Could CO_2 capture and storage happen in developing countries? A study beyond the obvious

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Executive Summary (restricted)

While industrialised countries are implementing research programmes, demonstration projects and in some cases policies that enable CCS, developing countries (either non-OECD or non-Annex I countries) are slower in adopting the technology (Global CCS Institute, 2010). If there are efforts at all in developing countries, they are mostly on the initiative of industrialised countries, and comprise relatively shallow efforts focussed on general awareness and the government's ability to make regulatory decisions on CCS. Yet according to the IEA Roadmap (2009), in 2020, on the order of 50 full-scale CCS projects need to be operational in developing countries in power as well as industry – an ambitious target.

This paper aims to look beyond the obvious parameters for assessing developing country interest in CCS by taking into account broader political interests in CCS. We discuss emerging countries with high absolute emissions and a strong dependence on coal for power production, but also smaller countries, for instance oil and gas exporters, or countries with high-emitting industry.

Apart from enabling conditions, such as technical potential for CCS and coal use, this paper looks at various political drivers for the technology. They might be concrete: countries may be interested in CO_2-enhanced oil recovery (EOR). But they can also be more diffuse: countries may have long-term interests in preventing climate change, or a short-term need for a technology that improves their green image. They might be after an image of political leadership, they might want to hedge against future climate change commitments, or they might want to secure fossil fuel exports in a carbon-constrained future.

The exploration in this paper covers a broad group of countries and a wide scope of enablers and drivers. The analysis therefore could not go into much depth on any of the aspects. For some countries, only very limited information was available. However, a pattern emerges that the large, coal-reliant countries that are often mentioned in the context of CCS are not necessarily those with the most explicit enablers or drivers for CCS.

From the analysis, we find the following. Fast-industrialising countries, substantially fuelled by coal, in particular China, India, South Africa, South Korea and Argentina, have much potential for capture, but not necessarily much potential for storage. Their political drivers for CCS are mainly in the field of hedging for future climate change commitments. Their investments in CCS might therefore be aimed at the longer term.

Affluent and industrialised oil and gas exporters, such as UAE, Saudi Arabia, Kuwait, Qatar, Malaysia and Russia, are the most likely first significant implementers of CCS outside of the developed world. They have high-purity sources, storage potential and potential for EOR. They might also want to hedge against other country's climate commitments or improve on their environmental reputation.

Developing countries with oil and gas industry, such as Nigeria, Algeria, Egypt, Mexico, Indonesia, Brazil, Angola, Kazakhstan and Iran, but with great development challenges and therefore a limited incentive to invest in CCS, would have the technical potential to deploy CCS in the short term, but would generally find more political arguments to invest in strategies that are more oriented towards development. International support, for instance from the CDM, the Green Climate Fund or the Technology Mechanism, would be essential to persuade these countries to use their potential.

Many developing countries with a small oil and gas industry, such as Botswana, Ghana, Mozambique and Vietnam, happen to also be vulnerable to climate change and care for solutions that work. Those with a fossil-fuel industry, such as Botswana with coal and Mozambique with both coal and gas, might be interested in showing larger, polluting countries the way towards a low-carbon future. They also have short-term potential to invest in CCS. Similar to the former category, international support would help them in realising any ambitions in CCS.

In conclusion, also countries other than large emerging economies with high coal reliance may have potential and drivers to look into CCS. Whether the drivers are strong enough to realise this potential will depend on many different factors, including on the ability to reduce costs and mobilise international support. When deciding where to do capacity building programmes, with whom to collaborate on R&D and demonstrations, and with which governments to set up programmes to form regulatory frameworks for CCS, governments and international organisations could respond to political drivers in addition to the more commonly used metrics of total emissions and use of coal.

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1.1 Abbreviations

bcm	billion cubic meters
CCS	CO_2 capture and storage
CDM	Clean Development Mechanism
CO_2	Carbon dioxide
CO_2-EOR	Enhanced Oil Recovery using CO_2
CO_2-EGR	Enhanced Gas Recovery using CO_2
CTL	Coal To Liquids
ECBM	Enhanced Coal Bed Methane recovery
GtL	Gas to Liquids
IEA	International Energy Agency
IEA GHG	IEA Greenhouse Gas R&D Programme
IPCC	Intergovernmental Panel on Climate Change
UAE	United Arab Emirates
UNFCCC	United Nations Framework Convention on Climate Change

2 Introduction

Global studies of climate change mitigation (IPCC, 2007; IEA, 2010) attribute a substantial role to CO_2 capture and storage (CCS) in reducing greenhouse gas emissions until 2050. While industrialised countries have embarked upon research programmes, demonstration projects and in some cases policies that enable CCS, developing countries are slower in adopting the technology. If there are efforts at all in developing countries, they are often on the initiative of industrialised countries, and comprise relatively shallow efforts focussed on general awareness and the government's ability to make regulatory decisions on CCS. Yet according to the IEA Roadmap (2009), in 2020, on the order of 50 full-scale CCS projects need to be operational in developing countries in power as well as industry.

The CCS efforts in developed countries are stimulated by an awareness that greenhouse gas emissions will eventually need to decline, combined with a perception that the continued use of fossil fuels is desirable for various reasons: affordability of energy as well as maintaining international markets for fossil fuel-exporting countries. The key difference with developing countries is their conviction that actions on climate change mitigation need to be taken by the industrialised world. The only exceptions may be China, which because of its size and rapid development is becoming an exceptional country on all accounts, and the United Arab Emirates, which are developing demonstrations of CCS on their own account.

This paper aims to look beyond the obvious parameters for assessing developing country interest in CCS by taking into account broader national interests in CCS. In the past, organisations aiming to support development of CCS have already applied criteria for selecting countries to focus their capacity development efforts on. Both the Carbon Sequestration Leadership Forum (CSLF) and the Global CCS Institute focussed on emerging countries with high absolute emissions and a high dependence on coal for power production. The thought is that CCS can make a bigger impact in large economies with high emissions. Taking such a view, one often ends up with the same countries: China, India and South Africa. Oil and gas, however, or the presence of high-emitting industry, can be as much an enabling condition for CCS as coal can be. A small country with a low population and therefore lower absolute emissions can have good reasons to take an interest in CCS, but might be overlooked by organisations that focus on the big players.

This paper takes a broader view on national interests in CCS. Enabling conditions, such as most "functions" in the context of approaches like the technological innovation system (Bergek et al., 2008) are not enough to make CCS happen; there also have to be drivers to implement the technology Those drivers can be diffuse as they are not obvious or reflect an interpretation or perception of a benefit, and diverse, as they are different for every country. For instance, countries may be interested in CO_2-EOR, they may have strong long-term interests in preventing climate change, or a short-term need for a technology that improves their green image.

The methodology of this paper is discussed in section 3. Our selection of countries is also introduced there. The deployment potential of CCS in terms of enabling conditions in the selected countries is discussed in section 4. While section 4 takes a more conventional view on developing country interest in CCS, section 5 investigates political potential of countries for CCS, taking into account both short-term and long-term interests. Section 6 combines the findings of sections 4 and 5 in a discussion, after which section 7 concludes with policy recommendations.

3 Methodology

For assessing developing country interests in CCS, this paper makes a distinction between enabling conditions or *deployment potential* for CCS in countries, which provides a data-based, objectified view on issues like sources of CO_2 or a regulatory framework, and *political potential* of CCS in developing countries, which takes into account political interests in the short and longer term that can act as positive drivers for CCS.

The term 'deployment potential' refers to the general preparedness of a country to deploy CCS. This term is used, as the parameters in this analysis go beyond an analysis of the technical potential, and incorporate other parameters such as distance between source and sinks, the presence of oil and gas industries and the countries involvement in existing or planned CCS demonstration project. Having enabling conditions in place does not yet mean that CCS will happen; they are passive conditions.

The political drivers are often summarised as "political will", after which the analysis ends. This paper attempts to go a step further; it disentangles "political will" into concrete drivers, and assesses them in a coarse manner for a range of developing countries. Drivers for CCS are a fully different category from barriers (or means to overcome barriers) to a technology. This paper is not doing a barrier analysis, as many of those have been done for CCS (see for instance Shackley et al., 2009; Coninck et al., 2009). Positive drivers are not intended as predictors of whether a country will implement CCS. Even when there are drivers for CCS, countries can also have other priorities, such as poverty reduction, energy efficiency or entrepreneurial activities other than those related to CCS.

The aim of this paper is to do add to a broad review of the enabling conditions for CCS an analysis of potential positive political drivers. Enabling conditions and drivers are not mutually exclusive or independent – e.g. having the EOR driver in a country means that oil industry experience is present and that storage capacity is also likely – but drivers can form quite autonomously and unrelated to energy or climate change matters.

