



GLOBAL
CCS
INSTITUTE

CARBON CAPTURE AND STORAGE READINESS INDEX

A global comparative analysis of CCS indicators for the wide-scale deployment of carbon capture and storage projects

Christopher Consoli, Senior Adviser – Storage, Asia Pacific

Ian Havercroft, Senior Adviser – Legal and Regulatory, Asia Pacific

Lawrence Irlam, Senior Adviser – Policy and Economics, Asia Pacific

November 2016

Contents

Executive Summary	3
1 Introduction	6
2 Method	7
3 Results	8
3.1 Storage Indicator	8
3.2 Legal Indicator	10
3.3 Policy Indicator.....	11
3.4 Overall CCS Readiness.....	12
4 Discussion.....	14
5 Summary.....	17
6 References.....	18

Executive Summary

Carbon capture and storage (CCS) is critical for meeting international climate change targets, and therefore deployment must be both rapid and global [1]. To date, deployment has been limited to only a few countries and industries, with several factors slowing further progress. These factors can be quantified to identify enabling opportunities for wide-scale commercial deployment of CCS in particular countries and over a set period of time.

The Global CCS Institute (Institute) has developed a 'CCS Readiness Index' (CCS Index) which quantifies these factors, based on assessment criteria across four indicators — inherent interest, policy, legal and regulatory (legal) and storage — which reflect major barriers or enablers for the deployment of CCS. Each of these individual indicators is built upon detailed country assessments involving various actions relevant to CCS, whereby data is combined and synthesised into high level quantitative rankings. This report compares results of the CCS Index and standardised results for over 30 countries, based on assessments undertaken in 2015.

The basic premise of the CCS Index is that the highest scoring countries have the best opportunity for the deployment of CCS facilities. This report illustrates CCS Readiness separately from Inherent Interest to examine the potential correlation between the two. The charts also incorporate data for total greenhouse gas emissions to provide a rough guide as to the relative importance of each country in global emission reduction efforts.

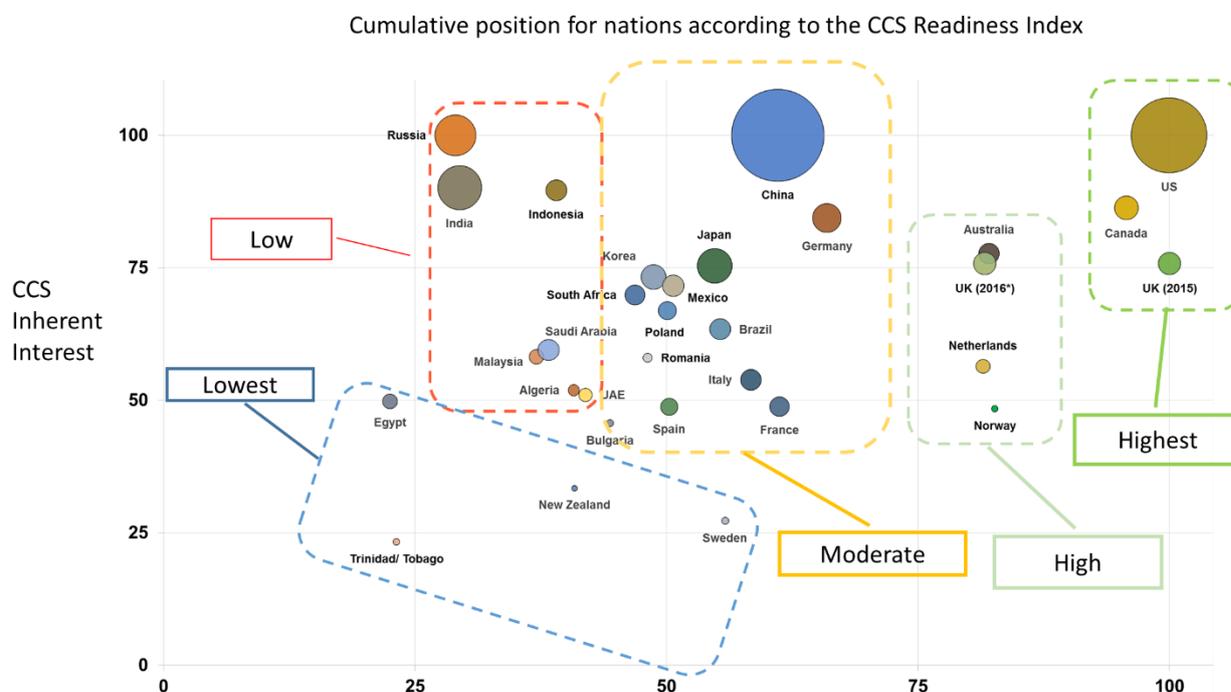
A key finding of the CCS Index is that the highest ranking countries have clear policy frameworks that support CCS as an emissions reduction technology. The legal and regulatory frameworks necessary to underpin project development are also generally present, which tend to flow from overarching government commitment in tandem with detailed policy instruments. These countries also have strong prospective storage resources and are advanced in their assessment of their storage prospectivity. The characterisation of suitable storage sites is a necessary precursor to any CCS project activity, and in many cases, this has benefited from data and experience gained from oil and gas exploration. Many countries display a coincidence of high Readiness and Inherent Interest as the presence of significant fossil fuel production and consumption activities spurs policy support but also benefits storage assessment through exploration activities.

