Potential impacts of CCS on the CDM

CATO-2 Deliverable WP 2.3-D01 and D02

Prepared by: Stefan Bakker, Tom Mikunda, Rodrigo Rivera Tinoco (ECN)

Reviewed by: Heleen de Coninck, Jos Sijm, Joris Koorneef, Markus Hagemann

Approved by: J. Brouwer (CATO-2 Director)

1 Executive Summary (restricted)

CO_2 capture and storage can ensure that stringent climate change mitigation targets are achieved more cost-effectively. However, in order to ensure a substantial role for CCS, deployment of CCS is required on a significant global scale by 2020. Currently, the CDM is the only international instrument that could provide a financial incentive for CCS in developing countries. In December 2010 it was decided that CCS could in principle be eligible under the CDM, provided a number of issues are resolved, including non-permanence, liability, monitoring and potential perverse outcomes.

The latter issue relates to the concern that that CCS projects could flood the CDM market, thereby crowding out other technologies that could be considered more sustainable. This report, therefore, aims to quantify the possible impact of CCS on the CDM market, in order to assess the relevance of the CDM market objection. However, the analysis in the report is also valid for the role of CCS in other types of international support mechanisms.

The first result of this study is a marginal abatement cost curve (MAC) for CCS in developing countries for 2020. Based on existing MAC studies, the IEA CCS Roadmap and an overview of ongoing and planned CCS activities, we compiled three scenarios for CCS in the power, industry and upstream sector, as shown below. The major part of the potential below \$30/tCO_2eq (70 – 100 MtCO_2/yr) is in the natural gas processing sector. The most important region is the Middle East and North Africa, followed by Asia-Pacific. These MACs are relevant for gaining insight in how CCS opportunities in developing countries can be supported in 2020, under the CDM, other carbon credit mechanisms, or non-market instruments.

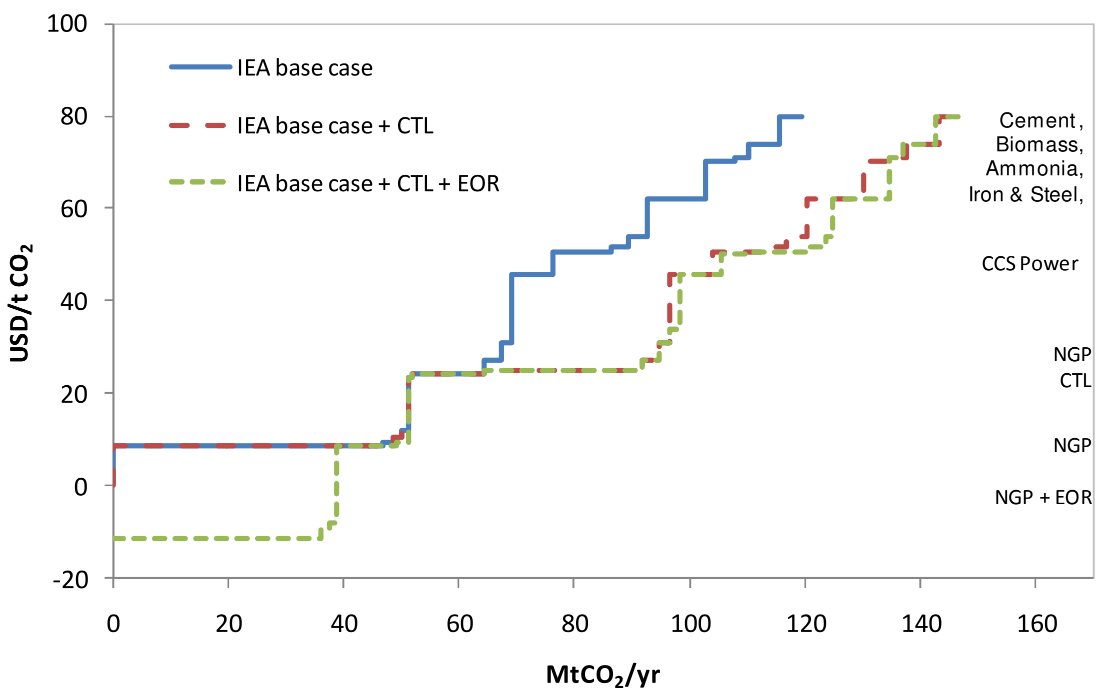


Figure ES.1. CCS MAC for developing countries in 2020.

Using the MACs for the CDM market, we estimate the economic potential for CCS projects to be 4-19% of the CDM credit supply in 2020. The uncertainty in these figures is, in addition to the uncertainty in the economic potential for CCS, predominantly a result of the uncertainty with regard to the global carbon market after 2012, including the role of the CDM. The lower figure corresponds to the scenario where the CDM covers all the demand for international carbon offsets, and the higher figure refers to the possibility that only the European Union continues using the CDM after 2012.

The potential impact inclusion of CCS in the CDM may have is assessed by using several possible CER supply and demand scenarios, as well as scenarios related to market price responsiveness and the role of CDM in the post-2012 carbon market. The impact is estimated to be between $ 0 and $ 4 per tonne of CO_2-eq, with three out of four scenarios indicating the lower part of this range (see Table ES.1).

Table ES.1 *Potential impacts of CCS on the CDM market*

Market responsiveness	CCS impact	Carbon market 2020	
		Fragmented	CDM only
Low	% of CER supply	14-19%	4-5%
	$/t$CO_2$-eq	0	0
High	% of CER supply	14-19%	4-5%
	$/t$CO_2$-eq	-	0-4

Distribution List

(this section shows the initial distribution list)

External	copies	Internal	Copies

Document Change Record

(this section shows the historical versions, with a short description of the updates)

Version	Nr of pages	Short description of change	Pages
2010.10.28	26	Final draft	
2011.11.24	33	Improved flow of text; better explanation of methodology in Chapter 5 and 6	
See header	See header	General update	

Table of Contents

2 Applicable/Reference documents and Abbreviations

2.1 Applicable Documents

(Applicable Documents, including their version, are documents that are the "legal" basis to the work performed)

	Title	Doc nr	Version date
AD-01	Beschikking (Subsidieverlening CATO-2 programma verplichtingnummer 1-6843	ET/ED/9078040	2009.07.09
AD-02	Consortium Agreement	CATO-2-CA	2009.09.07
AD-03	Program Plan	CATO2-WP0.A-D.03	2009.09.29