3.1 Parameters for enabling conditions

In order to assess the possibility of CCS becoming deployed in the developing countries included in this analysis, a number of parameters have been devised. The parameters that will be used are commonly used in exploratory country reviews such as those by the Global CCS Institute, and are outlined below:

- **Presence of stationary CO_2 point sources**
  This parameter concerns the amount of CO_2 which is emitted from known stationary point sources within the country, which also provides an approximate indication of the technical potential[1] for CCS deployment. Data on current sources are based on the IEA GHG database[2] of CO_2 point sources. Future sources are estimated based on plans for industrial development that the authors are aware of.

- **Presence of high-purity CO_2 point sources**
  High-purity sources of CO_2 are concerned with the industrial production process of natural gas, coal-to-liquids, ethylene oxide and hydrogen. These stationary point sources are singled out due to the potential to deploy CCS at these sources at a low cost. Also here, data on current sources are based on the IEA GHG database of CO_2 point sources and future sources are estimated based on plans for industrial development that the authors are aware of.

- **Potential geological storage capacity, or likely presence thereof**
  The presence of potential geological storage capacity in a country greatly facilitates CCS, barring the transboundary movement of captured CO_2. For a number of countries estimates for geological storage capacity are known, however for other countries data are limited. The presence of oil and gas fields in a country can provide an indication that there is storage potential.

[1] Technical potential refers to the potential to deploy CCS irrespective of economic barriers.
[2] Available online from http://www.ieaghg.org/index.php?/20091223127/co2-emissions-database.html.

- **Storage and CO_2 sources matching**
  The presence of CO_2 point sources and geological storage capacity does not necessarily mean that CCS can be done against certain costs. The distance and terrain between sources and potential reservoirs is not always easy to find, but matters for feasibility and cost.

- **Capacity to regulate CCS**
  Of course the activities can only take place in countries if the legal provisions are available to provide certainty to the developer and other stakeholders. A limited amount of literature exists which comments on the status of certain developing countries capacity to regulate CCS, and this will be used to provide an indication of regulatory capacity.

- **Oil and gas industry experience**
  The presence of the oil and gas industry is a very good indicator for the deployment potential of CCS in a country. This is because; a) due to oil and gas exploration, data on suitable storage sites can be made available by operators; b) technical capacity in gas transportation, site exploration and well drilling/injection is highly relevant for CO_2 storage; c) a country with significant oil and gas activities may be more familiar with regulating underground activities. Oil and gas experience will be described as being either 'high', 'moderate' or 'low', based on data on oil and gas production.

- **Involvement in CCS demonstration activities**
  The involvement of a country in CCS demonstration activities can indicate that the country is more advanced in terms of the technical and regulatory capacity.

Where possible, these parameters use quantitative data from the recent literature and databases concerning stationary CO_2 point sources, and the availability of geological storage capacity. Unfortunately, data availability, particularly on geological storage capacity is limited, and thus for certain countries no data can be provided. For other parameters, such as the 'Capacity to regulate', a qualitative approach will be taken based on available literature and expert judgement.

3.2 Parameters for political interest

The political potential for CCS cannot be completely distinguished from the techno-economic potential: resources for instance can determine political strategies, and economic interests are often a driver for political action. The parameters discussed here, however, differ from those discussed in section 3.1 in the sense that they are not enabling factors of CCS, but could be drivers of the technology. Such drivers are not independent of the enabling factors and can be the resultant of the techno-economic parameters (e.g., geological storage capacity, the presence of an oil industry and the potential for EOR are clearly related), but they could also emerge autonomously. The drivers are not based on any reference, but are established through expert judgment based on discussions in workshops on CCS in developing countries (see e.g. ECN, 2010).

3.2.1 Short-term political interests

Short-term political interests are immediate interests, that have potential to pay off in the short term, i.e. within five to ten years. For many short-term political interests, the benefits are certain compared to long-term drivers, as the chance that unexpected developments affect them is smaller.

The following short-term political interests are discussed in this paper:

- <u>Potential for CO_2-Enhanced Oil Recovery</u>: CO_2-EOR could provide revenue, prolong the lifetime of declining oil reservoirs and reduces import dependency for oil. Especially for countries heavily dependent on oil for their national income, CO_2-EOR can be an interesting technology. In many areas of the world, the challenge for CO_2-EOR is the availability of CO_2 as well as technical capacity. CCS may provide a way out of this problem.

- Technology-exporter (presence of equipment manufacturers and high-tech service companies): Those industries that stand to benefit most from global deployment of CCS are the companies supplying the hardware and knowledge around the technology. This includes the capture equipment, transport infrastructure and storage facilities and services. If a country has a thriving company that stands a good chance in this market, it might be more motivated to implement CCS.
- Ability to make use of CCS in the CDM: Countries that have a successful track record in CDM projects might anticipate income and business opportunities now that CCS is eligible under the CDM. In this paper, new climate instruments are not taken into account yet as their scope and funding are not yet clear. This driver will be affected in many countries – such as emerging economies - will be excluded from CDM markets because of new UNFCCC rules.
- Climate-friendly image: Countries that have a bad reputation on environmental issues may want to show their critics that they can act responsibly in the area of climate change through CCS. In democracies, the attitude of the public around CCS will co-determine whether the wish for a climate-friendly image translates in a positive driver for CCS.

3.2.2 Long-term strategic drivers

Long-term strategic drivers or interests of countries relate to structural economic and political characteristics of the country. Often they cannot be pinned down in a very concrete way. It is hard to assign indicators as the interests are often rather diffuse. Benefits of a successful strategy around long-term drivers are not easy to quantify. Still, long-term strategic interests, when embraced by leaders in a country, can determine the economic and political direction of a country, or its view on a technology. From current international politics, numerous examples can be identified.

The following long-term political interests are discussed in this paper:

- Securing export of fossil fuels: Economies that depend strongly or partly on the export of coal, oil or gas have a long-term strategic interest in application of CCS in the countries they export their resources to. If these countries decide to achieve their mitigation targets through other means than CCS, an export market and country income would be lost.
- Hedging against future climate obligations: For countries using much fossil fuels domestically, mitigation targets might come at a high cost if a sudden and deep reduction of CO_2 emissions is required for some, at this point unclear, political reason. CCS could buy such countries time to make a switch to non-fossil sources.
- Political leadership and international credibility; Countries that like to see themselves as serious players on the world's political podium may want to consider CCS as a sign of leadership in the field of climate change. It could increase their international credibility.
- Vulnerability to climate change: Countries highly vulnerable to climate change, that stand to lose from not addressing greenhouse gas emissions, have a stake in furthering low-carbon technologies as much as possible.[3] They could implement CCS (among other technologies, this driver does not go exclusively for CCS) with the aim of showing the world that it works and reducing costs for others, so that chances that climate change is addressed increase. In this way, they could lead by example.

3.3 Developing countries studied

In order to provide a broad picture of the situation around CCS in developing countries (countries classified as non-Annex I in the UNFCCC), a broad portfolio of 24 countries is selected from over 130 developing countries globally. In general, countries that show no indication whatsoever of interest in or potential for CCS are assumed to lack any drivers for CCS and have been excluded from the analysis.

[3] Such countries also have a stake in adaptation. Vulnerability to climate change may lead to a bias to adaptation rather than mitigation, but some countries may still follow the logic presented in this political interest, and therefore (probably in combination with other interests) this could be a potential driver for CCS.

The 24 countries discussed in this study include those that have been extensively studied or that are known players in the international CCS scene, as well as countries that have played a limited role in CCS so far. For the latter category, data availability is limited. To make the outcomes better comparable, even countries where more detailed data are available are reported on a relatively coarse level.

For ease of analysis, the countries have been allocated to four rough categories (see Table 3.1)

Table 3.1 Categories of non-Annex I countries

Category	Countries
Fast-industrialising countries, substantially fuelled by coal	China, India, South Africa, South Korea, Argentina
Affluent and industrialised oil and gas exporters	UAE, Saudi Arabia, Kuwait, Qatar, Malaysia, Russia
Developing countries with a substantial oil and gas industry	Algeria, Egypt, Mexico, Indonesia, Brazil, Angola, Kazakhstan, Iran
Developing countries without or with a small oil and gas industry	Botswana, Ghana, Mozambique, Vietnam

4 Deployment potential

This section assesses, as far as possible given information and data constraints, the deployment potential for CCS in each of the four country categories highlighted in Section 3.3. The annual production figures for oil and gas are used as an indication of the country's oil and gas experience and human capacity. As mentioned above, for certain countries data regarding the geological storage capacity is unavailable.

The stationary CO_2 point sources are derived from the International Energy Agency Greenhouse Gas R&D Programme emissions database[4], and although the database used is very extensive, it cannot be assumed that all the stationary point sources in each country are included. The figures for the oil and gas production for each country are taken from another online database[5].