For the purposes of this report, the Institute has grouped countries into five categories (Figure 1):

1. **Highest** ranking countries are characterised by credible, long-term commitments to CCS as part of climate change and energy strategies. These countries have squarely addressed the key precursors to CCS deployment. They have developed effective and comprehensive legal frameworks for CCS and in places have CCS-specific laws or have existing laws that are applicable across most parts of the CCS project cycle. Countries in this group also have investigated their storage potential and, in most cases, have completed a significant CO₂ injection project.
2. **High** ranking countries have few barriers to CCS deployment, with issues still being resolved in one or a limited number of Index criteria.
3. **Moderate** ranking countries are the largest in number. These are countries that have some barriers or are making progress, with mixed results across the criteria examined. Countries in this group, like China and Japan have notable project activity at smaller scale and are making significant progress, while others such as Germany have strong strategic interest in developing CCS but have not shown signs of recent support.
4. **Low** ranking countries have a high or moderate degree of inherent interest but a low degree of readiness. This reflects the relatively little effort placed into examining the role of CCS as an emission reduction technology. This is in spite of the benefits CCS can deliver, in terms of decarbonising significant emissions from these countries and in enabling continued consumption and export of fossil fuels as a means for further economic development.

5. Conversely, countries classed as **lowest** have low Inherent Interest and, as might be expected, virtually no CCS related activity.

Figure 1. CCS Readiness Index results



The CCS Index also suggests that nations that score highly across the legal, policy and storage indicators also have the most number of large scale CCS projects. This observation supports the notion that providing an enabling environment for CCS and removing barriers can result in the deployment of CCS. The highest ranking nations in the CCS Index host all but three of the 15 operational large-scale CCS projects (LSIP) recognised by the Institute. Some countries, such as Brazil, the UAE, China and Saudi Arabia, have large-scale project activity regardless of low rankings on some criteria. This reflects the presence of particular factors, primarily a strong role of the state, which are not standard or observable 'policies' and so the CCS Index results for these countries may be somewhat understated.

Further examination of the results gives rise to the following key themes:

1. The legal, policy and storage indicators provide a point-in-time assessment of a country's strengths and weaknesses in seeking investment for CCS deployment. Information presented at a high level in combined form, and further in depth-analysis using disaggregated data, can better highlight individual barriers to CCS and assist stakeholders in identifying potential solutions.
2. Long-term, cohesive and clear policies, in concert with the development of storage sites and regulatory frameworks across the entire CCS technology chain, creates an enabling environment for investment in CCS.
3. High-scoring nations have developed their CCS industry over at least two decades. This has included the development of policy commitments, legislative development, and storage characterisation, as well as industry engagement and applied research.

4. If the emission reduction goals and climate change objectives of the majority of the 30 nations reviewed are to be achieved, establishing an enabling environment for CCS must be expedited.

The quantitative analysis made possible via the CCS Index is intended to frame discussion between various stakeholders in understanding the barriers or enablers for CCS in a particular time and place, thus allowing more targeted efforts by those advocating for greater CCS deployment. Information in this report and underpinning the various indicators is also available to Institute members.

1 Introduction

The deployment of carbon capture and storage (CCS) as a critical technology for reducing greenhouse gas emissions is becoming increasingly urgent [2]. CCS is prominent amongst a suite of technologies that can be deployed immediately and widely in the power sector and other industries, to reduce atmospheric carbon dioxide (CO₂) emissions – the primary cause of climate change [1]. CCS can contribute up to 12 per cent of the cumulative CO₂ emissions reduction through to 2050 if we are to limit the rise in global temperature to 2 degrees Celsius at least cost, [according to the International Energy Agency \[2\]](#). This equates to around 90 gigatonnes (GT; billion tonnes) of predominantly anthropogenic CO₂ to be captured, transported and geologically stored. Further, the deployment of CCS needs to be rapid and widespread across many nations around the world [3].

CCS component technologies are mature and the capture, transport and geological storage of CO₂ has been undertaken for over three decades, primarily for enhanced oil recovery (EOR) [4]. The application of CCS technologies at commercial scale for the reduction of emissions in a range of emission intensive industries has been active for the past 20 years with the commissioning of the Sleipner Project in the Norwegian North Sea in 1996 [4]. Not all countries are ready for the wide-scale deployment of commercial CCS and the deployment of CCS has not been uniform around the world.

The Institute identifies four key pillars that are seen as either major barriers or accelerators to drive investment in CCS as a low-carbon technology:

1. A predictable and enduring policy environment
2. Effective and comprehensive CCS law and regulation
3. Early storage site identification and site characterisation
4. Research and development into cost reduction of CCS technologies.

The Institute continues to track the progress of CCS technologies and projects and has built a large knowledge base that has enabled a critical review of the deployment of CCS including those four enabling factors as well as barriers to the technology's success. A series of CCS-specific 'indicators' have been developed which consolidate a range of data for 'inherent interest', law and regulation (legal), policy, and storage. Earlier work has combined the indicators of inherent interest with policy, illustrating a broad correlation with the number of large scale projects tracked by the Institute [5].

To further this assessment, the CCS Index combines these four indicators to provide a unified, quantified assessment and enables the tracking of a country's CCS development and deployment.

In this report, 30 countries have been assessed. The CCS Index will be periodically updated to maintain a systematic, repeatable approach that can, in the future, show how conditions for CCS deployment change in individual countries and also globally.

2 Method

The CCS Index quantifies the extent to which a country has created an enabling environment for investment in the wide-scale, commercial deployment of CCS. A nation's readiness is based on an aggregation of scores from four specific sub-indicators: inherent interest, legal, policy, and storage. Data underlying this report is drawn from the [Global Storage Readiness Assessment](#), [Carbon Capture and Storage Legal and Regulatory Indicator](#), and [Carbon Capture and Storage Policy Indicator](#). A summary of each of the indicators is outlined below. For the detailed methodology behind each section please see the individual reports [5] [6] [7]. The Institute's Inherent Interest indicator is explained in the Policy Indicator report.

All four methods score each country against a series of criteria relevant to that indicator. In order to combine data into a single CCS Index, the final country scores for each of the four individual indicators were normalised to a score of 0 to 100.

The comparative assessment is designed to be updated regularly to track the progress of each of these 30 countries as CCS deployment progresses. Note that the underlying dataset reflects the status of each country as at 2015, and that a country's score can change dramatically, particularly in the policy and regulatory space. This report does not present an exhaustive examination of each country's results, but instead aims to provide a broad overview of the trends in key indicators, and provide a high level quantitative framework for further in-depth analysis of the relative status of CCS in the range of countries examined.