2.2 Reference Documents

(Reference Documents are referred to in the document)

	Title	Doc nr	Version
AD-01a	Beschikking (Subsidieverlening CATO-2 programma verplichtingnummer 1-6843	ET/ED/9078040	2009.07.09
AD-01b	Wijzigingsaanvraag op subsidieverlening CATO-2 programma verplichtingennr. 1-6843	CCS/10066253	2010.05.11
AD-01c	Aanvraag uitstel CATO-2a verplichtingennr. 1-6843	ETM/10128722	2010.09.02
AD-01d	Toezegging CATO-2b	FES10036GXDU	2010.08.05
AD-01f	Besluit wijziging project CATO2b	FES1003AQ1FU	2010.09.21
AD-02a	Consortium Agreement	CATO-2-CA	2009.09.07
AD-02b	CATO-2 Consortium Agreement	CATO-2-CA	2010.09.09
AD-03a	Program Plan 2009	CATO2-WP0.A-D.03	2009.09.17
AD-03b	Program Plan 2010	CATO2-WP0.A-D.03	2010.09.30

2.3 Abbreviations

(this refers to abbreviations used in this document)

AAU	Assigned Amount Unit
CDM	Clean Development Mechanism
CER	Certified Emission Reduction
CTL	Coal-to-liquids
COP	Conference of the Parties to the UNFCCC
EB	Executive Board
ERU	Emission Reduction Unit
EUA	European Union Allowance
GHG	Greenhouse gas

HFC	Hydrofluorocarbons
IEA	International Energy Agency
IGCC	Integrated Gasification Combined Cycle
IRR	Internal rate of return
KM	Kyoto Mechanism
NAMA	Nationally appropriate mitigation action
NGP	Natural gas processing
OECD	Organisation for Economic Cooperation and Development
SBSTA	Subsidiary Body for Scientific and Technological Advice
UNFCCC	United Nations Framework Convention on Climate Change

3 Introduction

The Clean Development Mechanism (CDM) is a policy instrument that was developed in the framework of the Kyoto Protocol under the United National Climate Change Convention (UNFCCC) in 1997. The overall objective of the CDM is to facilitate a cost effective reduction of greenhouse gas emissions, while encouraging a flow of capital to developing countries to support sustainable development. The CDM does not reduce emissions globally, however it allows industrialised (Annex I) countries to meet part of their emission reduction requirements through the procurement of certified emission reduction (CER) credits. CERs can only be generated via projects in developing countries (non-Annex I) that contribute to the reduction of greenhouse gas (GHG) emissions. Projects can be implemented by state or private actors from within the developing country or internationally, and the resulting CERs can be used by state or private actors in developed countries. As the CDM is a market mechanism, the price of a CER can fluctuate depending on supply and demand. Currently there are over 5000 CDM projects in the pipeline, expected to generate approximately 200 million CERs (equalling 0.2 $GtCO_2$-eq) in the period 2008-2012 (URC, 2010). Total annual greenhouse gas (GHG) emissions in developing countries in 2005 were approximately 25 $GtCO_2$-eq, which is about half the global total.

Given the growing portion of global GHG emissions attributed to developing countries, particularly emerging economies such as China, there is a strong rationale for the worldwide deployment of carbon capture and storage (CCS) technologies (G8, 2009). Efforts are being made to build capacity and disseminate knowledge about CCS to China (NZEC, 2008), parts of Asia (see Bachu, 2009) and several nations in Africa (see Bakker et al., 2007a; de Coninck et al., 2010). Currently the CDM is the only instrument that could provide an international financial incentive for investors to consider reducing CO_2 emissions through CCS in non-Annex I countries. However, the inclusion of CCS technologies within the portfolio of acceptable CDM projects has so far been rejected by the CDM Executive Board (CDM EB). The arguments in favour of and against the inclusion of CCS in the CDM are manifold, and include the early stage of the technology, possible risks related to seepage, continued reliance on fossil fuels, low sustainable development benefits, and the risk of flooding the carbon market (UNFCCC, 2008; de Coninck, 2008)[1]. However at COP16 in Cancún in December 2010 it was decided that CCS is in principle eligible under that CDM, provided certain conditions are met[2] (UNFCCC, 2010a) including those related to the concerns mentioned above.

This latter concern, i.e. the risk that CCS may unbalance the carbon market, stems from previous experiences with end-of-pipe GHG abatement technologies in the CDM. When the first CDM methodologies were approved in 2003, the bulk of the CERs were brought to the market by HFC-23 destruction activities. Such projects generated a large amount of credits for very low abatement costs, estimated to be as little as 0.5 $/$tCO_2$-eq (Schwank, 2004). Unsurprisingly, these cost effective technologies swamped the CDM project portfolio, depressing the CER price and effectively blocked investment in more expensive options such as renewable energy[3]. Since

[1] A full list of the possible implications of CCS as CDM projects can be found in Annex 11 of CDM EB meeting 50 (UNFCCC, 2009a).

[2] See Section 4.3 for a more detailed discussion of the COP16 decision.

[3] Options in renewable energy at that period were estimated to require a minimum CER price of 4 $/$tCO_2$-eq (Schwank, 2004).

then, the mitigation potential for HFC-23 destruction activities has been exhausted (Seres et al., 2009), while ongoing HFC projects have come under scrutiny (Point Carbon, 2010).

At its current level of development, cost estimates for implementing CCS in the power sector are above 40 $/tCO_2$ (Deutsche Bank, 2008), which when looked at from a rudimentary perspective would eliminate the business case for CCS as a CDM project. However, ‘early opportunities’ exist for CCS in natural gas processing (NGP), where CO_2 removal from field gas is a requirement to produce natural gas suitable for transport and use[4]. Such NGP CCS combinations are already operating successfully in projects in the North Sea (Sleipner and Snøhvit) and Algeria (In-Salah), implying lower technical and economic barriers compared to other sectors (Bakker et al., 2010). Calculated estimates suggest that CCS could be implemented in the NGP sector for under 20 €/tCO_2$ (Zakkour et al., 2008). Thus, hypothetically speaking, the inclusion of CCS projects in the CDM, initially NGP but perhaps eventually projects in other sectors, has the potential to influence the market.