4.1 Fast-industrialising countries

This category includes the countries of China, India, South Africa, South Korea and Argentina. The full analysis can be found in Table 4.1. Both China and India have an extremely large technical potential, in terms of CO_2 sources, for the deployment of CCS, with emissions from point sources approximately 3 and 1,5 $GtCO_2$ per annum. The technical potentials in South Africa, South Korea and Argentina are significant at 231, 312 and 55 $MtCO_2$ per annum respectively, but are far smaller than those of India and China. In terms of high purity CO_2 sources, from the available data it appears that South Africa has sizeable potential for capture from high-purity CO_2 sources, due to the presence of coal-to-liquid (CtL) and gas-to-liquid (GtL) installations which produce transport fuel for the country. Typically these processes result in a very pure stream of CO_2 flue gas, which has to be removed from the fuel mixture to increase the combustibility of the final product. Both India and China appear to have few high-purity CO_2 sources, however it is highly probable that this is a limitation of the International Energy Agency Greenhouse Gas R&D Programme emissions database.

From the current understanding of the geology of China, it appears that the country has sufficient theoretical geological potential for CO_2 storage, both in oil and gas reservoirs and saline aquifers. The location of these potential storage areas, and the location of the majority of CO_2 point sources in the Eastern part of the country are relatively well matched and thus transportation distances are generally

4 Available online from http://www.ieaghg.org/index.php?/20091223127/co2-emissions-database.html
5 See: http://www.indexmundi.com/g/r.aspx?c=bc&v=88

thought to be low (less than 150) (World Resources Institute, 2010). The matching between sources and sinks in both India and South Africa in general less favourable, with the majority of potential storage areas located offshore. For example, from initial studies (Cloete, 2010), in South Africa the majority of the industrial production takes place in the Gauteng province (Johannesburg and Pretoria), however the bulk of the potential storage locations are found offshore in the South-west. South Korea is understood to have unsuitable geology for extensive CO_2 storage, with a theoretical storage potential estimated at 0,4 $GtCO_2$ (Dooley, 2006). In Argentina, the geology is understood to be generally suitable for CO_2 storage, i.e. sedimentary basin, however no quantitative information is available.

None of the countries in this group have a specific legal framework for CCS. Regarding oil and gas experience, China, India and Argentina are considerable oil and gas producers, South Africa has moderate production levels and South Korea is a relatively minor oil and gas producer. In terms of demonstration activities, China, South Africa and South Korea have plans to demonstrate the technology before 2020. The Global CCS Institute (2011), has identified six large scale integrated CCS projects that are in the planning stage in China. South Africa has plans for a test injection in 2016, and then a fully integrated CCS demonstration in 2020. South Korea is planning two demonstration projects, a post combustion and an oxyfuel combustion project, for 2017 and 2019 respectively. Although India has a number of ongoing CCS research projects, there are currently no official plans to demonstrate the technology. Argentina also has no ongoing or planned CCS demonstration activities.

Table 4.1 Deployment potential analysis of fast industrialising countries

Countries	Discussion of techno-economic parameters						
	Stationary CO_2 sources ($MtCO_2$/yr	High-purity CO_2 sources ($MtCO_2$/yr)	Potential geological storage capacity	Distance between sources and sinks	Capacity to regulate CCS	Oil and gas industry experience	Involvement in CCS demonstration
China	2968.6	3.3	2020 $GtCO_2$ (maximum theoretical potential). 202 $GtCO_2$ viable capacity. 10 $GtCO_2$ storage in oil and gas fields[6].	In general the distance between sources and sinks is considered to be low[7].	There is currently no legal framework for CCS, but there are hydrocarbon laws.	2010 production figures: 3,991,000 bbl/day of crude oil (5th largest oil producer globally). 94 bcm total of natural gas (6th largest natural gas producer globally).	6 large scale integrated CCS demonstration projects have been identified to be in the planning stage[8].
India	1565.8	0.7	India's coalfields 345 $MtCO_2$, Oil fields 922 $MtCO_2$ Potential storage in gas fields and saline aquifers[9].	There may be limited storage capacity close to industrial areas, however the majority of the storage capacity is located offshore.	There is currently no legal framework for CCS, but there are hydrocarbon laws.	2010 production figures: 878,700 bbl/day (23rd largest oil producing nation). 53 bcm total of natural gas (21st largest gas producing nation).	There are no demonstration activities taking place in India.
South Africa	231.2	24	150 $GtCO_2$ (maximum theoretical potential). 98% of storage potential offshore[10].	Highly suitable saline aquifers and oil and gas fields are generally located in the South-west, with the majority of the point sources in the North-east.	There is currently no legal framework for CCS, although this is being developed.	2010 production figures: 191,100 bbl/day of crude oil (42nd globally). 1.9 bcm total of natural gas (ranked 52nd of the gas producing	Test injection planned for 2016. Fully integrated demonstration project planned 2020.

6 Source: IEA/OECD, 2009.
7 Source: Le Gallo and Le Comte, 2011
8 Source: Global CCS Institute, 2011.
9 Source: Holloway et al., 2007.
10 Source: Cloete, 2010.

						nations).	
South Korea	312. 1	1.28	0,4 $GtCO_2$ (maximum theoretical potential). Offshore saline aquifers[11].	No information	There is currently no legal framework for CCS.	2010 production figures: 48,180 bbl/day of crude oil (65th globally). 0,54 bcm total of natural gas (ranked 64nd of the gas producing nations)	There are currently 2 large scale integrated demonstration projects planned to be completed by 2017 and 20198.
Argentina	55.5	3.1	There is no data available on the storage potential, however the presence of sedimentary basins and oil and gas fields indicate a likely presence of suitable storage areas.	No information	There is currently no legal framework for CCS.	2010 production figures: 763,600 bbl/day (25th globally). 40,1 bcm of natural gas (ranked 19th of the gas producing nations).	There are no demonstration activities taking place in Argentina.

4.2 Affluent and industrialised oil and gas exporters

Countries considered in this category are the United Arab Emirates (UAE), Saudi Arabia, Kuwait, Qatar, Malaysia and Russia. These countries are comparable from the perspective that they all have quite a high level of industrial production, and have petroleum and petroleum products as their main exports, and thus the primary source of national income. The full analysis can be found in Table 4.2.

[11] Source: Dooley, 2006.

Table 4.2 Deployment potential of affluent and industrialised oil and gas exporters

Countries	Discussion of techno-economic parameters						
	Stationary CO_2 sources ($MtCO_2$/yr	**High-purity CO_2 sources ($MtCO_2$/yr)**	**Potential geological storage capacity**	**Distance between sources and sinks**	**Capacity to regulate CCS**	**Oil and gas industry experience**	**Involvement in CCS demonstration**
United Arab Emirates	37.58	18.3	No estimates are available, however the abundance of oil and gas reservoirs through the country have significant storage potential.	Being a small country, the distance between sources and sinks is considered to be low and the terrain is favourable.	There is currently no legal framework for CCS, but there are hydrocarbon laws.	2010 production figures: 2,8 million bbl/day of crude oil (8th largest oil producer globally). 48,8 bcm total of natural gas (17th largest natural gas producer globally).	1 large scale integrated CCS demonstration project has been identified to be in the planning stage[12]. A number of EOR test injections are underway.
Saudi Arabia	112.6	18.2	No estimates are available, however the abundance of oil and gas reservoirs through the country have significant storage potential.	Although a large country, in general the distance between sources and sinks is considered to be low as most sources of CO_2 relate to oil industry operations.	There is currently no legal framework for CCS, but there are hydrocarbon laws.	2010 production figures: 10,52 million bbl/day (the largest oil producing nation). 83,9 bcm total of natural gas (10th largest gas producing nation).	There are no demonstration activities taking place in Saudi Arabia. It was announced in 2009 that CO_2 would be injected into the Ghawar oil field (the world's largest), by 2013[13].
Kuwait	28.6	1.82	No estimates are available, however the abundance of oil and gas reservoirs through the country have significant storage potential.	Being a small country, the distance between sources and sinks is considered to be low and the terrain is favourable.	There is currently no legal framework for CCS, but there are hydrocarbon laws.	2010 production figures: 2,45 million bbl/day of crude oil (10th globally). 11,5 bcm total of natural gas (ranked 36th of the gas producing nations)	There are no demonstration activities taking place in Kuwait. It was announced in 2010 that Kuwait would test CO_2 EOR in 2013[14].