The individual sub-indicators are:

1. Storage Readiness Indicator — based on geological and technical aspects that could impact a storage project within the borders of that country including the geology, the maturity of storage assessments and technical ability to store CO₂. Download a full version of the [Global Storage Readiness Indicator](#).
2. Legal and Regulatory Indicator — based on detailed examination and assessment of a country's national legal and regulatory frameworks which are critical to the regulation of CCS. These can include environmental assessments, public consultation and long-term-liability. Download a full version of the [CCS Legal and Regulatory Indicator](#).
3. CCS Policy Indicator — based on policy measures of national and state/provincial governments. This includes direct support for CCS as well as broader implicit support through measures such as carbon pricing, research or project funding and initiatives. Download a full version of [CCS Policy Indicator](#).
4. CCS Inherent Interest — represents a country's reliance on the burning of fossil fuels either in production or consumption within the country or as an export product. The maturity of a country's oil, gas and coal resources and development are also part of this assessment. This indicator was published with the [CCS Policy Indicator](#).

The CCS Index is an un-weighted aggregation of the Storage, Policy and Legal indicators. The analysis in this report retains Inherent Interest as a separate explanatory variable, which the CCS Index is plotted against. One hypothesis behind this analysis is that a higher Inherent Interest should give some impetus for a country to support CCS. This would thereby establish the appropriate policy and legal frameworks and progress assessments of suitable geological storage resources. Further data for total greenhouse gas emissions is overlaid on the CCS Index to provide additional insights into these relationships and other factors that may affect CCS deployment.

3 Results

Overall, four themes emerge from the review of the results:

1. The legal, policy and storage indicators provide a point-in-time assessment of a country's strengths and weaknesses in seeking investment for CCS deployment. Information presented at a high level in combined form, and further in depth-analysis using disaggregated data, can better highlight individual barriers to CCS and assist stakeholders in identifying potential solutions.
2. Long-term, cohesive and clear policies, in concert with the development of storage sites and regulatory frameworks across the entire CCS technology chain, creates an enabling environment for investment in CCS.
3. High-scoring nations have developed their CCS industry over at least two decades. This has included the development of policy commitments, legislative development, and storage characterisation, as well as industry engagement and applied research.
4. If the emission reduction goals and climate change objectives of the majority of the 30 nations reviewed are to be achieved, establishing an enabling environment for CCS must be expedited.

A significant amount of government and private sector activity has been focused on CCS technology development, particularly the capture and storage, which are now mature technologies. Less emphasis has been placed on the two components that drive investment, that is a supportive policy environment driving CCS and legal and regulatory frameworks that enable the projects to proceed. The early focus on proving technical aspects of CCS is evident in the larger number of countries rating higher on the storage indicator compared to the policy or legal and regulatory indicator scores. Indeed, cumulatively, the policy scores of all the nations are the lowest across the three indicators. This may reflect the desire of policy makers to examine the technical feasibility of storage and other aspects of CCS prior to implementing policies and legislation to support fuller deployment of CCS. Data behind the policy indicator results supports this, with a large number of countries engaging in R&D and knowledge sharing activities ahead of market based incentives and grant programmes for large scale projects.

This section presents the results of the sub-indicators, before examining the relative placement of countries in terms of overall CCS Readiness and a discussion of large scale project developments.

3.1 Storage Indicator

The storage component of the CCS Index has a higher score on average than the other indicators (Figure 1). Geological potential and the development of that storage has the greatest weighting in the storage indicator. Subsequently, high scoring countries generally have favourable geology for storage, such as the Northwest Shelf of Australia [8], North Sea for Norway [9] or the Cambrian Sands of Canada [10]. Whilst previous studies have found that the majority of nations have sufficient theoretical storage potential to meet emission reduction targets for CCS [3], favourable geology does not necessarily mean vast storage resources. However, the identification and appraisal of storage potential is just as critical as the storage resource itself; identifying suitable storage sites increases the prospectivity for future CCS projects. Almost all of the higher ranked nations have completed a national storage resource assessment and in most cases then completed further analysis such as basin-scale storage resources estimates and basin prospectivity studies. For the highest ranking nations, such as Canada, Norway and the US, individual geologic storage formations have been identified.

Nations that rank more highly against the CCS Index generally have an advanced, mature petroleum industry or CO₂-enhanced oil recovery (CO₂-EOR) operations. CO₂-EOR provides a commercial driver for CCS projects and shows that storage is achievable in that nation. Moreover, countries with a