The primary aim of this paper is to quantify the market potential of the inclusion of CCS in the CDM and the potential impacts this may have on the CDM market in 2020. This year is chosen as earlier CCS is not expected to be deployed on a significant scale[5]. Looking beyond this year the uncertainties related to the CDM market become too large to make any significant impact analysis. However, as the uncertainty on the future of the CDM beyond 2012 is also considerable, with possible competing carbon market instruments being considered by several countries and in the UNFCCC (Hagemann et al., 2010), we also adopt a broader approach focussing on the potential of CCS in developing countries in general.

The following research approach is adopted in this study. We make an assessment of the potential supply and costs of CCS projects in developing countries based on existing studies, CCS roadmaps, planned CCS activities and an inventory of emissions sources. As the year 2020 is rather close, particular attention will be given to ‘early opportunities’. Due to the importance of enhanced oil recovery (EOR) for short-term CCS deployment, we include an additional scenario that includes EOR. Due to lack of detailed data, we do not pay specific attention to matching of sources and sinks This could mean that in practice the abatement costs for specific CCS projects could be higher or lower, as we use average data for transport and storage.

When the supply curve for CCS in developing countries is compiled we look at possible CER demand scenarios for the CDM and other possible carbon market mechanism. As the CDM market is still in an early stage, we will look at the market dynamics to give a realistic picture of the possible impacts of CCS projects. The market impacts will be quantified for the potential supply of CERs or other credits from CCS projects and the potential impact this may have on the carbon price in 2020.

Chapter 4 gives an overview of the current activities with respect to CCS in developing countries, as well as a state-of-the-art assessment of the CDM market. It also discusses the policy arena for CCS in the CDM, and a post-2012 outlook for the carbon market. Chapter 5 analyses the potential for CCS projects in the developing countries, resulting in a CCS abatement cost curve. Chapter 6 provides an assessment of the potential carbon market impacts, after which the conclusions are presented.

[4] Other early opportunities may be e.g. in ammonia, ethanol and ethylene production, but the costs are thought to be higher than in natural gas processing.
[5] This does not mean that the full potential is limited to those projects built in 2020: all CCS projects completed before 2020 can generate credits in 2020 and are therefore also included in the potential.

4 Opportunities for CCS in the carbon market

This chapter provides a brief general assessment of the opportunities for different types of CCS projects in the CDM. It includes an overview of the current state of affairs regarding CCS in developing countries and the CDM market, and the discussions on inclusion of CCS in the CDM.

4.1 Current CCS activities in developing countries

In parallel with the mounting attention CCS has received as a potentially cost effective mitigation solution to climate change, the numbers of planned and active projects have increased steadily over recent years. Recently, WorleyParsons (2009) identified 275 CCS projects varying both in scale, technology and development status, using the database of CCS projects compiled by the Global Carbon Capture and Storage Institute (GCCSI). 101 of these projects are active or planned at a commercial scale, with nine of these projects situated in non-Annex I countries. Activities in China accommodate for five of these developments.

To date, Algeria has the world's largest onshore CO_2 storage project. The project, which is a joint venture company called In Salah Gas between Sontrach, BP and Statoil, started in 2004 and can store up to 1.2 MtCO_2 per year in a deep saline formation. The carbon dioxide is produced during the removal of CO_2 from the field gas, whereby the CO_2 content must be reduced from approximately 5-10% to 0.3% to reach the natural gas feedstock grade. There is no commercial benefit for the operators in storing the CO_2, which is normally just vented into the atmosphere. Nevertheless, in 2009, a CDM new methodology (NM) for the In Salah CCS project was submitted to the CDM Executive Board. However the methodology was not submitted for desk review, presumably due to the uncertainty surrounding CCS as an official CDM activity. The successful application of CCS in the NGP industry at In Salah, and at the Sleipner and Snøhvit projects in the Norwegian North Sea, has increased confidence in geological storage of CO_2, but has also led to the reasoning that business cases do exist for CCS in the NGP industry in non-Annex I countries, given the inclusion of CCS in the CDM.

In China, there is currently one large-scale project incorporating CCS technologies that is moving towards a stage of implementation. In Ordos, Inner Mongolia, China Shenhua Energy Company is applying CCS to the process of coal to liquid (CTL) manufacture. Morse et al. (2009) clarify however, that the key driver for the investment is not to reduce CO_2 emissions to the atmosphere. The development of CTL technologies is seen as a potential pathway to reduce oil imports, and the process itself offers an economically efficient means of extracting a high purity CO_2 stream which can be used for enhanced oil recovery. However, within the CTL process, CO_2 is already removed from the process using conventional removal techniques much simpler than capture technologies related to power generation, which may limit the potential of a spill-over in technological advancement.

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. Morse et al. (2009), however, state that the design of the capture equipment is in a hypothetical phase, and no storage locations have been selected. More positively, if proven technically and financially feasible, the integration of CCS and IGCC plants seem suited to both meeting national energy intensity reduction targets as well as reducing emissions from the power sector. Disadvantages, however, include the energy penalty and the costs.

There are also a number 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. The intention of the Chinese government to develop CCS is expected to be outlined in a document to be completed by the Chinese Ministry of Science and Technology (MOST). The document, which was assumed to be completed by mid-2009, will include objectives for development of the technology, and identify key tasks for future five-year plans.

Outside of China, other non-Annex I countries have stated an interest in CCS. There are at present concrete plans to capture CO_2 from the Emirates Steel Industries' Mussafah steel rolling mill in the United Arab Emirates, one of the ambitions of Masdar (the Abu Dhabi Future Energy Company). A tender for the project is expected to be released in the final quarter of 2010 to a list of prequalified potential contractors. The Abu Dhabi National Oil Company announced that a trial injection for EOR was already successfully completed. The larger project, which is expected to capture up to 800 $ktCO_2$/yr, is the first one of a number of planned CCS projects by Masdar, which include a series of power plants that will adopt CCS. The project developers anticipate that approximately 5 $MtCO_2$/yr will be captured from 2014 onwards, with the CO_2 sold to Abu Dhabi National Oil Company (ADNOC) for the purposes of enhanced oil recovery (EOR) (Power-Gen, 2010). The use of CO_2 for the purposes of EOR may become a more common practice in many Gulf states, as oil companies try to maintain production from aging oil wells. However, demand for natural gas (normally used for EOR) is threatening to outstrip supply in a number of regions (Carlisle, 2010).

