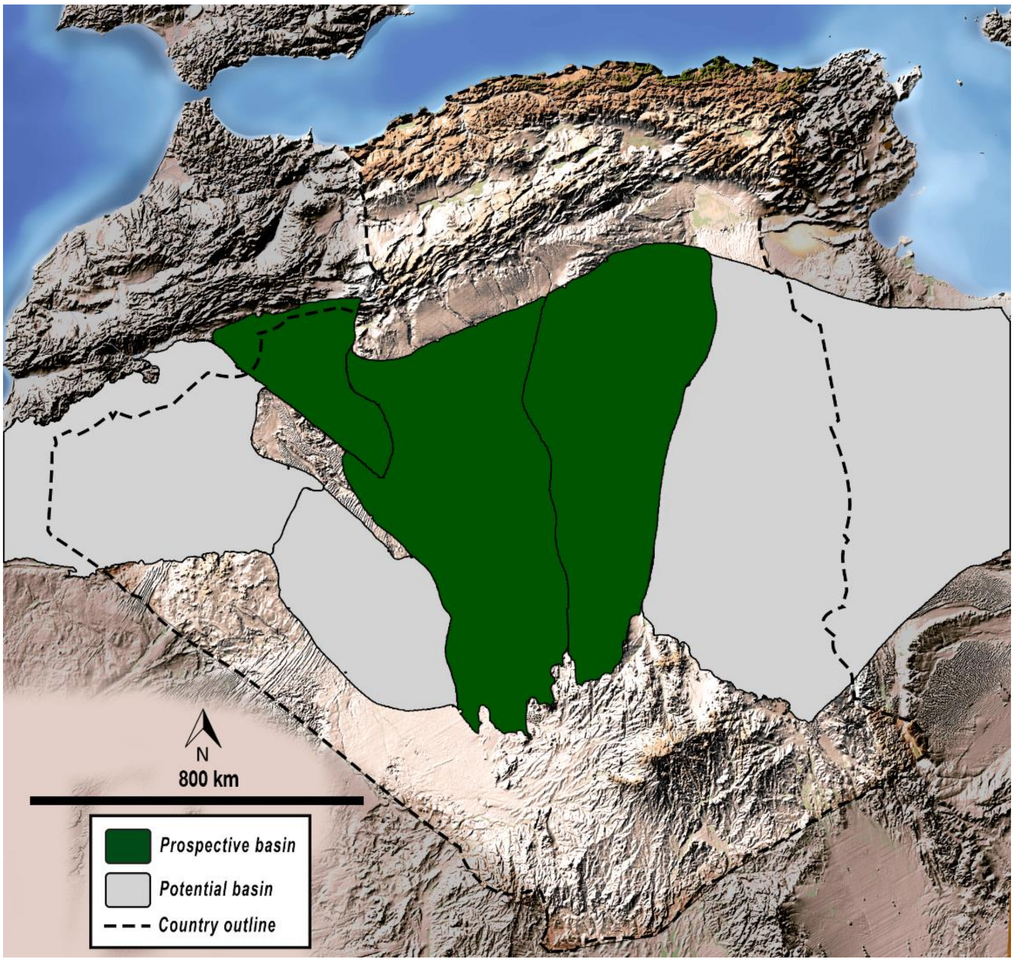
Status: Very Limited

Estimated resource ($GtCO_2$)	Resource level	Resource Calculation Method
10*	Theoretical	Standard CO_2 replacement volume.
*DGF only		
IEAGHG 2009		

7.1.3 Prospective basins

The individual basin resources have not been published.

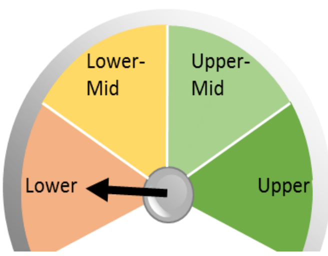
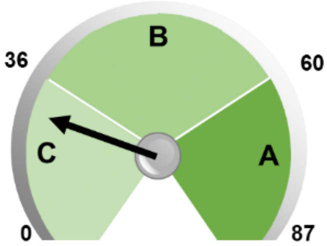
7.1.4 Map



7.1.5 Projects

LSIP: In Salah CO_2 Storage Project (Onshore, Ahnet-Timimoun Basin, Central Sahara): In Operate stage: CO_2 injection was temporarily suspended in June 2011; DSF.