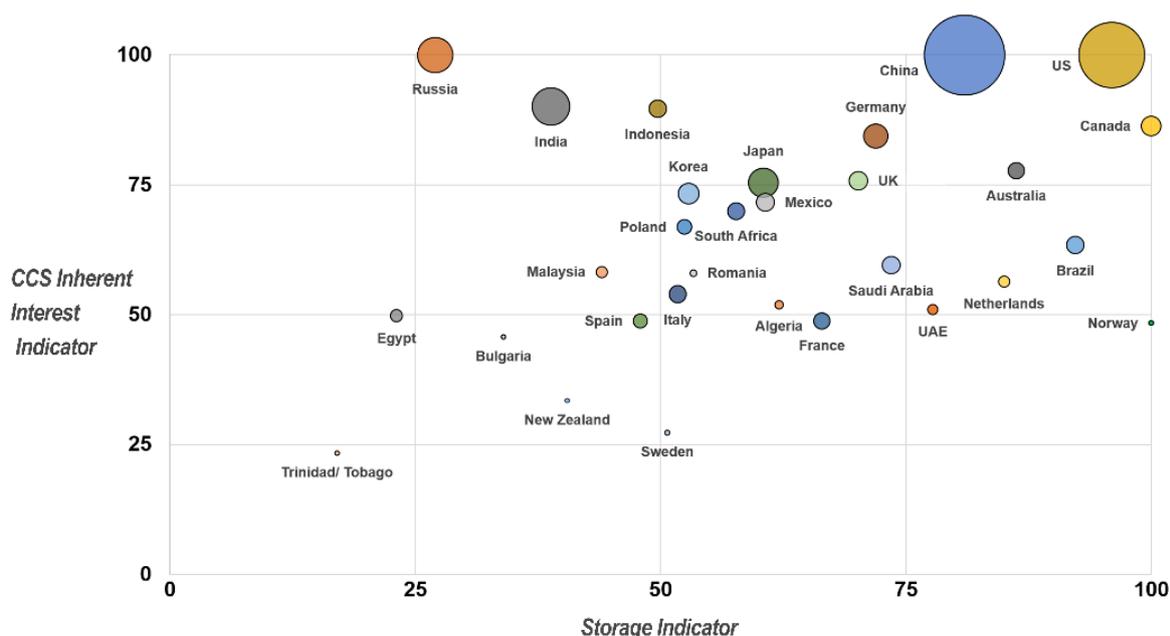
mature hydrocarbon industry and developed hydrocarbon provinces have a distinct advantage in developing their storage potential. These nations typically have better knowledge of the subsurface due to active hydrocarbon exploration which includes access to subsurface data. Using this knowledge and data can speed up the storage potential assessment process, reduce uncertainty, and also reduce the amount of expenditure needed to appraise potential storage targets.

Furthermore, all of the higher ranking nations, apart from the UK, have completed a CO₂ injection project either as a commercial operation or a reasonable scale (>50,000 tonnes of CO₂) test facility. An injection project at either of these scales is a highly weighted criteria for the storage indicator in the CCS Index. An actual injection project can show that CCS is commercially achievable in a nation, or at the very least, that it is possible to inject CO₂ into the subsurface. The latter may seem trivial, but CO₂ injection means that technical, community and regulatory barriers have been overcome [11]. An injection project can also bolster local and national sentiment towards CCS.

The majority of nations are identified as moderate scoring nations in the storage indicator. These countries have mixed results within the criteria-based analysis and hence there is no single unifying feature amongst them. Some nations have favourable geology and a mature oil and gas industry, but have not published geological storage assessments of their storage potential, such as Saudi Arabia. Moreover, some nations may have completed detailed national assessments and even have a storage project, such as France, but have comparatively lower geological storage potential than other nations. Finally, nations including Korea and Japan have immature or sporadic hydrocarbon field development which can lower their score.

For nations with the lower scores, there is not an individual criterion which has not been addressed, but a combination of factors which have impacted storage development. These lower-scoring countries have typically not completed detailed geological storage assessments and have no experience in completing an injection project at any-scale. Figure 2 shows the comparison between the storage and interest indicators. The majority of the countries with high scores also score highly in their interest indicator, with a few critical exceptions in India, Indonesia, Malaysia and Russia.

Figure 2. Comparison between the storage and interest indicators. Bubble size reflects the total emissions according to the World Resources Institute 2010 data [12].



3.2 Legal Indicator

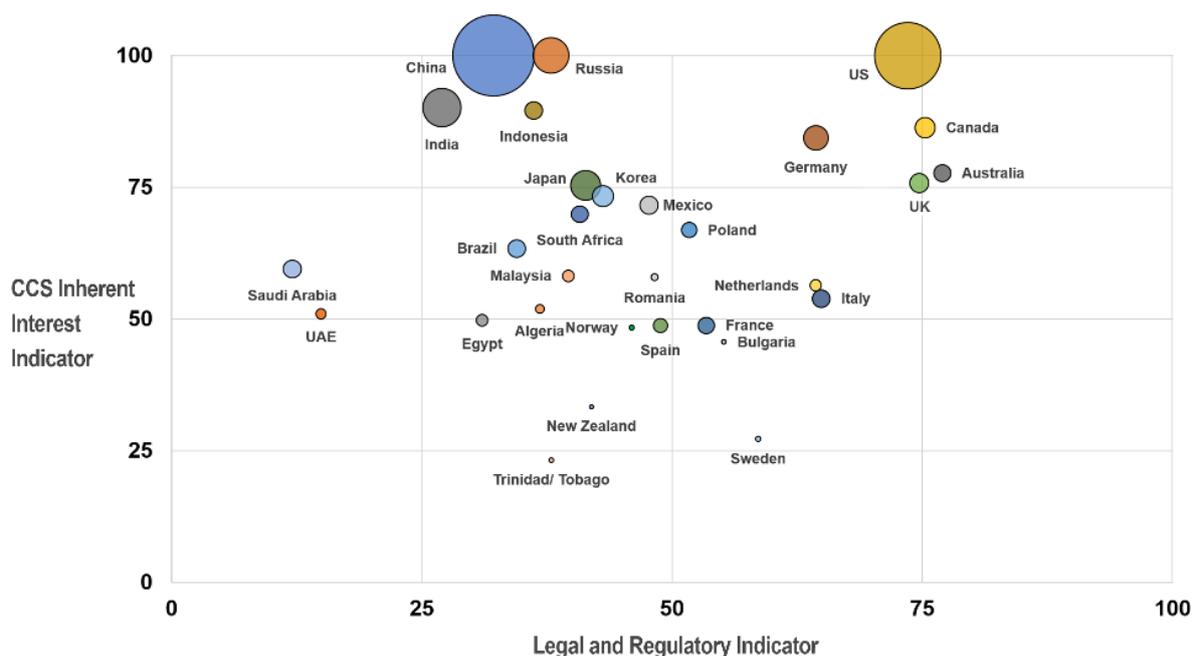
The majority of countries received moderate scores under the legal and regulatory indicator, which reflects the present level of progress in the development of CCS laws and regulations globally (Figure 2). Only four countries scored particularly highly. These countries, Australia, Canada, UK and US, have been historically recognised as champions of the development of effective and comprehensive legal frameworks for CCS [3]. These nations have developed detailed CCS-specific laws or have existing laws that are applicable across most parts of the CCS project cycle.