South Africa is another country that has recently announced plans for building capacity for CCS in preparation for demonstrating the technology over the next decade. The country has a vision for a CCS demonstration plant to be established by 2020. South Africa has a well established synthetic fuel industry, including a number of coal-to-liquid plants owned by petrochemical company Sasol. Cumulatively, these installations produce approximately 30Mt of high-purity (approximately 95%) CO_2 per year, and thus represent low-cost abatement possibilities as significant additional capture equipment is not required (Surridge, 2010). Furthermore, South Africa's energy system is heavily based on coal-fired power plants, and the country is a major exporter of coal. In March 2009, the South African Centre for CCS was established as part of the South African National Energy Research Institute. The centre is responsible for building national human and technical capacity for achieving the CCS vision.

In 2009, The Republic of Korea also revealed multi-billion dollar investments in developing and demonstrating CCS technologies, including the construction of a 500MW power plant to test the feasibility of the technology on a large scale by 2015. It has been reported that the government will give $1.1bn to the state-run Korean Electric Power Corp (KEPCO) by 2020 to further its CCS research activities (BusinessGreen, 2009).

4.2 CDM market conditions

As of November 2010, there were 2463 registered CDM projects, with 802 of these projects leading to issuance of CERs so far. The total amount of CERs issued from the projects is 450 million, though it is estimated that the total amount of registered projects has the cumulative potential to generate 1878 million CERs by the end of 2012. However, it must be noted that due to delays in issuance of CERs, the amount of CERs available in the period 2008-2012 is likely to be 954 million (URC, 2010). As of the same date, there were 5619 projects in the entire CDM project pipeline, which includes projects that are registered (2463), registering (207) or are in the earlier validation stage of the process (2949). Due to the back log of CDM projects that are currently issuing CERs, URC estimates that the annual issuance of CERs is likely to be in the region of 666 million in the second CDM period 2013-2020, compared to 191 million during the 2008-2012 period (URC, 2010; see also Figure 4.1).

Table 4.1 *Current and estimated future CER issuance from 2008 to 2020 (URC, 2010)*

	Expected	**Available**	**Available**
Table 9	2008-12	**2008-12**	**2013-20**
CER's	**Million CERs (all types)**		
2012 CER's expected from existing projects in validation stage	850	0	610
2012 CER's expected from projects requesting registration	94	0	85
2012 CER's expected from registered projects	1878	390	984
Total amount of CERs expected from future projects until 2012	362	0	260
Total amount of CERs from existing projects produced after 2012			3390
Total amount of CERs issued	**450**	**954**	**5328**
Total requesting issuance	114		
Share Of Proceeds (SOP) for the Adaptation Fund	9.0	19	107
Annual amount available		191	666
	Exp 2013-20		
Total amount of CERs from future CDM projects starting after 2012	7741	0	1558

The economic downturn in 2008-2009 has led to a drop in demand for CERs from the European and Japanese markets, primarily due to reduced industrial output, leading to a decrease in GHG emissions and as a consequence less reliance on emission offset mechanisms (KPMG, 2009). Since the recession, estimates on demand for Kyoto Mechanism[6] credits (KMs) have dropped considerably. Government requirements for KMs from EU-15 Member States are predicted to have fallen from 640 $MtCO_2$ eq in 2008 to 450 $MtCO_2$ eq in 2009, in light of reduced industrial emissions of 3.5% during the period 2008-2012. Demand for KMs from the Japanese government could be as little as 100 $MtCO_2$ eq, with requirements from Norway, Australia and New Zealand not exceeding 20 $MtCO_2$ eq. Annex I private sector compliance requirements from the CDM and JI in the period have also assumed to have declined by 40%, dropping from 1065 $MtCO_2$ eq in 2008 to 1775 $MtCO_2$eq (World Bank, 2009).

The impact of the economic crisis can also be seen on the carbon market. Figure4.1 displays the spot price for CERs between September 2008 and February 2010 based on data from Bluenext trading exchange. In September 2008 CERs were trading for approximately €21, however, in sync with reduced investor confidence in global stock markets, by February 2009 the price had declined to below €8. During 2009 prices have not managed to recover to pre-crisis levels, and have averaged between €10-12 throughout 2009 towards early 2010.

[6] Kyoto Mechanism credits (KMs) is a blanket term for Certified Emission Reduction (CERs) units from the CDM, Emission Reduction Units (ERUs) from Joint Implementation (JI) projects and Assigned Amount Units (AAU) from International Emissions Trading (IET).

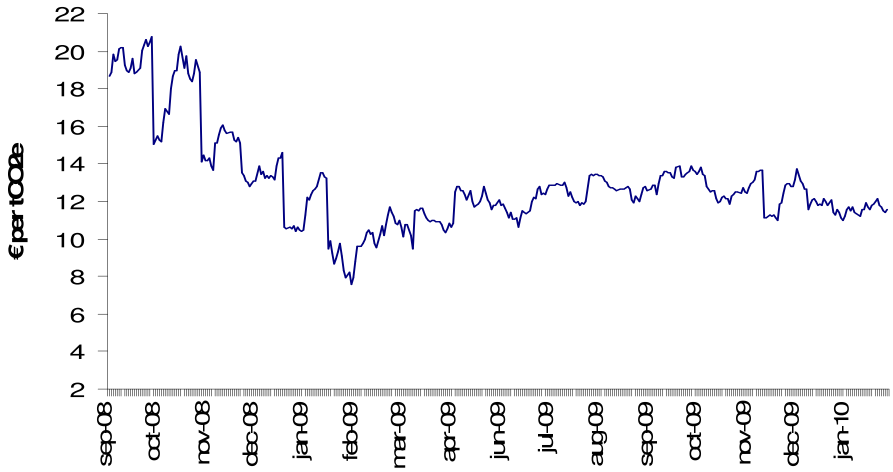


Figure 4.1 *Spot CER Prices in the Carbon Market 2008-2010*
Source: data acquired from BlueNext, 2010.

Low prices generated for CERs, coupled with estimates of reduced pre-2012 demand, could reduce investment in new CDM projects, with banks and financial players shying away from project implementation. Investment has also been staunched due to a preference of buyers for guaranteed (secondary) CERs rather than those from new projects (World Bank, 2009). Reduced investment in CDM project origination is not expected to impact the supply of CER units up until 2012, due to the large number of projects already in the CDM project pipeline.