7.1.6 CCS Indicators

Storage Readiness Indicator	Policy Indicator	Legal & Regulatory Indicator
		

7.1.7 References

Eiken et al. 2011. Lessons learned from 14 years of CCS operations: Sleipner, In Salah and Snöhvit. Energy Proc., 4: 5541–5548

IEAGHG. 2009. CO_2 storage in depleted gas fields, IEAGHG Report 2009/01.

Vasco et al. 2008. Reservoir monitoring and characterization using satellite geodetic data: Interferometric Synthetic Aperture Radar observations from the Krechba field, Algeria. Geophys., 73: WA113–WA122

7.2 Morocco

7.2.1 Summary

Morocco was the focus of COMET (Integrated infrastructure for CO_2 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 $GtCO_2$ 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 CO_2-EOR storage potential.

7.2.2 National Resource Assessment Status

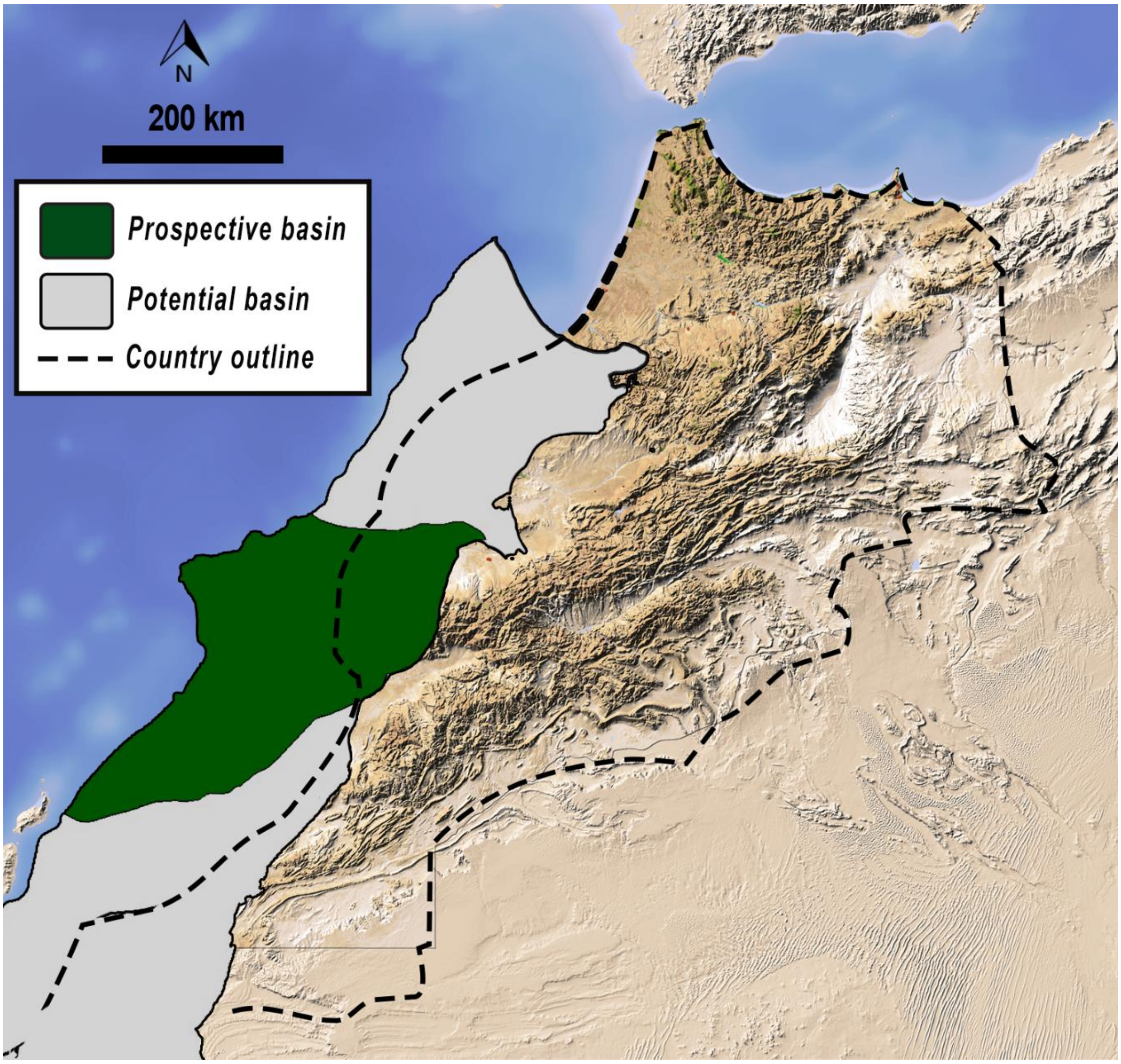
Status: Limited

Estimated resource ($GtCO_2$)	Resource level	Resource Calculation Method
0.6*	Theoretical	Volumetric
*onshore basins only		
Martinez et al. 2013.		