Despite this progress, there are no countries that have a regime that comprehensively addresses all of the core elements of a legal and regulatory model for the technology. Accordingly, there are no countries with an exceptionally high score (90+) as seen in the storage assessment. The four countries listed previously, as well as some of those with more moderate scores, have relatively comprehensive frameworks that can address legal and regulatory aspects across most of the CCS technology chain. Some countries have made amendments to existing resource legislation to regulate CCS activities, which indicates that mature industrialised countries, with an established oil and gas industry, may have a distinct advantage in CCS development.

Countries with low to moderate scores have far fewer CCS-specific laws and, in some instances, have prohibited CO₂ storage activities in their territory. When comparing the legal indicator results to the inherent interest and emissions profile of nations, there is a clear trend that the majority of countries do not yet have adequate legal and regulatory frameworks across the entire CCS technology chain to support CCS development in their nations (Figure 3).

Many of the countries with a moderate score are mature industrialised countries. This category is heavily dominated by EU nations. In many instances they have comprehensively addressed one or several assessment criteria, but national regimes do not address all of the CCS project technology chain. For EU nations, which have implemented the EU Directive on the '*geological storage of carbon dioxide*' this has resulted in higher scores. Worldwide, countries with lower to mid scores have far fewer CCS-specific laws or existing laws and, in some instances, have prohibited CCS across the entire CCS technology chain. However, some of these countries may comprehensively address one or several legal and regulatory aspects related to CCS specific requirements. When comparing the legal and regulatory indicator results to the inherent interest and emissions profile of nations, there is a clear trend that the majority do not have adequate legal and regulatory frameworks for the entire CCS technology chain to support CCS development in their nations (Figure 3).

Figure 3. Comparison between the legal and interest indicators. Bubble size reflects the total emissions according to the World Resources Institute 2010 data [12].



3.3 Policy Indicator

The majority of countries in the policy indicator have low scores (Figure 3). This finding is unsurprising as CCS does not receive equal policy support compared to other greenhouse gas mitigation technologies such as renewable electricity generation. It should also be noted that the policy indicator is a relative measure – there are currently no countries with policy settings that are sufficient to encourage deployment of CCS at large scale, consistent with global ambitions to limit temperature increases to within 2 or 1.5 degrees Celsius.

Countries with higher relative scores (Canada, Netherlands, Norway, UK and US) have long-term, clear and targeted support for CCS as a specific greenhouse gas mitigation technology. As can be seen from Figure 3, the Institute calculated a preliminary 2016 observation for the UK given the cancellation of its CCS Commercialisation Programme, resulting in a significant drop in ranking. Notwithstanding this, it still has various policies that can act to encourage CCS, in the form of emission performance standards and a carbon price floor, as well as supportive institutions. Hence, the policies of the UK still enable a high score relative to most nations. The UK Government's stance on CCS in the absence of large-scale funding is expected to become clearer by early 2017.

Countries that rank highly within the policy indicator have employed a broad range of measures to pursue climate change targets. Governments in these countries have also made consistent statements that identify the important role of CCS alongside other low and zero emission technologies. Investment in CCS projects and research is supported via a combination of legislated requirements, market based incentives and supportive institutional arrangements. Countries with higher rankings have direct regulation of emissions from power plants, thus encouraging the deployment of CCS in this sector. Subsequently, aside from the UK, most of the nations that rank highly against the policy indicator have an operational CCS project.

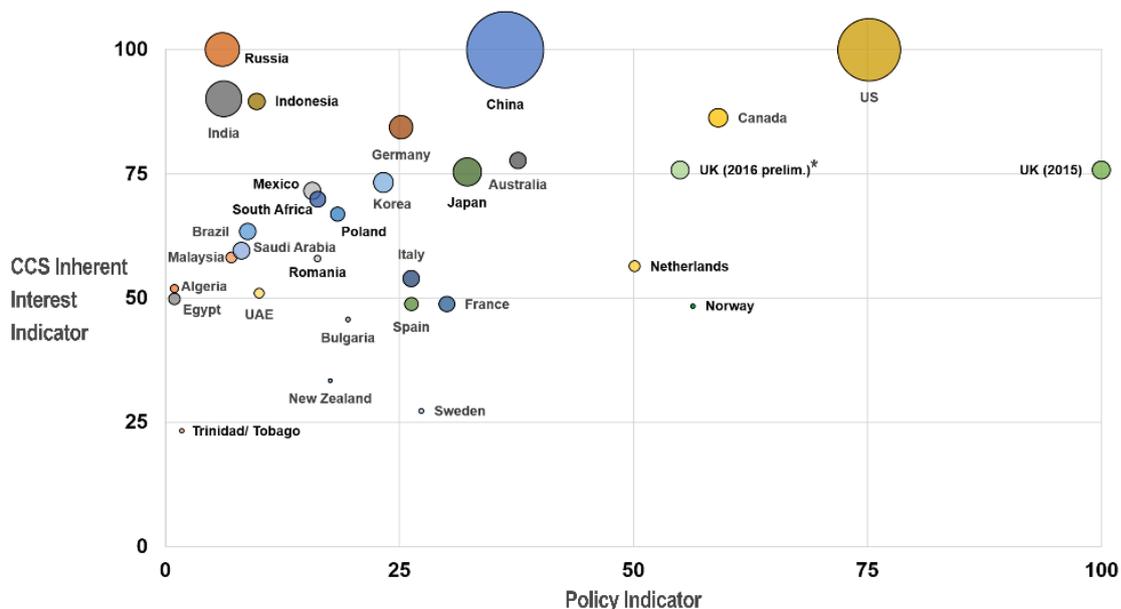
Countries that score moderately have fewer direct policies with regard to the role of CCS in overall climate change policy. Some of these countries have CCS projects in the operational stage, but without significant direct subsidies, rely upon CO₂-EOR to make the projects commercially viable. Like

the Legal and Regulatory Indicator, many mature industrialised countries score moderately, including member states of the EU that register policy observations such as overarching strategies and political statements regarding CCS, as well as funding mechanisms and the ETS which are also broadly applicable to CCS.