12 Source: Global CCS Institute, 2011.
13 Source: TradeArabia, 2009.
14 Source: Al-Ramadhan, 2010.

Qatar	10.9	1.3	No estimates are available, however the abundance of oil and gas reservoirs through the country have significant storage potential.	Being a small country, the distance between sources and sinks is considered to be low. However, much of the gas fields are located offshore.	There is currently no legal framework for CCS, but there are hydrocarbon laws.		There are no demonstration activities taking place in Qatar. However in 2010, the Qatar submitted a CDM methodology to the UNFCCC.
Malaysia	112.4	5.7	No estimates are available, however the large number of oil and gas reservoirs and saline aquifers through the country have significant theoretical storage potential.	No information, although some of the gas fields are located offshore.	There is currently no legal framework for CCS, but there are hydrocarbon laws.	2010 production figures: 693,600 bbl/day (25^{th} globally). 58,6 bcm of natural gas (ranked 19^{th} of the gas producing nations)	No CCS demonstration activities in Malaysia. In 2005, a CDM methodology for an integrated CCS project was submitted to the UNFCCC[15]. However it was rejected as CCS was not an official project activity.
Russia	676.4	No data	A conservative estimate states that North-west Russia has a theoretical storage potential of 5,7 $GtCO_2$ in oil and gas fields[16]. No other data is currently available.	Insufficient detail regarding the specific location of storage areas.	There is currently no legal framework for CCS, but there are hydrocarbon laws.	2010 production figures: 10.1 million bbl/day (2^{nd} globally). 610 bcm of natural gas (ranked 2^{nd} of the gas producing nations).	There are no demonstration activities taking place in Russia.

[15] NM0168 (CDM-PDD: "The capture of the CO_2 from the Liquefied Natural Gas (LNG) complex and its geological storage in the aquifer located in Malaysia"). The project design document was initiated by Petronas the national oil and gas company.

[16] Source: Shogenova et al., 2009.

Russia has a very large technical potential as it produces approximately 700 $MtCO_2$ per year from stationary point sources. There is also technical potential for CCS deployment, albeit relatively smaller than Russia's, in all of the countries in this group. Due to the large reserves of natural gas in the Gulf states, natural gas is the primary fuel for power generation. Prior to use, the natural gas must be processed whereby in some cases, the CO_2 content needs to be reduced, with the removed CO_2 released as a pure stream of CO_2. Qatar is also a major exporter of liquefied natural gas, the production of which also results in a purified CO_2 flue gas. Because of this, the technical potential for CCS deployment against lower costs because of the combination with high-purity CO_2 sources is significant, with the annual high-purity CO_2 emissions approximately 20 $MtCO_2$ per year for both the UAE and Saudi Arabia.

With the exception of Russia, no estimates of CO_2 storage capacity are available for the countries in this group. However, the geology of the Gulf States, and the abundance of oil and gas reservoirs means that storage capacity will not constitute a limiting factor for the deployment of CCS. On this premise, it can also be assumed that in general the distances between sources and sinks is low. Similarly for Malaysia, the large numbers of oil, gas and saline aquifers mean that suitable storage areas will be available, although primarily offshore. The theoretical storage potential for CO_2 in Russia's North-Western oil and gas reservoirs is estimated to be 5.7 $GtCO_2$. With the exception of Malaysia, all the countries in this group are ranked amongst the top ten of oil and gas producing nations, and therefore lack no oil and gas expertise.

None of the countries in the affluent and industrialised oil and gas exporters group have a specific legal framework for CCS. What is different between gas- and oil-producing countries and other countries is that any ongoing or planned CCS activities could potentially be covered by existing legislation for the oil and gas industry, in combination with general environmental regulations, or new regulation would still need to be developed.

Interestingly, all of the countries in this group, with the exception of Russia, have current or past plans for CCS projects. The UAE have advanced plans for the MASDAR Project, a flagship large-scale integrated project that would capture CO_2 from multiple sources, including a steel plant, and transport the CO_2 for use in EOR activities. In fact, all of the Gulf States have plans to test the injection of CO_2 as a potential tertiary oil recovery technique. To extend the life of oil fields, the fields are flooded with water and/or natural gas to increase the pressure and improve recovery. The possibility to use CO_2 as a complementary or substituting recovery agent has attracted the interest of several Gulf States, in particular as other uses for the natural gas emerged – such as export or domestic power production. Both Kuwait and Saudi Arabia have announced to commence test injection of CO_2 into an oil field by 2013. The UAE are currently running test injections.

Qatar and Malaysia have previously submitted proposals to the UNFCCC to initiate CCS projects under the Clean Development Mechanism (CDM). Both submissions were declined due to absence of approved modalities and procedures for CCS in the CDM, but as these were approved in December 2011, new submissions can be expected.

4.3 Developing countries with oil and gas industry

The countries considered in this category are Nigeria, Algeria, Egypt, Mexico, Indonesia, Brazil, Angola, Kazakhstan and Iran. These countries are generally comparable as they are either less dependent on oil and gas export for their gross domestic product, or have yet to fully develop the infrastructure to exploit hydrocarbon resources. They distinguish themselves from the previous categories by lower per capita income levels, more wide-spread poverty and lower industrialisation levels.

The majority of the countries in this group have significant technical potential for CCS in terms of the number of known stationary CO_2 point sources. However, the sub-Saharan African countries of Nigeria and Angola have very few registered CO_2 point sources, producing just 13 and 3 $MtCO_2$ per annum respectively. This could mean that in such countries few opportunities exist for deployment of CCS at present. Both Kazakhstan and Indonesia have potential to capture CO_2 from high-purity streams, due to the large reserves of natural gas in these countries. Brazil has a strong reliance on the use of bioethanol as a transportation fuel. The fermentation process of the sugarcane used results in a very pure stream of CO_2 which could be easily captured. The high-purity technical potential from bioethanol production is approximately 70 $MtCO_2$ per year. An initial scoping study for CCS in Iran identified a number of high-purity industrial sources and several possible storage locations (NIOC, 2010).

Estimates of storage potential are only available for the countries of Brazil and Indonesia. However, based on the basic geology and the presence of oil and gas reservoirs it can be assumed with some certainty that storage potential is available in the other countries as well. Brazil has a very large theoretical storage potential of 2000 $GtCO_2$, and according to Ketzer (2007), there is good matching between the CO_2 sources and identified storage areas in the South-eastern part of the country. In Indonesia, storage areas have been identified with a total maximum estimated capacity of 188 $MtCO_2$, however the theoretical storage potential for the entire country is likely to be much higher (Indonesia CCS study working group, 2009). Insufficient information is available to comment on source sink matching in the other countries.

None of the countries in this category has a regulatory framework for CCS, however a CCS demonstration project in Algeria has been permitted based on existing national hydrocarbon legislation. The In Salah CCS Project has been in operation since 2004, jointly implemented by BP and the Algerian oil company Sonatrach. The project, which captures CO_2 from a natural gas processing plant and injects it into the water layer under the gas in the same formation, is a demonstration project and receives no funding from the CDM and doesn't involve enhanced hydrocarbon recovery. The project is expected to abate 17 $MtCO_2$. In Mexico, the Carmito CO_2 project implemented by PEMEX and Halliburton removes CO_2 from a natural gas processing plant and injects it for the purposes of EOR/EGR. The project is estimated to sequester 8.5 $MtCO_2$ between 2004 and 2013. Petrobras, the Brazilian national oil and gas company has 25 years of experience in CO_2 injection for EOR. Recently the company has been exploring the potential for CCS. Petrobras currently has a pilot project injecting 400 tonnes per day into a saline aquifer, and are operating a pilot scale oxy-fuelled fluid catalytic cracker with carbon capture at a refinery. Brazil is also seeking funding for a capture project from a small scale bio-ethanol plant in Sao Paulo.

Table 4.3 Deployment potential of developing countries with oil and gas industry

Countries	Discussion of techno-economic parameters						
	Stationary CO_2 sources ($MtCO_2$/yr	High-purity CO_2 sources ($MtCO_2$/yr)	Potential geological storage capacity	Distance between sources and sinks	Capacity to regulate CCS	Oil and gas industry experience	Involvement in CCS demonstration
Nigeria	13.5	No data	No estimates are available, however there are a large number of offshore oil and gas reservoirs off the coast of Nigeria which may be suitable for storage.	Insufficient information regarding the location of sources and sinks.	There is currently no legal framework for CCS, but there are hydrocarbon laws.	2010 production figures: 2,5 million bbl/day of crude oil (14^{th} largest oil producer globally). 23,2 bcm total of natural gas (25^{th} largest natural gas producer globally).	There are no demonstration activities taking place in Nigeria.
Algeria	33.5	0.4	No estimates are available, however the abundance of oil and gas reservoirs through the country have significant storage potential.	The majority of the industrial hubs are located in the coastal areas of the country, whereas the major gas fields are located in the interior of the country. In some cases, distances could be large.	There is currently no legal framework for CCS, a CCS demonstration project has been accommodated under the country's hydrocarbon law.	2010 production figures: 2 million bbl/day (the 15th largest oil producing nation). 85,1 bcm total of natural gas (6^{th} largest gas producing nations).	The In Salah CCS project has been operation since 2004. The project, initiated by BP, has injected 3 $MtCO_2$ from a natural gas processing plant into a deep saline formation, with plans to inject a total of 17 $MtCO_2$ over the lifetime of the project.
Egypt	87.2	0.3	No estimates are available, but oil and gas reservoirs suggest the presence of storage reservoirs.	Insufficient information regarding the location of sources and sinks.	There is currently no legal framework for CCS, but there are hydrocarbon laws	2010 production figures: 662,600 bbl/day of crude oil (the 28^{th} largest oil producing nation). 62,7 bcm total of natural gas (ranked 13^{th} of the gas producing nations)	There are no demonstration activities taking place in Egypt.