7.2.3 Prospective basins

Essaouira (onshore, westernmost High Atlas region): Total basin estimate: 298 $MtCO_2$; effective storage resource based on reservoir-scale assessment (COMET 2015).

7.2.4 Map



7.2.5 CCS Indicator

Storage Readiness Indicator

7.2.6 References

Boavida et al. 2011. Integrated infrastructure for CO_2 transport and storage in the west Mediterranean. Energy Proc., 4: 2440-2447.

Boavida et al. 2013. Planning CCS Development in the West Mediterranean. Energy Proc., 37: 3212-3220.

COMET. 2015. http://comet.lneg.pt/. Accessed: November, 2015.

Martinez et al. 2013. Storage capacity evaluation for development of CO_2 infrastructure in the west Mediterranean. Energy Proc., 37: 5209 – 5219.

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 $GtCO_2$ (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

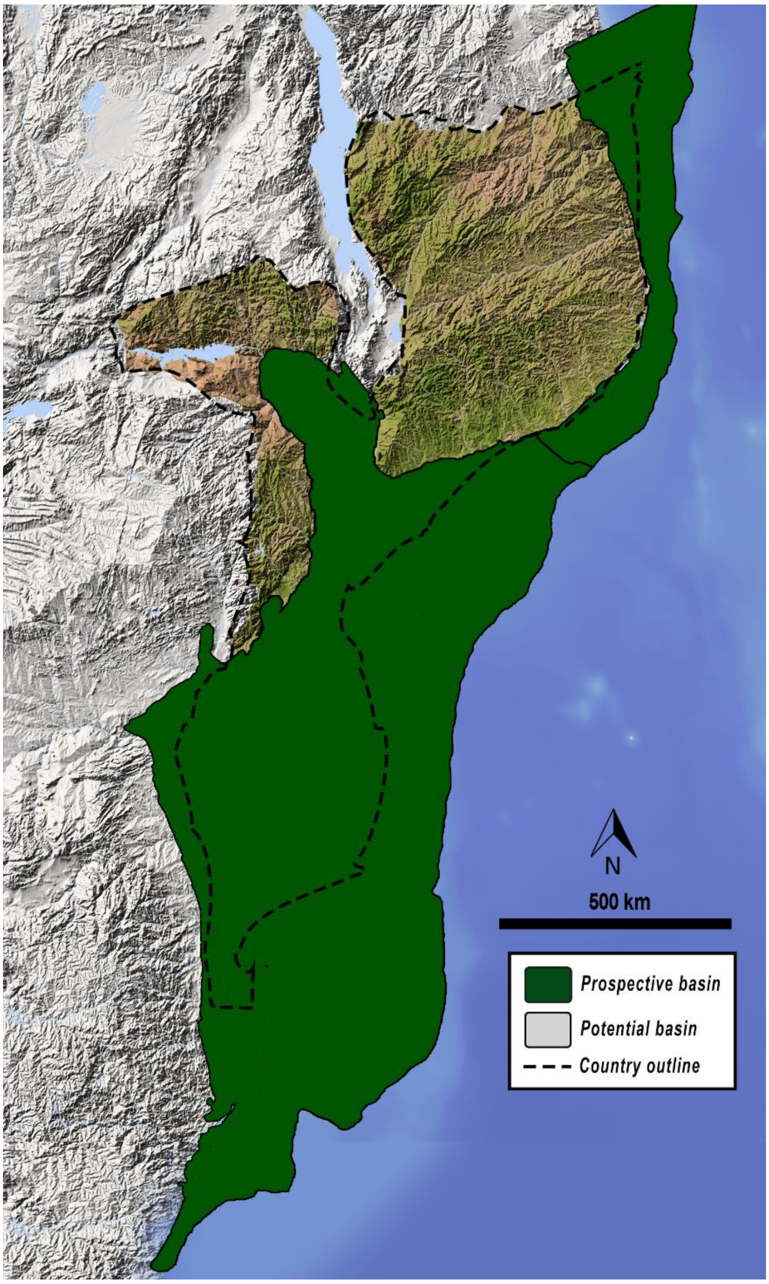
Estimated resource ($GtCO_2$)	Resource level	Resource Calculation Method
2.7-229	Theoretical	Volumetric using storage efficiency factor
(Carneiro et al. 2014 ; Solomon et al. 2014)		

7.3.3 Prospective basins

Mozambique (onshore, east coast): Total basin estimate: 2.4-228 $GtCO_2$; theoretical resource based on basin study (Solomon et al. 2014).