Countries with lower scores have not developed clear policies on the role of CCS as a specific greenhouse gas mitigation technology. Despite a significant proportion of countries scoring moderately, in the overall comparative assessment, nations such as Australia, China and Japan are making significant progress.

Compared to the legal and storage indicators, the majority of nations in the policy assessment receive lower scores. Countries in this category have relatively less stringent climate change targets than higher scoring nations or are at earlier stages of economic development. Accordingly, CCS may be considered to be less of a priority in the short term. Brazil, Indonesia, Mexico, Poland, Saudi Arabia and UAE have demonstrated an interest in pursuing CCS in achieving climate change objectives, but generally also observe CCS primarily for EOR. Some of these nations do have CCS demonstration and pilot projects, which suggest that a CCS project can still be developed.

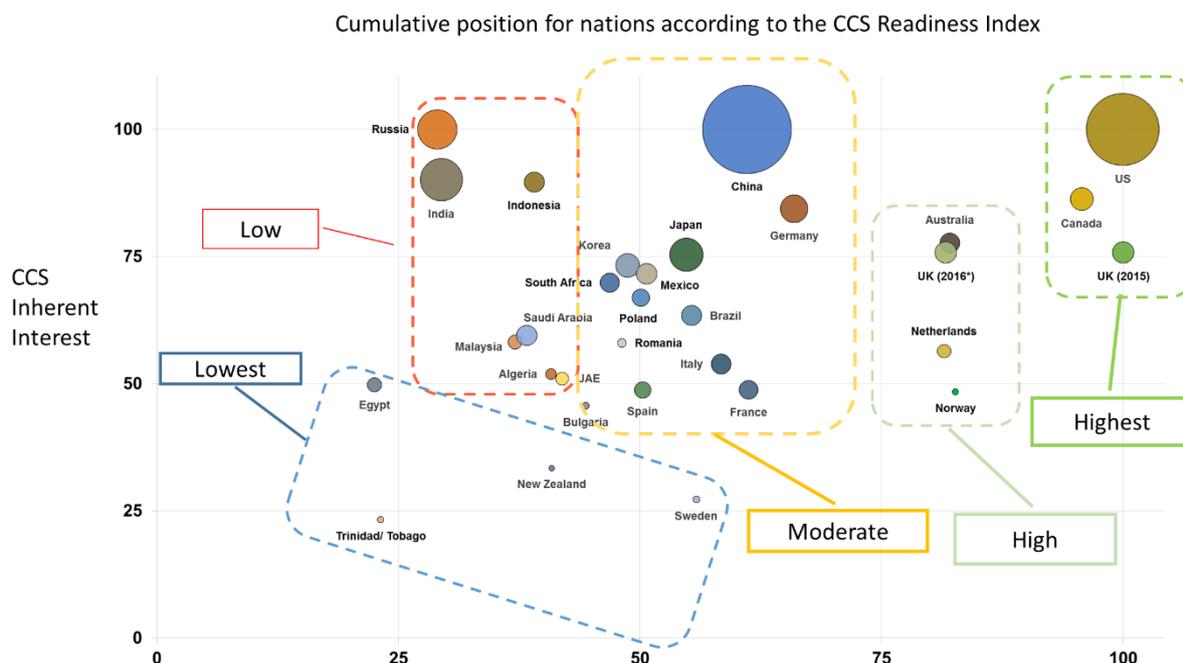
Figure 4. Comparison between the policy and interest indicators. Bubble size reflects the total emissions according to the World Resources Institute 2010 data [12].



3.4 Overall CCS Readiness

Results for the CCS Index are plotted in figure 5. The key observation is that there are very few high-scoring countries with long term, strategic approaches to CCS which have addressed various criteria and can lead to higher levels of CCS deployment.

Figure 5. Comparison between the CCS Readiness and interest indicators. Bubble size reflects the total emissions according to the World Resources Institute 2010 data [12].



For the purposes of this report, the Institute has grouped countries into the following categories:

1. **Highest** ranking countries are characterised by credible, long-term commitments to CCS as part of climate change and energy strategies. These countries have squarely addressed the key precursors to CCS deployment. They have developed effective and comprehensive legal frameworks for CCS and in places have CCS-specific laws or have existing laws that are applicable across most parts of the CCS project cycle. Countries in this group also have investigated their storage potential and, in most cases, have completed a significant CO₂ injection project.
2. **High** ranking countries have few barriers to CCS deployment, with issues still being resolved in one or a limited number of Index criteria.
3. **Moderate** ranking countries are the largest in number. These are countries that have some barriers or are making progress, with mixed results across the criteria examined. Countries in this group, like China and Japan have notable project activity at smaller scale and are making significant progress, while others such as Germany have strong strategic interest in developing CCS but have not shown signs of recent support.
4. **Low** ranking countries have a high or moderate degree of inherent interest but a low degree of readiness. This reflects the relatively little effort placed into examining the role of CCS as an emission reduction technology. This is in spite of the benefits CCS can deliver in terms of decarbonising significant emissions from these countries and in enabling continued consumption and export of fossil fuels as a means for further economic development.
5. Conversely, countries classed as **lowest** have low Inherent Interest and, as might be expected, virtually no CCS related activity.

4 Discussion

Policy and regulation tend to be leading drivers

A review of the countries and their scores across the three indicators demonstrate that policies (including emission mitigation targets) that identify CCS as a low carbon mitigation technology, and incentivise investment in CCS are the most effective drivers of CCS deployment. Further, policy and effective regulation remain the leading drivers of CCS deployment even where the CO₂ is used for EOR.