Mexico	153.5	1.3	No estimates are currently available, but the presence of oil fields indicates offshore potential for storage.	Insufficient information regarding the location of sources and reservoirs. Of the latter, most are likely offshore.	There is currently no legal framework for CCS, but there are hydrocarbon laws.	2010 production figures: 3 million bbl/day of crude oil (7th globally). 59,1 bcm total of natural gas (ranked 14th of the gas producing nations).	The Carmito CO_2 Project (PEMEX/Halliburton) removes CO_2 from a natural gas processing installation and injects it for the purposes of EOR/EGR. The project is estimated to sequester 8,5 $MtCO_2$ between 2004 and 2013. There are no other CCS activities in Mexico.
Indonesia	81.8	7.8	It is estimated that between 38-152 $MtCO_2$ may be stored in depleted oil reservoirs in East Kalimantan, and between 18-36$MtCO_2$ in South Sumatra. It is also likely that CO_2 can be stored in depleted natural gas reservoirs[17].	Insufficient information regarding the location of sources and sinks.	There is currently no legal framework for CCS, but there are hydrocarbon laws.	2010 production figures: 1 million bbl/day (21st globally). 82.8 bcm of natural gas (ranked 7th largest of the gas producing nations).	There are no CCS demonstration activities in Indonesia.
Brazil	130.4	70	Brazil reports an effective storage capacity of approximately 2000 $GtCO_2$.	The majority of the stationary point sources are in South-eastern Brazil, which matches well with the oil fields and the saline aquifers. Here in general, distances are expected to be small[18].	There is currently no legal framework for CCS, but there are hydrocarbon laws.	2010 production figures: 2.5 million bbl/day (9th globally). 12,4 bcm of natural gas (ranked 40th of the gas producing nations).	Petrobras, the Brazilian national oil company, has been operating EOR using CO_2 for approximately 25 years. They currently have a pilot project capturing CO_2 from a oxyfueled fluid catalytic cracker at a refinery. There is also

[17] Source: Indonesia CCS study working group, 2009.
[18] Source: Ketzer, 2007.

							a planned project to capture CO_2 from a sugarcane processing facility in Sao Paulo.
Angola	3.1	No data	No estimates are currently available, but oil and gas reservoirs suggest the presence of storage reservoirs.	Insufficient information regarding the location of sources and sinks.	There is currently no legal framework for CCS, but there are hydrocarbon laws.	2010 production figures: 2 million bbl/day (16th globally). 0,69 bcm of natural gas (ranked 64th largest of the gas producing nations).	There are no demonstration activities taking place in Angola.
Kazakhstan	48.1	5.9	No estimates are currently available, but oil and gas reservoirs suggest the presence of storage reservoirs.	Insufficient information regarding the location of sources and sinks.	There is currently no legal framework for CCS, but there are hydrocarbon laws.	2010 production figures: 1.6 million bbl/day (18th globally). 35,6 bcm of natural gas (ranked 23rd largest of the gas producing nations).	There are no demonstration activities taking place in Kazakhstan.
Iran	95.1	0.6	No estimates are currently available, but oil and gas reservoirs suggest the presence of storage reservoirs.	Insufficient information regarding the location of sources and sinks.	There is currently no legal framework for CCS, but there are hydrocarbon laws.	2010 production figures: 4.3 million bbl/day (4th globally). 138,5 bcm of natural gas (ranked 3rd of the gas producing nations).	There are no demonstration activities taking place in Iran.

4.4 Developing countries without or with a small oil and gas industry

The countries included in this category are Botswana, Ghana, Mozambique and Vietnam. These countries are comparable as they possess little or no oil and gas resources, or have yet to develop the capacity to undertake exploration and development activities. A full analysis can be found in Table 4.4.

In Botswana and Ghana the deployment potential for CCS is quite low as neither country has significant stationary CO_2 point sources at present, although both are planning fossil-fuelled power production. Vietnam has slightly more CO_2 point sources at 25 $MtCO_2$ per year. Mozambique is developing coal fields, has a large cement plant and may have potential for high-purity CO_2 capture given its currently developing natural gas industry. Mozambique and Botswana have the additional circumstance that they are located close to some of the largest high-purity CO_2 sources in the world: the coal-to-liquid facilities in South Africa. The development of a bio-ethanol industry in Mozambique may lead to CO_2 sources from biofuel conversion plants.

Not much is known regarding the geological storage potential in any of the countries, as the oil and gas sectors in these countries is underdeveloped. Botswana could have significant potential for enhanced coal bed methane (ECBM) recovery. ECBM can also be configured to indefinitely storing the CO_2 used during the process. It is also assumed that the presence of gas fields in Vietnam and Mozambique means that some of these countries have CO_2 storage potential. Ghana is currently developing an oil operation offshore, indicating that potential may be present there. None of these estimates have any certainty until a specific geological storage investigation is conducted.

Mozambique and Vietnam have relatively small natural gas extraction activities, and only Vietnam produces oil. None of the countries in this group have legal frameworks for CCS. No CCS demonstration projects are active or planned in these countries. Some attempts early on have been made though: Vietnam has previously expressed interest to undertake a CCS project under the UNFCCC CDM, although this was well before the modalities and procedures were agreed. Botswana's coal exploration has been accompanied by suggestions to make new coal-fired power plants CCS-ready. Mozambique has expressed some interest in CCS at a workshop conducted in 2010.

Table 4.4 Deployment potential of developing countries without or with a small oil and gas industry

Countries	Discussion of techno-economic parameters						
	Stationary CO_2 sources ($MtCO_2$/yr	High-purity CO_2 sources ($MtCO_2$/yr)	Potential geological storage capacity	Distance between sources and sinks	Capacity to regulate CCS	Oil and gas industry experience	Involvement in CCS demonstration
Botswana	3.1	No, but CTL plant in South Africa at less than 500 km.	No estimates are available, however Botswana has significant potential to store CO_2 through the process of coal-bed methane recovery.	The planned coal-fired power plant near Gaborone is close to the ECBM potential.	There is currently no legal framework for CCS. There are concerns about potable water pollution.	Botswana produces no oil or gas.	Botswana is exploring "CCS-ready" coal-fired power. Otherwise, there are no demonstration activities taking place in Botswana.
Ghana	0.4	No	No estimates are available.	Insufficient information regarding the location of sources and sinks. Ghana's oil exploration is offshore.	There is currently no legal framework for CCS.	2010 production figures: 9,000 bbl/day (the 88th largest oil producing nation). Ghana currently produces no natural gas.	There are no demonstration activities planned or taking place in Ghana.
Mozambique	0.8	No, but CTL plant in South Africa at less than 500 km. In future, potentially biomass conversion.	No estimates are available. However there may be opportunities to store CO_2 in offshore gas fields once they become expended.	Insufficient information regarding the location of sources and sinks. Mozambique's gas fields are onshore, but remote from its coal developments.	There is currently no legal framework for CCS.	2010 production figures: 3,6 bcm total of natural gas (ranked 50th of the gas producing nations). Mozambique currently produces no oil.	There are no demonstration activities planned or taking place in Mozambique.
Vietnam	24.5	No	No estimates are currently available. However there may be opportunities to store CO_2 in offshore oil and gas fields once they become expended.	Insufficient information regarding the location of sources and sinks.	There is currently no legal framework for CCS	2010 production figures: 343,000 bbl/day of crude oil (35th globally). 9.4 bcm total of natural gas (ranked 41st of the gas producing nations)	There are no demonstration activities taking place in Vietnam. In 2005 a project proposal for a CCS project under the CDM was submitted to the UNFCCC. The project involved capturing CO_2 from a power plant and using it for EOR[19]. The project was rejected based on desk review, and the absence of CDM modalities and procedures for CCS.

[19] NM0167 CDM-PDD: The White Tiger Oil Field Carbon Capture and Storage (CCS) project in Vietnam.