Demand for CERs and ERUs is expected to be further eroded by International Emissions Trading (IET) of Assigned Amount Units, the third flexibility mechanism under the Kyoto Protocol. As of May 2009, nearly 100 $MtCO_2$-eq of AAUs worth €910 million had been traded (World Bank, 2009). Major transactions of AAUs have involved former Eastern Bloc countries such as the Czech Republic, Slovakia and Ukraine selling surplus[7] AAUs mainly to the Japanese government. It is understood that transfers of AAUs have the ability to undercut savings from the CDM and JI, watering down the price of CERs and ERUs and can lead to a structural imbalance on the carbon market (IETA, 2009). The extent to which transfers of AAUs will impact the CER price is unclear, as due to issues of environmental integrity, governments using significant amounts of AAUs to meet their Kyoto targets may face political and reputational risks (Ramming, 2008). Additionally, AAUs cannot be used by companies within the EU ETS.

Progress within international climate negotiations will decide the future of the carbon market after 2012. In December 2009, at the 15th Conference of Parties (COP) in Copenhagen, talks broke down during discussions to agree on a post-2012 climate regime. At COP16 in Cancún the climate talks took place in a better atmosphere, with renewed trust between Parties, but no decisions were made that ensure a future for a global carbon market in the way the Kyoto Protocol envisaged it. Currently, investors considering procurement of CERs for crediting after 2012 face substantial risks given the political uncertainty of the future of the CDM. If an

[7] The Kyoto targets were based on 1990 emission levels, but deindustrialisation has since occurred in former communist states, leading to huge stockpiles of unused AAUs often referred to as ‘hot air’. Russia is estimated to be able to carry forward between 4 and 6 billion tonnes to a post-2012 climate treaty (IETA, 2009).

agreement on a new international treaty can be agreed upon, including ambitious emission reduction target for developed countries including the US, demand for offsets could be substantial.

Leading from international climate negotiations, post-2012 demands of CERs are partly dependent on domestic policy developments. A reduction in emission unit allocations in Phase III (2013-2020) of the EU ETS, and the inclusion of the aviation and shipping industries into the scheme should raise demand from European buyers. The potential introduction of cap and trade systems in the US, Australia and Japan has the potential to significantly restimulate investment in both CDM and JI projects.

4.3 CCS-CDM in the climate negotiations

Since COP11 in 2005, the decision on whether CCS should be eligible for crediting under the CDM has received considerable attention both within the UNFCCC process and from observer organisations. A decision was expected at every COP since COP12 in 2006, but parties continued to disagree on a number of issues including: how to monitor for leakage from storage locations; post-crediting period liability issues; whether the CDM modalities and procedures are suitable for CCS technologies; and also the risks of CCS unbalancing the carbon market. In COP15, Copenhagen, December 2009, diverging pinions on the inclusion of the technology were voiced, and the decision was again deferred to a future conference and the conclusions of the conference (Decision 2/CMP.5; UNFCCC, 2009b) included a recognition the importance of CCS as 'a possible mitigation technology, bearing in mind the concerns related to the following outstanding issues, inter alia:

a) Non-permanence, including long-term permanence;
b) Measuring, reporting and verification;
c) Environmental impacts;
d) Project activity boundaries;
e) International law;
f) Liability;
g) The potential for perverse outcomes;
h) Safety;
i) Insurance coverage and compensation for damages caused due to seepage or leakage'

At COP 16 in December 2010 in Cancún, however, it was decided that CCS projects are principle eligible as CDM project activities, provided that the issues mentioned above are resolved. The Subsidiary Body for Scientific and Technological Advice (SBSTA) is requested to elaborate modalities and procedures for CCS in the CDM at its 35th session, with a view to recommend a decision at COP17 in December 2011, based on submissions from Parties and observer organisations and a technical workshop to be held in 2011, prior to COP17. In order to address the issues mentioned in 2/CMP.5, these modalities and procedures should address, inter alia:

- Stringent criteria for site selection
- Stringent monitoring plans, including consideration of the 2006 IPCC guidelines for national greenhouse gas inventories and the accounting of possible seepage;
- Spatial and temportal project boundaries;
- Transboundary CCS projects;
- Emissions related to the CCS project itself;
- Risk and safety assessments by independent entities related to possible CO2 seepage points, including the environmental and socio-economic impacts;

- Liability for possible short, medium and long-term seepage should be defined before approval of the CDM project, be applied during and after the crediting period and be consistent with the Kyoto Protocol.

UNFCCC (2009c) includes an analysis and broad recommendations for addressing these issues as well as other issues such as institutional implications.

The discussions on CCS in the CDM started after two CDM projects and baseline and monitoring methodologies were submitted to the CDM EB in 2005. The White Tiger oil field CCS project in Vietnam (NM0167) includes the capture of CO_2 emissions from a combined cycle natural gas power plant, which would then be transported by pipeline and used for EOR. The forecasted emission reduction potential for the project, approximately 7.7 $MtCO_2$ per year, is particularly high when compared to the emission reductions of existing CDM projects. For example, the average annual emission reduction of HFC destruction projects is 3.7 $MtCO_2$, and 0.09 $MtCO_2$ for wind projects (URC, 2010). The project was not deemed economically attractive by the developers without the income from CERs, with EOR alone providing a calculated IRR of 11.1%, which is not enough to offset the associated risks of the project (i.e. fluctuating oil price and equipment costs) (UNFCCC, 2005).

A second submission to the CDM EB (NM0168) concerns a capture and storage project in Malaysia. Carbon dioxide would be recovered from a liquid natural gas complex, and injected into an aquifer below the seabed. A projected emission reduction of just over 3 $MtCO_2$ per year was expected. The recovered CO_2 would not be used for EOR, thus the project required incentivising through the CDM (UNFCCC, 2006). Both submissions were rejected as CDM projects for a number of reasons. Questions were raised about how methodologies can address project boundaries, leakage and permanence (UNFCCC, 2006). Since the initial two submissions for CCS projects in 2006, there has been one additional methodology submitted focusing on the In Salah CCS project in Algeria, as described in Section 4.1. This methodology was not assessed for validity due to continuous uncertainty over the status of CCS in the CDM.

Recently, the Qatari Minister for Energy announced that Qatar is submitting another methodology for CCS in the CDM to the UNFCCC. Like the In Salah methodology, however, it is unclear whether this methodology will be reviewed.

4.4 Carbon market post-2012

Even if CCS will never be included in the CDM, there may be other opportunities to support CCS in developing countries through carbon market mechanisms[8] or other international instruments (Hagemann et al., 2010). These other international instruments, such as multilateral partnerships, are thought to be important in the near future for CCS technology development and demonstration projects. In this section we will therefore explore possible scenarios for the CDM and other carbon market mechanisms.