Rovuma (onshore, east coast): Total basin estimate: 235 – 470 $MtCO_2$; theoretical resource based on basin study (Carneiro et al. 2014).

7.3.4 Map



7.3.5 Key References

Carneiro et al. 2014. Preliminary Assessment of CO_2 Storage Potential in the Rovuma Sedimentary Basin, Mozambique. Energy Proc., 65: 5141-5152.

Portuguese Language Countries (CPLP). 2015. Carbon capture and storage in the community of Portuguese language countries: Opportunities and challenges. Escola de Ciências e Tecnologia, Universidade de Évora, Évora, 34p.

Solomon et al. 2014. CO_2 Storage Capacity Assessment of Deep Saline Aquifers in the Mozambique Basin, Energy Proc., 63: 5266-5283

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

Estimated resource ($GtCO_2$)	Resource level	Resource Calculation Method
162	Theoretical	Volumetric using storage efficiency factor and probabilistic modelling.
Viljoen et al. 2010		

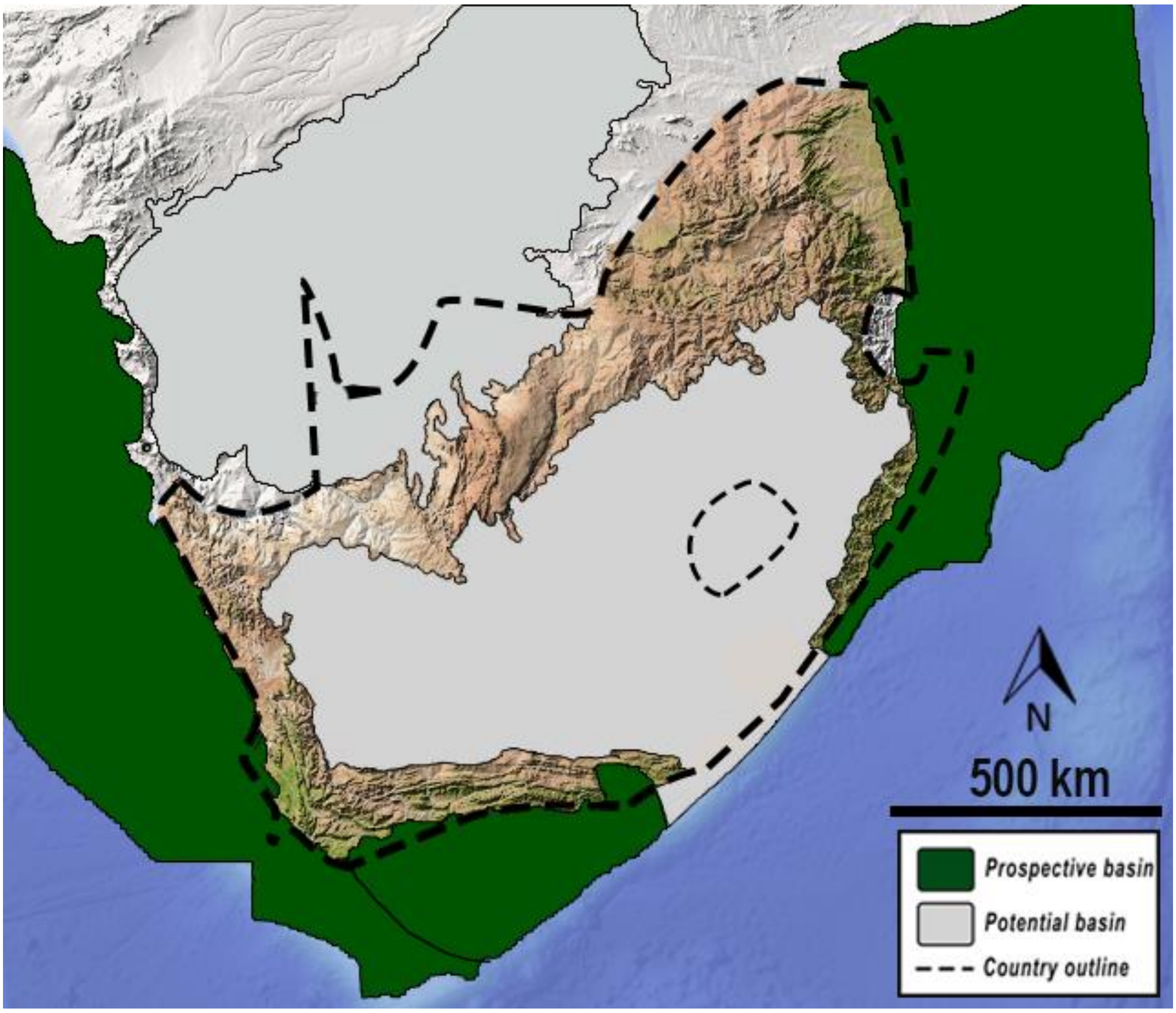
7.4.3 Prospective basins

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 s 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).

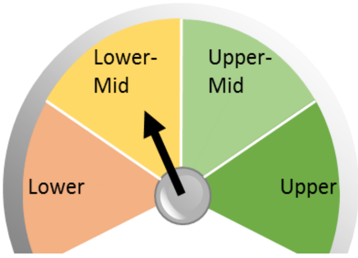
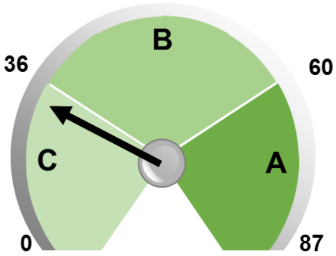
7.4.4 Map



7.4.5 Projects

Pilot Injection Project: Inject up to 50,000 t CO_2 potentially in Zululand or Algoa Basin (onshore): Define; DSF.

7.4.6 CCS Indicators

Storage Readiness Indicator	Policy Indicator	Legal & Regulatory Indicator
		

7.4.7 References

Alderson et al. 2013. Techno-economic analysis of CCS in South Africa: Presentation to 3rd South African CCS Conference 3rd – 4th October 2013.

Beck. 2014. An Update on the South African Pilot CO_2 Storage Project. Energy Proc., 63: 6188-6193.

Cloete. 2010. Atlas on geological storage of carbon dioxide in South Africa.

Viljoen et al. 2010. Technical report on the geological storage of carbon dioxide in South Africa.

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 inTable 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 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

Criterion		Grades				
		E	D	C	B	A
		Low				High
1	Has the country any conventional storage potential? Yes/No					
Standard of country storage assessment						
2	Regional potential	Extremely limited		Limited		Extensive
3	Regional assessment	None	Limited	Partial	Detailed	Full
4	Dataset	None	Sparse	Moderate (Appropriate)	Detailed	Extensive
Maturity of science						
5	Assessment maturity	Regional, Country-scale/Theoretical capacity		Basin-scale/Effective capacity		Site-scale/Practical capacity