4.5 Summary

The analysis above highlights the large technical potential in the fast industrialising economies of China, India, South Africa and South Korea. However initial estimates indicate that the available storage potential in South Africa and South Korea may be insufficient, or unfavourably located to economically store large amounts of CO_2. Of the fast industrialising economies, China, South Africa and South Korea have announced plans for CCS demonstration projects to be built before 2020, however there has been no plants constructed to date. Affluent and industrialised countries have significant technical potential for CCS and although publicly available information is not available, the storage capacity in these countries (United Arab Emirates, Saudi Arabia, Kuwait, Qatar, Malaysia and Russia) is likely to be large given the number of oil and gas fields present. The potential to combine CO_2 storage with enhanced oil recovery in these countries is also considerable, however with the exception of the United Arab Emirates, none of the countries in this category have planned demonstration activities.

In the category of countries with an established oil and gas industry, Kazakhstan and Indonesia have the potential to capture CO_2 from high-purity streams, due to the large reserves of natural gas in these countries. Brazil has a strong reliance on the use of bioethanol as a transportation fuel, and the fermentation process of the sugarcane used results in a very pure stream of CO_2 which could be easily captured. The high-purity technical potential from bioethanol production is approximately 70 $MtCO_2$ per year. For the countries with or without an oil or gas industry (Botswana, Ghana, Mozambique and Vietnam), the technical potential for CCS is very low from both conventional and high-purity sources. Furthermore, very little quantitative information is available on the storage capacity in these countries. In all of the countries in this analysis, no regulatory frameworks are in place for CCS, with the partial exception of South Africa which is in the process of regulatory review and development for the purposes of CCS.

5 Political potential

The previous analysis shows a varying picture for CCS in developing countries. Some countries both have the means and the potential to do CCS. Some have very low potential but still show interest. Such interest may come as a surprise to many, but may be explained by political drivers.

This section aims to discuss such drivers for the same developing countries as discussed in section 4. A distinction is made between short-term strategic interests, defined as providing immediate benefits or benefits occurring in the next five to ten years, and long-term drivers, that may pay off on longer time scales of beyond ten years, or may never pay off at all.

The data sources for the results in this section are difficult to quantify or even to reference. As political interests are rarely explicitly stated, they are derived from general statements, personal communications by the authors, and based on general characteristics of the countries, such as those reviewed in section 4. For example, the information on EOR is partly based on whether there is an oil/gas industry in a country (see section 4). Whether there is interest in CDM is partly based on the UNEP Risoe Centre CDM pipeline[20]. Where the authors lacked information, no political interest was assumed.

5.1 Short-term strategic interests

The short-term strategic interests of the 24 countries considered are summarised in Table 5.1. CO_2-EOR could be a driver for CCS in almost all countries, but the scale at which this will feature differs greatly. Oil-exporting countries, in particular those with oil fields that have been in operation for a long time and may in the future start experiencing decline, are likely to be interested in CO_2-EOR. These countries include the Gulf States, Russia, Nigeria, Malaysia and Iran. Although perhaps not as dominant a driver as in economies relying predominantly on oil exports, countries with a smaller oil industry, EOR can raise interest for exploring capture of CO_2, and thinking of long-term storage as well. These countries could include Mexico, Argentina, Vietnam, India and Indonesia.

This does not mean, however, that CO_2-EOR is easy to do. It requires considerable skills as well as planning between sources and reservoirs, as demand for CO_2 in a reservoir is not stable over time; it requires much CO_2 at the start and lower quantities later on (UNIDO, 2011). In addition, the sources are not necessarily located conveniently compared to the reservoirs; only for some sources, such as gas processing, there is a geographical correlation. In addition, operators of lucrative oil fields may think twice before they start experimenting with a new and costly technology, even when possible revenues may be considerable.

The countries with an interest in technology export on the short and longer term are a small number: only China, South Africa, the UAE, South Korea and Brazil were found to invest in technology industries that could play a role in the world market for engineering, manufacturing capture equipment, pipeline construction or geological storage equipment. Investments in technology often coincide with investments in knowledge and skills.

[20] www.cdmpipeline.org

Table 5.1 Short-term strategic interests of non-Annex I countries. Cells are left blank when no interests could be identified (possibly due to lack of information)

Countries	Indicative review of short-term strategic interests			
	CO_2-EOR potential	Technology export	CCS in the CDM	Climate-friendly image
China	Potential for CO_2-EOR but it is unlikely to be a major economic driver	Strengthening its position in equipment manufacturing	Much success in CDM, but unlikely that new UNFCCC developments allow for more	Global reputation as threat to climate, domestic taking measures.
India	Small potential		Much success in CDM, but unclear whether new UNFCCC developments allow for more	Growing reputation as contributor to climate change, but also seen as acting on renewable energy
South Africa		Investing in R&D around CCS	Several projects ongoing in the CDM.	South Africa has per capita emissions higher than some developed countries
South Korea		Strengthening its position in equipment manufacturing	South Korea is unlikely to continue applying for CDM	Strategy for green growth may or may not include CCS
Argentina	Potential for EOR is small but probably present		Some success in the CDM (landfill projects)	
UAE	EOR could be a strong driver for CCS	Investing in its knowledge position in low-carbon technology, including CCS	No CDM experience.	Working on more low-carbon image
Saudi Arabia	EOR could be a strong driver for CCS		No CDM experience.	
Russia	EOR could be a strong driver for CCS		Not eligible	
Kuwait	EOR could be a strong driver for CCS		No CDM experience, but has shown interest.	Working on more low-carbon image
Qatar	EOR could be a strong driver for CCS		No CDM experience, but has shown interest.	Working on more low-carbon image
Malaysia	EOR could be a strong driver for CCS		Experience with CDM, has shown interest	
Nigeria	EOR could be a strong driver for CCS		Limited CDM experience, may have interest.	
Algeria	Possible but unclear if EOR plays a role		No CDM experience, but has shown interest.	
Egypt	Possible but unclear if EOR plays a role		Limited CDM experience, may have interest.	
Mexico	EOR could be a driver for CCS		Extensive CDM experience	As an OECD country, some urge to act on domestic emissions
Indonesia	EOR could be a driver for CCS		Experience with CDM	Reputation of deforestation

Brazil	EOR could be a strong driver for CCS	Investing in its knowledge position in low-carbon technology, including CCS	Much success with the CDM, likely interest in more, but unclear whether the UNFCCC will allow	Reputation of deforestation as well as renewable energy
Angola	EOR could be a driver for CCS		No experience with CDM	
Kazakhstan	EOR could be a driver for CCS			
Iran	EOR could be a strong driver for CCS			
Botswana			Limited experience with CDM	
Ghana	Limited potential, only on the long term		Limited experience with CDM	
Mozambique	Limited potential, only on the long term		Limited experience with CDM	
Vietnam	Limited potential		Experience with CDM, has shown interest	

On the CDM, various countries discussed here have benefited greatly from the CDM in the past, in particular China, India and Brazil. However, those are not the countries that have been pushing to get CCS approved under the CDM over the years 2006-2011, resulting in the acceptance of CCS in the CDM in December 2011. The countries most actively favouring CCS have in particular been Saudi Arabia, Qatar, Kuwait and the UAE. In addition, Vietnam and Malaysia were the countries from which the first submissions of CCS in the CDM methodologies came, and in that region, also Indonesia has shown interest. Lastly, Algeria is currently the only developing country with a full-scale CCS project. For this project, a methodology was also developed but at the moment the CCS modalities and procedures had not yet been finalised.

Countries with a reputation of being high carbon emitters due to their coal use and who may feel the obligation to reduce emissions, potentially through CCS, include China, India and South Africa. Due to its coal use, South Africa has per capita carbon emissions that are currently higher than those of some developed countries. The oil-exporting countries in the Gulf region have a reputation of stalling climate negotiations going forward, and Indonesia and Brazil are known as countries where deforestation is rampant, and so are their emissions. Mexico and South Korea are both OECD members as well as non-Annex I countries under the UNFCCC. This sets them apart; the OECD does not urge its members to undertake mitigation actions but being in a club of otherwise developed countries may have some consequences for domestic politics. In particular, South Korea, with a per-capita GDP and greenhouse gas emission higher than many non-Annex I countries, has explicitly aimed for green growth in its national policies.

5.2 Long-term strategic drivers

Four potential long-term strategic drivers of CCS in countries with no current obligations to reduce emissions are reviewed in Table 5.2. When there is an indication that the country could consider the long-term strategic driver as a reason to look or invest into CCS, the box is ticked.