Future of the CDM
Under the European Emission Trading Scheme (ETS) companies are allowed to buy (a limited number of) CERs to comply with their emission caps. The third phase of the ETS will continue to 2020. EU national governments are also likely to continue to be CER buyers to comply with the EU emissions target of 20 to 30% below 1990 levels in 2020. However, there are proposals by

[8] The voluntary carbon market, where credits are being traded for voluntary offsets, is ignored here as it is not believed to play a significant role compared to the compliance market in the future.

the EU that could limit the eligible host countries to the poorest countries (Least Developed Countries, mostly in sub-Saharan Africa). Other developed countries, such as the US, Japan, Canada and Australia are likely to be buyers of international emission offsets to meet their targets announced under the Copenhagen Accord (UNFCCC, 2010b).

Potential non-UNFCCC instruments

Several developed countries have proposed mechanisms that may become alternatives to the CDM, be it under the UNFCCC or not. Japan is engaged in a bilateral partnership with China to develop emission credits that could be used by Japanese companies and the government to comply with their emission targets. Its aim is to be an efficient system, e.g. based on emission benchmarks, with lower transaction costs and faster procedures than the CDM. The US has established the Carbon Action Reserve, which is an offset registry that can be used by companies and governments (Point Carbon, 2010). At the moment it is uncertain to what extent the instruments being developed by the US and Japan are compatible with UNFCCC procedures. Moreover, nothing is known about the possible role CCS could play in these mechanisms.

Nationally appropriate mitigation actions (NAMAs)

A new mechanism to support GHG reduction in developing countries is through NAMAs. The details of this new instrument are being negotiated in the UNFCCC, and not much is known about the details yet. However, the general understanding is that a NAMA can be a project, programme or a policy, voluntarily proposed by a developing country in the context of sustainable development. There could be three types of NAMAs: 1) unilateral, which are implemented by the host country without external support; 2) actions supported by finance, technology and capacity building from developed countries and 3) actions support by the carbon market, i.e. NAMAs that will generate carbon credits that can be used by developed countries. It is expected that CCS could play a role in supported[9] and credited NAMAs (Hagemann et al., 2010), and possibly unilateral NAMAs if EOR makes CCS activities attractive.

Figure 4.1 gives a schematic picture of these mechanisms and the role they may play in stimulating CCS deployment in developing countries. There is some overlap between the different instruments. The CCS projects developing in bilateral or multilateral partnerships may also be eligible under the carbon market. Secondly the potential mechanisms developed by Japan and the US may further be developed to created (credited) NAMAs. If CCS would be allowed in the CDM, EOR projects are still not likely to be eligible due to difficulty with accounting for the CO_2 emissions from the consumption of the extracted oil. For other crediting mechanism there is not sufficient clarity on the rules and procedures to provide an assessment of the potential eligibility of EOR.

[9] An example of this could be bilateral cooperation using fast track financing under the UNFCCC (Hagemann et al. 2010)

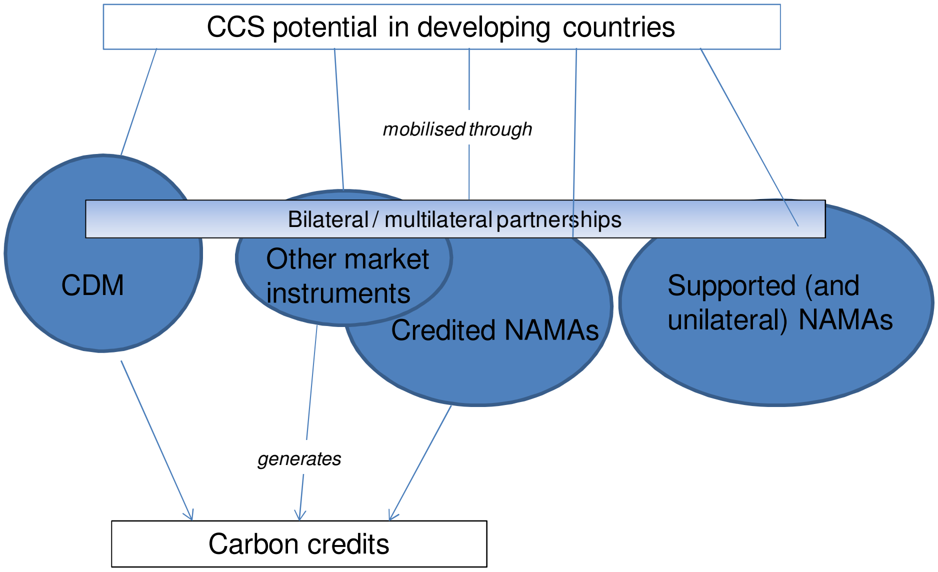


Figure 4.2 *Mobilisation of the CCS potential through different post-2012 mechanisms.*

5 Potential and cost of CCS in developing countries

5.1 Literature on CCS potential in developing countries

The technical potential of CCS deployment in China is considered large. On the capture side, 1,623 large stationary CO_2 sources account for 64% of the nations CO_2 emissions (Dahowski et al., 2009). Costs of deployment of CCS in China is also expected to be lower than in many Western countries due to lower fuel, material and labour costs (US DOE, 2007). In addition, approximately half of China's stationary CO_2 sources are situated directly above a potential geological sink, and 80% are within 80km of suitable geological storage sites (Qian, 2009), although the suitable storage potential is contested by others. In terms of impacts on the CDM market, there is a significant potential for low-cost CO_2 abatement in China that, given the incentive, could be realised in the near term. Often coined as 'early opportunities', there are 185 high purity CO_2 sources within the large-scale ammonia, hydrogen and ethylene producing industries, equalling 130 $MtCO_2$ per year. This figure is expected to rise to 203 $MtCO_2$ once further planned production facilities are realised. The abatement costs are expected to be in the region of between \$10 – 20 per tCO_2 (Qian, 2009). Similar work has been completed in China by Zheng et al. (2010), who identified 18 >1$MtCO_2$/annum high-purity CO_2 sources located within 10km of potentially suitable storage sites. Based on existing cost models from compression and transport, the costs ranged from 9-13 \$$tCO_2$ stored.