More importantly, the high scoring nations have largely developed a long-term strategic approach to the technology and have a cohesive and holistic framework around CCS. Lower-scoring nations, conversely, have adopted a sporadic approach to the inclusion of CCS in their domestic emission reduction targets. Among some of the lower scoring countries, certain nations score highly in storage (for example China and Germany), but those same nations do not have, publically at least, clear and targeted support for CCS as a specific greenhouse gas mitigation technology. Nations such as Canada and Australia have clearly identified a need for CCS and have policies supportive of CCS across many key government platforms (direct regulation, CCS funding agreements etc.), whilst collectively developing their CO₂ storage potential and legal and regulatory frameworks to enable a CCS project. Subsequently, Canada and Australia have CCS projects operating (Quest CCS Project, Canada) or under construction (Gorgon CO₂ Injection Project, Australia) that will capture and store CO₂ from industrial processes specifically for emission reduction.

Conversely, the lack of clear CCS policy is the primary reason why numerous countries with prospective storage potential and amenable regulatory frameworks have not built a large-scale CCS facility – the United Kingdom being primary example. In the update of the policy indicator in 2015, the United Kingdom had the strongest policy leadership in encouraging CCS, which resulted in two leading CCS facilities and prospects for many others [13]. The UK has market based mechanisms in the form of a carbon price floor and contracts for difference which supported these investments. But it was a relatively strong long-term commitment to CCS and direct funding that provided the greatest incentive for deployment. This commitment was removed in late 2015 resulting in the termination of the two leading projects. Subsequently, the UK's ranking has fallen and this, even if major policy announcements are made in the coming months, will still be reflected in the 2017 indicator update.

There is correlation between high CCS Index scores and deployment

The overall premise of the CCS Index is that a high score across the storage, legal and policy indicators, especially for those nations with a high CCS interest will create an enabling environment for investment in the wide-scale, commercial deployment of CCS. The Institute currently recognises 38 large-scale projects (LSIP) which span the planning to operational phases of the project life cycle.

The highest ranking nations in the CCS Index host all but four of the 22 LSIPs that are operating or under construction recognised by the Institute [3]. The United States and Canada, being the highest ranking countries in terms of CCS Readiness have ten operational projects in the world today, with a further five in construction. It is important to note that of these projects the majority are associated with CO₂-EOR. The capture of anthropogenic CO₂ from industrial sources and power stations with storage has mainly been commercially viable because of the revenue from the increase in production of oil. CO₂-EOR has not only enabled the deployment of CCS technologies across a wide range of industries, but also geological environments, providing the technology and knowledge for future CCS projects aimed at reducing emissions. Moreover, it is unsurprising that nations with CO₂-EOR operations also have more defined legal and regulatory frameworks for CCS, as well as a supportive policy environment.

Moving forward, six large-scale projects (operational or under-construction) that are not CO₂-EOR projects and are directly related to emissions reductions are also all hosted by high scoring nations. This includes Norway (with two operational LSIPs), Australia (three LSIPs with one about to become operational in 2017), and the Netherlands (one LSIP in advanced planning). The two Norwegian projects suggest that a modest but stable price on carbon can be an effective driver for CCS deployment with dedicated storage, while direct regulation was a key factor in the Gorgon project in Australia (also dedicated storage). The distribution of projects in mostly high scoring nations show that by providing an enabling environment and policy support, commercial CCS projects can be deployed. A contrasting example is the UK. The UK, also a high ranking country, hosted five projects in planning stages as at 2015 on the back of significant policy support, although two of these were effectively cancelled with the withdrawal of the government's Commercialisation Programme.

China has eight large scale projects in various stages of planning, in addition to significant project activity at smaller scale. As noted above, China's CCS Index is somewhat understated on policy criteria as the role of the state and state-owned enterprises in pursuing CCS activity is not always visible in terms of standardised policy assessment.

Algeria, Brazil, Saudi Arabia and UAE do not have overall high scores, but each have one LSIP operational or under construction. These projects show that country-specific factors within the CCS Index criteria do not need to be all satisfied to encourage CCS deployment. This finding is reinforced by the fact that many projects have been enabled via CO₂-EOR revenues and in relatively low cost CCS applications such as natural gas processing. Also appropriately designed policy incentives or regulations can be an apparently easy substitute for CO₂-EOR revenues to encourage wider deployment of CCS. Projects associated with CO₂-EOR enable various stakeholders to build a familiarity with CCS technology in specific locations, reinforcing activities which further improve CCS readiness, including public engagement and legal and regulatory frameworks.

All countries need to do more to support project deployment

A further important observation from the CCS Index is the fact that that no country possesses a perfect score. Storage results, when contrasted with those from the policy and legal indicators, are typically higher despite several areas of potential improvement. The significant majority of countries score moderate to low in the legal indicator, and low in the policy indicator, which is perhaps indicative that technological development always leads policy and regulatory development. This assumption reflects the desire of policy makers to examine the technical feasibility of a technology, in this case the capture, transport, storage of CO₂ prior to implementing policies and legislation to support fuller deployment of CCS. The lower scores of the policy and legal indicators actually present significant opportunities. Specifically, countries could readily create an enabling environment with policy or legal developments by addressing particular low scoring criteria within the indicators. Japan, for example, received a low regulatory assessment score for its current regulatory frameworks for offshore storage, however the government is actively addressing many of the remaining barriers and according to Gibbs [14] is developing its regulatory framework for CCS. More broadly, all countries are expected to improve in policy rankings over time in line with high levels of ambition sought under the UNFCCC's arrangements, and as commitments to limit global temperature rise translate into detailed policy action.

CCS contributes to energy resource security and emissions reduction

An encouraging result from the comparative assessment of indicators shows that a large number of high emitting nations with a high interest score also have high to moderately high scores in the three indicators. This includes countries such as China, Korea, Japan, and the larger EU nations. This suggests countries are actively engaged in the deployment of CCS but have not comprehensively met all the criteria within the three indicators. Importantly, these nations could, with only moderate CCS commitments, rapidly develop CCS projects. Overall the countries are advanced, industrialised

nations with some clear government commitments to CCS through primarily multilateral CCS initiatives. The countries are most evidently high producers/consumers of fossil fuels and generally display a higher commitment to effective climate change policies than those identified in the lower categories.