Table 5.2 Long-term strategic drivers of non-Annex I countries and Russia. A tick means that (according to limited information) the driver has played a role in domestic affairs and applies. If there is no tick this does not mean the driver does not apply; it only means that no evidence was found

Countries	Indicative review of long-term strategic drivers			
	Securing export of fossil fuels	Hedging against future climate obligations	Political leadership and international credibility	Climate change vulnerability
China		√	√	√
India	√	√	√	√
South Africa	√	√	√	
South Korea		√		
Argentina				
UAE	√	√	√	
Saudi Arabia	√	√	√	
Russia	√	√		
Kuwait	√	√		
Qatar	√	√		
Malaysia		√		
Nigeria	√			√
Algeria				
Egypt				
Mexico		√	√	√
Indonesia		√		√
Brazil	√	√	√	
Angola	√			
Kazakhstan	√	√		
Iran	√			
Botswana	√	√		√
Ghana		√	√	√
Mozambique				√
Vietnam				

Securing export of fossil fuels is an issue for developed countries as much as for developing countries. Countries like Australia and Norway are large fossil fuel exports (coal and oil/gas respectively). If they invest in CCS, and strong mitigation policies become a reality in many parts of the world, they can continue exporting fossil fuels. A similar potential driver can be identified for the fossil fuel exporters in this group of developing countries and emerging economies. The greater the rents from the exports, the greater the need to secure exports in the longer term. So large oil-exporters that rely strongly on these exports for their economic performance, might be most susceptible for this argument.

Hedging against future climate commitments may be another reason to invest in CCS. As an end-of-pipe technology, fossil fuel-based installations could be retrofitted with the technology, and it can allow for continued use of (domestic) fossil fuels. Investing in CCS, for instance through building up a knowledge and skills base through education, R&D and technology demonstration, can therefore be a strategy. It is thought that especially emerging economies and countries with high per capita carbon emissions may be taking this possibility into account. However, CCS was also discussed in countries that currently have low emissions but that have prospects of fast-growing emissions. Such countries include Botswana and Ghana.

Regional leaders and active countries in the climate negotiations may be interested in exemplifying CCS in their countries. Being among the first to implement a high-tech, complex mitigation option can be reputation-enhancing and increases the international credibility and potentially even the investment climate. Countries where this may play a role include South Africa, Ghana, Brazil and Mexico.

The last long-term driver identified is the country's own vulnerability to climate change. This may urge a country to lead by example, similar to low-lying island states committing to ambitious greenhouse gas reduction plans. Countries where vulnerability to climate change plays a role in national debates include most African countries, India, China, Indonesia and Brazil. Compared to other political drivers, it is less likely that vulnerability to climate change can by itself be a driver for CCS, but combined with other factors, it can contribute.

6 Discussion and conclusion

This section aims to review the results from the previous sections into a broad assessment on which countries are most susceptible to CCS, not just because of the enabling conditions (Section 4) but also for political drivers for CCS as discussed in Section 5. Countries that have some of both could be categorised as countries that are highly likely to use CCS at some point in time. It needs to be said in general that this report does not aim to assess the general CCS prospects or make predictions, it merely assesses indicators and drivers on the country level and what this could mean for international cooperation.

The discussion in this section should be read with the following in mind. The assessment done is not only highly data-constrained and reflects the researchers' incomplete perceptions of the situation in a country. It is not a sufficient basis for a multi-criteria analysis or ranking of countries according to likelihood of CCS being pursued. Hence, summarising tables that suggest a level of exactness will not be found in this section. There are too few demonstrations of CCS in developing countries to validate the parameters used in this paper. The analysis reported here should be seen as a high-level, general assessment of what could constitute enabling conditions and political will around CCS.

For many countries, political drivers confirm enabling conditions. Larger countries that are growing fast, fuelled by coal, have growing numbers of stationary CO_2 sources and at the same time are often the focus of attention in the climate negotiations as well as leaders in their respective regions. They generally have stronger institutions for regulatory frameworks and higher human capacity, including in fossil fuel industries, leading to a better starting point for CCS projects. Almost all countries having an interest in technology export of CCS-related equipment and knowledge are fast-industrialising countries. Countries dependent on oil exports are more likely to have geological storage reservoirs as well as EOR potential, and have an interest in securing long-term exports.

But in addition, the picture is more diverse than one would initially estimate. CCS activities or interests are not restricted to countries with immediate EOR potential or to high-coal using, fast industrialising countries under threat of climate obligations. There are several countries towards which fewer support efforts are directed, but that still have a keen interest. Algeria, for instance, hosts a CCS project but could benefit from capacity development – the In Salah project has proven its potential for very cost-effective CCS, and more of such operations could be identified. Botswana has shown an interest in CCS given its high vulnerability to climate change and its significant coal reserves, potentially combined with ECBM or underground coal gasification. There are several countries which could be seriously looking into biomass and CCS, in particular Mozambique, Indonesia and Brazil. Brazil has many drivers in favour of CCS but is often overlooked as it does not rely on coal for its electricity supply.

This assessment shows that CCS in developing countries may be more likely to happen than one might expect in the absence of a direct price incentive. Now that a small price incentive is in place since CCS is eligible under the CDM, other political drivers may interest countries into CCS. This does not mean, however, that CCS will happen easily. Even in developed countries with carbon prices in place and with more political drivers to deploy CCS, such as the United Kingdom and the Netherlands, implementing CCS is challenging.

The question is how the international community can help catalysing CCS for countries that have a genuine interest. It is relevant to look not only at the short term, but also at the longer term. CCS deployment takes time, as for instance the South African roadmap on CCS demonstrates. What do these results mean for capacity building programmes in developing countries? Current programmes, such as that of the Global CCS Institute and the CSLF, tend to focus on the first category of countries: fast-industrialising, larger economies that rely on coal. However, as these countries have their own domestic drivers to want CCS or not, and growing own funding means to enable CCS, international organisations may make less of a difference compared to countries that have to rely more on donor funding. The World Bank (funded by Norway) has a more diverse portfolio and responds to country requests, including to requests from smaller countries. It could be argued that capacity development funding should be channelled away from fast-industrialising countries and affluent oil-exporters, and towards facilitating pilots and demonstrations in other countries.

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Annex I: Detailed information on China, India and South Africa

<table>
<tr><td>China</td><td colspan="4"></td><td></td></tr>
<tr><td>Parameter</td><td colspan="4">Description</td><td>Value</td></tr>
<tr><td rowspan="5">Stationary CO_2 point sources</td><td colspan="4">$MtCO_2$/yr</td><td>$MtCO_2$/yr</td></tr>
<tr><td>Ammonia</td><td>56.3</td><td>Biomass</td><td>-</td><td rowspan="4">2968.6</td></tr>
<tr><td>Cement</td><td>21.6</td><td>Refineries</td><td>40.5</td></tr>
<tr><td>Ethylene</td><td>17.9</td><td>Power</td><td>2772.5</td></tr>
<tr><td>Iron and steel</td><td>59.8</td><td></td><td></td></tr>
<tr><td colspan="6"></td></tr>
<tr><td rowspan="2">High-purity stationary CO_2 point sources</td><td>Natural gas</td><td>3,3</td><td>Ethylene oxide</td><td></td><td rowspan="2">3.3</td></tr>
<tr><td>Hydrogen</td><td>-</td><td>CTL/GTL</td><td>-</td></tr>
<tr><td>Potential geological storage capacity</td><td colspan="4">The IEA considers a viable capacity of 202 Gt and a maximum theoretical capacity 2020 Gt CO_2 (IEA/OECD 2009). The storage potential in oil and gas deposits is estimated at 10 Gt.</td><td>High</td></tr>
<tr><td>Capacity to regulate</td><td colspan="4">China has no specific CCS regulation, however there is a range of existing regulatory provisions on health and safety, land-use zoning, Environmental Impact Assessment, hydrocarbon pipeline regulation that, given modifications, will allow the Chinese government to regulate CCS. A non-exhaustive list of the legal acts relevant for CCS and the responsible ministries is provided below (World Resources Institute, 2010):

National Development and Reform Commission (NRDC)
- Approving Domestic and Foreign Investment Projects

Ministry of Environmental Protection (MEP)
- Water Pollution Control
- Environmental Protection Law
- Environmental Impact Assessment
- Law and Standards on the Prevention and Control of Air Pollution
- Solid Waste Pollution Law
- Standard for Underground Storage of Hazardous Waste
- Marine Environmental Protection

Ministry and Land and Resources (MLR)
- Property Rights Law
- Land Administration & Mineral Resources Law

State Administration of Work Safety (SAWS)
- Protection of Oil and Natural Gas Pipelines
- Provisions for Safe Supervision and Management of Petroleum and Natural Gas Pipelines
Ministry of Water Resources (MWR)
- Water Law</td><td>High</td></tr>
</table>