India also has a high technical potential for CCS deployment, however low cost opportunities from industrial facilities such as ammonia plants, are limited due to the demand in CO_2 for the production of urea. In some cases there is a shortage rather than an excess of CO_2, attributed to the shift from naphtha to natural gas as a feedstock (Shackley and Verma, 2008). There are however possibilities for using CO_2 stripped from offshore sour gas installations, either for enhanced oil recovery (EOR) or selling it to fertilizer plants. These projects are not thought to be profitable outside of the CDM (Shackley and Verma, 2008).

A thorough investigation of the potential of CCS in Indonesia has also been completed, including a detailed inventory of existing CO_2 sources and sinks across the archipelago (Indonesia CCS Study Working Group, 2009).The emissions sources were subdivided into two categories, 'flue gas' sources from power generation and 'CO_2 streams' from industrial production processes. The total projection of CO_2 emissions from power plants in Indonesia was estimated at 116 million tonnes in 2008, and is expected to rise to 270 million tonnes in 2018. Indonesia has a large oil and gas industry, with numerous natural gas processing, liquid natural gas production plants and oil refineries. The total estimated CO_2 emissions from the oil and gas industry operating in Indonesia was 17 million tonnes in 2009, but the CO_2 emissions from other industrial sources such as ammonia and steel production plants are also significant. Figure 5.1 displays the locations of both CO_2 sources from industry and power generation in Indonesia.

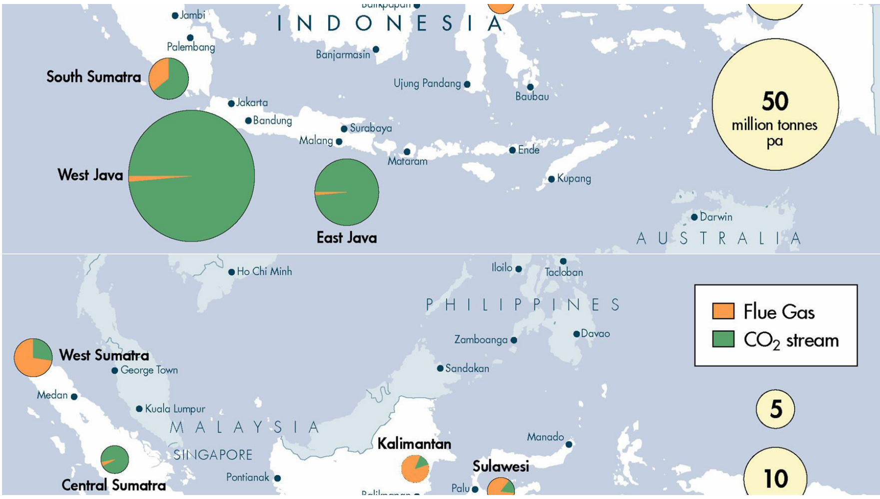


Figure 5.1 *CO_2 sources in Indonesia (Indonesia CCS Study Working Group, 2009)*

In terms of storage, depleted oil and gas reservoirs provide the most accessible CO_2 storage possibilities. Oil and gas exploration is well established in Indonesia, and data on the geological integrity of potential storage sites may be available. The presence of existing infrastructure and expertise, as well as the possibility for enhanced oil recovery (EOR) using CO_2 may help to facilitate CCS in the country. It was estimated that between 38 – 152 $MtCO_2$ could be stored in depleted oil reservoirs in East Kalimantan, and between 18 – 36 $MtCO_2$ could be stored in depleted oil and gas fields in South Sumatra (Indonesia CCS Study Working Group, 2009).

5.2 Review of existing CCS in CDM assessments

There are a number of assessments that aim to shed light upon the potential impact that CCS activities could have on the price and supply of CERs, if it were to be accepted into the CDM project portfolio. A report by the International Energy Agency (IEA, 2007), used a top-down assessment to generate the technical CO_2 abatement potential for CCS applications in non-annex I countries. A range of industries including *inter alia* refineries, ammonia production, natural gas processes, cement production and fossil-fired power stations were investigated, and both near-term (2012) and longer-term (2020) technical abatement potentials were generated. The near-term technical abatement potential was calculated at approximately 480 $MtCO_2$/y by 2012, and 9300 $MtCO_2$/y by 2020. The estimated average annual issuance of CERs until 2012 is 207 million, and 635 million in the post-2012 period. Therefore, even if CCS only reaches 50% of the maximum technical potential in non-annex I countries, it could supply a huge number of CERs that could hypothetically flood the carbon market. The authors of the report recognise however that in view of the high investment costs of CCS, the actual implementation of CCS projects would be much lower than the technical potential.

By means of a bottom-up assessment, an initial study by Bakker et al. (2007b), provided an analysis of CER supply from an array of potential greenhouse gas emission mitigation projects in non-annex I countries from 2013 to 2020 in the power and industry sector. It was based on a bottom-up database of CO_2 point sources and the potential for CCS related to these sources was based on ‘realistic’ deployment scenarios (as opposed to the approach used by the IEA). With regard to the limitations of basing potential market impacts on the technical potential alone, the assessment also included the abatement costs of various mitigation projects to produce a set of marginal abatement cost curves (MACCs). Furthermore, a number of scenarios where developed to simulate varying levels of uptake of CCS in power generation and industrial sectors. From the results of the study, it was estimated that CCS could provide an annual emission reduction of 158 $MtCO_2$ per year by 2020. However, the cost of all these options is above $30 per tonne of CO_2 reduced.

The main limitation of the study was that natural gas processing (NGP), a potentially low-cost CCS application, was omitted due to a lack of data availability. The IEA (2007) had estimated the technical CO_2 abatement potential of NGP at 167 $MtCO_2$ and 334 $MtCO_2$ in 2012 and 2020 respectively. In an update, Bakker et al. (2010) included NGP in their earlier assessment of CER supply potential assessment. This was based on a database of over 900 natural gas fields in 49 non-Annex I countries. The total economically recoverable CO_2 from these fields was estimated to be 6.1 Gt. The annual CCS potential was estimated to be 146-222 $MtCO_2$/yr in 2020. A credible assessment of the potential for CCS in the CDM was thought to include only options up to $30/tCO2 as the CER price is not likely to exceed this figure in the foreseeable future. The total CDM potential (all eligible project types) was estimated to be just over 3 $GtCO_2$ eq/yr (see Figure 2.2.). However the market potential could also be lower due to several barriers related to technology uptake or uncertainty related to the CDM market (see also Bakker et al., 2007b). Considering these conditions, Bakker et al. (2010) estimate the potential of CCS to take a maximum of 5-10% of the CDM market.