In contrast to the nations above, there are significant number of countries that have a high Inherent Interest either due to their high emissions or consumption and/or production of fossil fuels that have low scores across all three indicators. Most prominent in this list are Russia and India. From the analysis, it is evident that these nations have publically at least, not defined a clear policy to mitigate their emissions of CO₂ from fossil fuel sources or identified CCS as a potential technology. India has a limited oil and gas industry, as well as environmental regulations associated with resources extraction when compared to other nations. Hence, it also scores low in law and regulations. Russia on the other hand has an advanced and mature oil and gas industry and has frameworks in which CCS legislation could fit. From a storage perspective, Russia has abundant storage potential, especially in depleted oil and gas fields as evidenced by storage assessments [15] but has not published any specific English-speaking national assessments¹. India on the other hand has published a few high-level, broad assessments of its storage potential and concluded that there is moderate potential (as compared to yearly emissions) in the offshore region [16]. Neither country has undertaken any detailed research nor undertaken a CO₂ injection project. Collectively, these reasons are why those countries score low in the storage indicator.

¹ According to author's extensive literature search.

5 Summary

The CCS Index provides a robust, high level framework for examining the current status of CCS in a range of countries and how this can change over time.

The overwhelming conclusion of the analysis of 2015 data in this report is that not one country has addressed all the critical factors that may prove to be barriers to the deployment of CCS. Indeed, the majority of countries score moderately to poorly in one or two of the indicators and this has the potential to limit the advancement of CCS deployment worldwide. For low scoring countries with high dependency on fossil energy, the issue is more pertinent because CCS can underwrite energy security in a global economy that increasingly is placing a cost on emissions.

That said, there are already 16 large-scale CCS projects operational in seven countries, with an additional six projects scheduled to commence operation within the next two years. Many of these projects are found in countries with high degrees of CCS Readiness however others are not, suggesting that a country need not rate highly in all three of the indicators to host a CCS project, nor address particular project barriers or enablers in a particular order.

The presence of large scale projects in countries such as the US, Canada, Australia and China indicate that large-scale CCS deployment requires:

- A moderate to high dependence on fossil fuel production/ consumption and a genuine desire by the government to address growing emissions from these sources
- Supportive national and regional policies to back this overall desire, including direct or indirect financing mechanisms;
- Legal and regulatory frameworks to ensure all components of the CCS technology chain are addressed; and
- A portfolio of storage sites which have been identified; with early opportunities appraised and developed.

The findings in this report reveal four main implications for CCS stakeholders:

1. The CCS Index provide a point-in-time assessment of a country's strengths and weaknesses in seeking investment for CCS deployment and can highlight individual barriers and opportunities through the criteria-based approach.
2. Long-term, cohesive and clear policies, in concert with the development of storage sites and regulatory frameworks across the entire CCS technology chain, creates an enabling environment for investment of CCS in a country.
3. High-scoring nations have developed their CCS industry over at least two decades. This has included the development of policy commitments, legislative development, and storage characterisation across government at all levels, as well as industry engagement and applied research.
4. If the emission reduction goals and climate change objectives of the majority of the 30 nations reviewed in the CCS Index are to be achieved, addressing of individual criteria to create an enabling environment for CCS investment needs to be expedited globally.

Acknowledgements

We would like to acknowledge the early contributions of Rick Causebrook and Mark Bonner.

6 References

- [1] IPCC, "Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change," IPCC, Geneva, Switzerland, 2014.
- [2] International Energy Agency, "Energy Technology Perspectives," IEA/OECD, 2016.
- [3] Global CCS Institute, "Global Status of CCS 2015," Global CCS Institute, Melbourne, 2015.
- [4] D. Reiner, "Learning through a portfolio of carbon capture and storage demonstration projects," *Nature Energy*, vol. 1, no. 15011, p. doi:10.1038/nenergy.2015.11, 2016.
- [5] Global CCS Institute, "Carbon Capture and Storage Policy Indicator (CCS-PI)," Global CCS Institute, Melbourne, Australia, 2015.
- [6] Global CCS Institute, "Global Storage Readiness Assessment," Global CCS Institute, Melbourne, Australia, 2015.
- [7] Global CCS Institute, "CCS Legal and Regulatory Indicator," Global CCS Institute, Melbourne, Australia, 2015.
- [8] Carbon Storage Taskforce, "National Carbon Mapping and Infrastructure Plan – Australia: Full Report," Department of Resources, Energy and Tourism, Canberra, Australia, 2009.
- [9] Halland et al. (eds), "CO₂ Storage Atlas, Norwegian Continental Shelf," The Norwegian Petroleum Directorate, 2014.
- [10] U.S. Department of Energy, "Carbon Storage Atlas - Fifth Edition (Atlas V)," 2015.
- [11] Cook et al., "What have we learned from small-scale injection projects?," *Energy Procedia*, vol. 63, p. 6129 – 6140, 2014.
- [12] World Resources Institute, "Climate Analysis Indicators Tool Country GHG Emissions 2010 dataset," World Resources Institute, 2015. [Online]. [Accessed 2015].
- [13] Global CCS Institute, "Global Status of CCS: 2015," 2015.
- [14] M. Gibbs, "Japan's legal and regulatory framework for CCS," Global CCS Institute, Melbourne, 2016.
- [15] K. Sidorova, "Economic assessment of the whole CCS technology cycle," in *Internationale Energiewirtschaftstagung*, Vienna, 2015.

- [16] Viebahn et al., “Prospects of carbon capture and storage (CCS) in India’s power sector – An integrated assessment,” *Applied Energy*, vol. 117, pp. 62-75, 2014.