6	Pilot project	No	Preliminary planning	Active preparation	Injection has occurred in one project	Injection has occurred in several projects
7	Commercial project	No	Active planning	Passed final investment decision	Injection has occurred	Mature project
Outreach						
8	Knowledge dissemination	Does not engage in any known dissemination activities	Attends knowledge sharing activities	Actively participates in knowledge dissemination activities organised by others	Has organised/held some knowledge sharing activities	Has active targeted program of knowledge sharing and/or dissemination

Table 3 Description and scores for the five status levels for the Storage Readiness Indicator

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

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 4 Description of categories in the *CCS Policy Indicator*

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 environment that reflect an early stage of technology demonstration.

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 5 Primary Assessment Criteria for *CCS Legal and Regulatory Indicator*

The clarity and efficiency of the administrative process under the CCS legal framework to apply for, and obtain, regulatory approval for CCS projects
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 **CO_2**.
The extent to which the CCS legal and regulatory framework provides for the appropriate siting of projects and adequate environmental impact assessment processes.
The extent to which the CCS legal and regulatory framework provides for and incorporates meaningful and effective stakeholder and public consultation.
The way in which laws and regulations deal with long-term liability for closure, monitoring and accidental releases of CO_2.

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*

3	Clearly and unequivocally capable of satisfying the criterion
2	Moderately capable of satisfying the criterion, subject to conditions or limitations
1	Capable of satisfying the criterion only in some minor respects
0	Largely incapable of satisfying the criterion

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*

Band	Description	Score
A	CCS-specific laws or existing laws that are applicable across most parts of the CCS project cycle	60-87
B	CCS-specific laws or existing laws that are applicable across parts of the CCS project cycle	36-60
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*.