	There is no regulation to accommodate for long-term liability of geologically stored CO_2.	
Oil and gas industry experience	In 2009 China produced 3,991,000 bbl/day of crude oil, the 5th largest oil producer globally. In the same year China produced 94 bcm of natural gas, the 6th largest natural gas producer globally. China's National Oil Companies (NOCs) are some of the largest in the world.	High
Involvement in CCS demonstration activities	There are a number of planned CCS projects in China. The GreenGen Corporations' integrated gasification combined cycle (IGCC) power plant is currently in the first stage of construction, with a total planned capacity of 1050MW. In the third and final stage of development (2015-2020), a 400MW IGCC unit is expected to have full scale CO_2 capture. There are also a number of CCS related research and development activities that have been funded by the EU, the UK, Australia and Japan, which will primarily result in feasibility studies and demonstration plants. An Asian Development Bank (ADB) financed 250 MW coal-based IGCC power plant, the first such plant, is under construction in the People's Republic of China (PRC). A pilot CCS project with a capacity of about 100,000 t/year CO_2 capture and storage from this power plant is being assessed by ADB for financing in 2011. According to the IEA/OECD (2009), 8 large scale (1 $MtCO_2$/year) CCS projects are planned to be completed in China by 2020.	High

<table>
<tr><td>India</td><td colspan="4"></td><td></td></tr>
<tr><td>Parameter</td><td colspan="4">Description</td><td>Value</td></tr>
<tr><td rowspan="5">Stationary CO_2 point sources</td><td colspan="4">$MtCO_2/yr$</td><td>$MtCO_2/yr$</td></tr>
<tr><td>Ammonia</td><td>18.8</td><td>Biomass</td><td>-</td><td rowspan="4">1565.8</td></tr>
<tr><td>Cement</td><td>57.9</td><td>Refineries</td><td>44.6</td></tr>
<tr><td>Ethylene</td><td>10.0</td><td>Power</td><td>1410.5</td></tr>
<tr><td>Iron and steel</td><td>24.0</td><td></td><td></td></tr>
<tr><td colspan="6"></td></tr>
<tr><td rowspan="2">High-purity stationary CO_2 point sources</td><td>Natural gas</td><td>0.2</td><td>Ethylene oxide</td><td>0.1</td><td rowspan="2">0.7</td></tr>
<tr><td>Hydrogen</td><td>0.4</td><td>CTL/GTL</td><td>-</td></tr>
<tr><td>Potential geological storage capacity</td><td colspan="4"></td><td></td></tr>
<tr><td>Capacity to regulate</td><td colspan="4">There is no bespoken regulation for CCS in India. However, as in most countries, there are a number of civil, health and safety and environmental regulations that may be applicable. A number of legal provisions which could be modified to regulate capture, transport and storage are outlined (Baker & McKenzie, 2009):

Capture
- The Environment (Protection) Act 1986
- The Air (Prevention and Control of Pollution) Act 1981
- The Water (Prevention and Control of Pollution) Act 1974
- The Hazardous Waste (Management, Handling and Transboundary Movement) Rules 1989

Concentrated forms of CO_2 would be classified as an environmental pollutant and a hazardous substance to be regulated under the Environment Protection Act 1986 and the Hazardous Waste Rules 1989 (Baker & McKenzie, 2009).

Transport
- The Petroleum and Minerals Pipelines (Acquisition of Right in User of Land) Act 1962 (onshore pipelines)
- The Petroleum & Natural Gas (Safety in Offshore Operations) Rules, 2008 regulates the safety in offshore oil and gas exploration, exploitation, production/drilling and matters connected therewith (offshore pipelines)
- Jurisdiction for the laying of pipelines on the sea bed of the continental shelf or exclusive economic zones have been prescribed under the Territorial Waters, Continental Shelf, Exclusive Economic Zone and Other Maritime Zones Act 1976 (offshore pipelines)</td><td>High</td></tr>
</table>

	Storage - Offshore Areas Minerals (Development and Regulation) Act 2002 (Exploration) - Production rights must be agreed with a production lease with the government There is no regulation to accommodate for long-term liability of geologically stored CO_2.	
Oil and gas industry experience	In 2010, India's oil production was 878,700 bbl/day, and is ranked as the 23rd largest oil producing nation. In the same year India produced 53 bcm of natural gas, ranked as the 21st largest gas producing nation.	High
Involvement in CCS demonstration activities	India signed an agreement with the United States in April 2006 to partner in the FutureGen–275 MW zero emission power plant. FutureGen is a public-private partnership to build a "first-of-its-kind coal fuelled, near-zero emissions power plant". The original plans for this project have been cancelled. India is an institutional partner in the Big Sky Carbon Sequestration Partnership (BSCSP). BSCSP is one of the United State's National Energy Technology Laboratory's seven regional CO_2 sequestration partnerships. The partnerships engage key stakeholders in creating a nationwide network that will help determine the best approaches for capturing and permanently storing GHGs that contribute to climate change. According to the Global CCS Institute (2010), there are no large scale integrated projects being planned in India. The Indian government is a member of the Carbon Sequestration Leadership forum and has hosted a number of capacity building workshops.	Low

<table>
<tr><th>South Africa</th><th colspan="4"></th><th></th></tr>
<tr><th>Parameter</th><th colspan="4">Description</th><th>Value</th></tr>
<tr><td rowspan="5">Stationary CO_2 point sources</td><td colspan="4">$MtCO_2$/yr</td><td>$MtCO_2$/yr</td></tr>
<tr><td>Ammonia</td><td>0.53</td><td>Biomass</td><td>-</td><td rowspan="4">231.2</td></tr>
<tr><td>Cement</td><td>9.05</td><td>Refineries</td><td>5.5</td></tr>
<tr><td>Ethylene</td><td>1.02</td><td>Power</td><td>208.55</td></tr>
<tr><td>Iron and steel</td><td>6.50</td><td></td><td></td></tr>
<tr><td colspan="6"></td></tr>
<tr><td rowspan="2">High-purity stationary CO_2 point sources</td><td>Natural gas</td><td>-</td><td>Ethylene oxide</td><td>-</td><td rowspan="2">24</td></tr>
<tr><td>Hydrogen</td><td>-</td><td>CTL/GTL</td><td>24.00</td></tr>
<tr><td>Potential geological storage capacity</td><td colspan="4">According to Cloete (2010), South Africa has an estimated theoretical storage potential of 150 Gt, however 98% of this storage potential is located offshore. Approximately 2.5 Gt of the theoretical storage capacity is located onshore. Offshore storage may increase the cost of CCS in South Africa.</td><td>Moderate</td></tr>
<tr><td>Capacity to regulate</td><td colspan="4">In April 2011, the South African Department of Energy established an Inter-departmental Task Team to develop a CCS regulatory framework in South Africa. South Africa has also received $1.2 million dollars from the World Bank to advance CCS in the country

Recently the possibility for regulating CCS in South Africa using existing legislation has been investigated (Kulichenko & Ereira; IEA, 2011). These studies highlighted a number of existing regulations of changes that could be modified to legalise CCS activities:

General
- National Environmental Management: Waste Management Act 2008 (CO_2 waste definition).
- South Africa National Standard (SANS) 10228 (2006). (CO_2 defined as ‘Class 2 dangerous good’)
- National Environmental Management Act regulates listed activities which must undertake an EIA prior to construction. CCS is not a listed activity.

Capture
- Air Quality Act 39 2004
- National Water Act 36 1998

Transport
- Gas Act 48 2001 (Transportation of substances including wastes)
- National Environmental Management: Integrated Coastal Management 2008. (Offshore pipelines)

Storage
- The Mineral and Petroleum Resource Development Act 28 of 2002 (MPRDA). (Defining property rights and ownership of stored CO_2)

Furthermore there is also regional legislation, relating to the South African Power Pool (SAPP):</td><td>High</td></tr>
</table>

	- Environmental and Social Impact Assessment Guidelines For Transmission infrastructure for the SAPP Region - Guidelines for Environmental Impact Assessment (EIA) for Thermal Power Plants South Africa also placed a carbon capture readiness requirement as part of the EIA approval process for the 5400MW coal-fired Kusile power station currently under construction. The power station is therefore reported to have the technical potential to be easily retrofitted with CCS in the future. There is no regulation to accommodate for long-term liability of geologically stored CO_2.	
Oil and gas industry experience	In 2010 South Africa's oil production was 191,100 bbl/day, ranked 42nd globally. In the same year, South Africa produced 1.9 bcm, ranked 52nd of the gas producing nations in 2010.	Moderate
Involvement in CCS demonstration activities	In 2010, a geological storage atlas for South Africa was completed, and a number of potential storage sites for a planned test injection in 2016 have been identified and are undergoing additional suitability studies. Furthermore, South Africa is investing in CCS through the establishment of the South African Centre for Carbon Capture and Storage, an ambitious roadmap with a demonstration project planned for 2020, and numerous capacity building/awareness raising workshops throughout the country. South Africa also benefits from financial support from the World Bank and the Global CCS Institute for capacity building activities.	