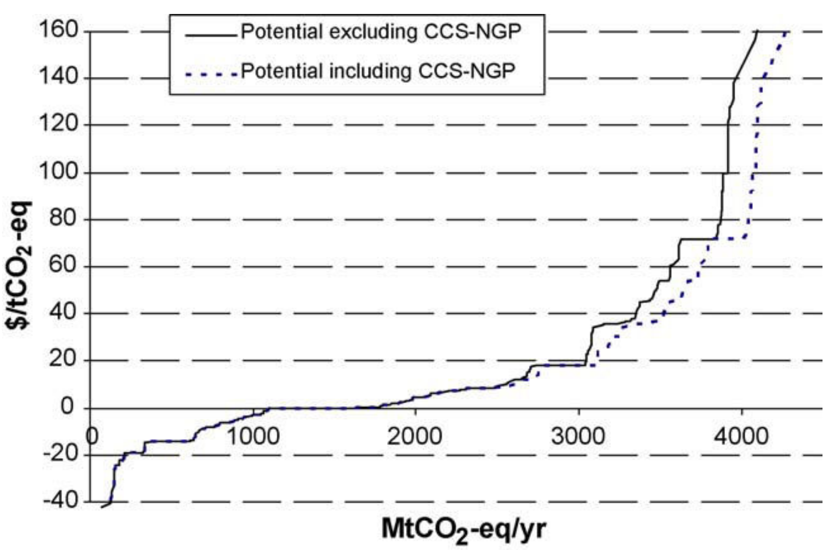


Figure 5.2 Marginal GHG abatement cost curve for CDM eligible technologies and CCS in NGP in all non-Annex I countries in 2020 (Bakker et al., 2010)

Zakkour et al (2010) provides an assessment of CCS from high purity sources (production of ammonia, hydrogen, ethylene oxide and natural gas processing). Current emissions in natural gas processing and in ammonia production amount to 160 $MtCO_2$ and 119 $MtCO_2$ respectively and might increase up to 270 $MtCO_2$ and 311 $MtCO_2$ by 2020. CTL emissions are 24 $MtCO_2$ in South Africa and 3.6 $MtCO_2$ in China and globally are expected to increase by approximately 30 $MtCO_2$. For ethylene production an average of 0.12 $MtCO_2$ per plant is estimated, and a total of 6.3 $MtCO_2$ growing up to 9 $MtCO_2$ by 2020 is calculated globally.

The CCS Technology Roadmap (IEA, 2009) is based on the IEA Blue Map scenario, which leads to a 50% reduction of global GHG emissions in 2050 compared to 2005 levels. Based on economic modelling, CCS takes a 19% share of the total GHG reduction in 2050 (of which 10% in the power sector). For developing countries, the scenario includes 50 CCS projects (of which 21 in China and India) capturing approximately 120 $MtCO_2$ in 2020. Globally in 2020, 38% would be in the power sector, 35% in industry and 27% in fuel production (upstream). In developing countries these shares are different, with 19 Mt in the power sector, and 97 $MtCO_2$ in industry and upstream. After 2020 the CCS deployment is expected to increase quickly around the globe.

Table 5.1 gives a brief overview of the assessments for CCS in the CDM and/or potential in developing countries discussed above. Results are mentioned only for 2020, as earlier years are not thought to be realistic for implementation of CCS.

Table 5.1 *Overview of studies on CCS in CDM and developing countries.*

Study	Coverage	Assumptions	Results (2020)
IEA (2007)	All sources	Technical potential based on all possible CCS options	9 $GtCO_2$, exceeding potential of other technologies
Bakker et al. (2007; 2010)	Power, NGP, and (near) pure CO_2 sources in industry	Rough deployment scenarios for CCS in power and industry; abatement cost from Zakkour et al. (2008); Only options up to $30/$tCO_2$ eq thought to impact CDM market.	0.2-0.3 $GtCO_2$; less than 10% of the CDM market; no price impact given
Zakkour et al. (2008)	All sources	Power sector potentials and total CDM potential from Bakker et al. (2007); Detailed bottom up cost analysis for industry and NGP options; CDM market impact based on CER supply and demand curves	0.1 – 0.3 $GtCO_2$; 6-9% of CER supply; CER price reduction of up to $30/$tCO_2$ eq at 2.1 billion CER demand[10]
IEA (2009)	All sources	Global deployment scenario based on cost-effective GHG reduction up to 2050	0.12 $GtCO_2$, mainly in industry and NGP
Zakkour et al. (2010)	Industry and NGP	Deployment scenarios based on IEA Blue Map.	0.12 $GtCO_2$

The IEA (2007) assessment may be an overestimation of CCS potential, given the early stage the technology is in and the high abatement cost compared to other mitigation options. The estimates by Bakker et al. (2010) and Zakkour et al. (2008; 2010) are in the same order of magnitude. This is partly due to the fact they use similar data: potentials for the power sector by Zakkour taken from Bakker et al. (2007) and in turn Bakker et al. (2010) use the cost assessment by Zakkour et al. (2008). Another commonality is the emphasis on the early opportunities of CCS in the natural gas processing sector. Zakkour et al. (2010) extend the analysis with other pure CO_2 options, which are thought to play a role up to 2020 as well, although the abatement costs are higher than for NGP. The IEA CCS Roadmap (2009) is on the lower side of the ranges mentioned, which can

[10] Partly based on this assessment, UNFCCC (2009c) concludes that due to technological and institutional barriers there are no indications that inclusion of CCS would introduce any risk of unbalancing of the CDM market.

be explained by their assumptions on realistic deployment scenarios, including for the industry and upstream sectors.

5.3 Improved assessment of costs and potentials

The assessment of the potential impact of CCS on the CDM market requires updated and realistic data on the carbon abatement potential by 2020. CCS is a new technology in demonstration phase, and represents a large potential for carbon abatement. Costs for CCS depend on the kind and size of CO_2 sources, their locations and the infrastructure regionally available, among other things. IEA has endeavoured to build a deployment scenario of CCS projects in several world regions in their CCS Roadmap (IEA, 2009). We considered this the most suitable and consistent source to base the CCS potentials on. It can be argued that the technical and economic potential is much larger, i.e. covering all large CO_2 point sources in 2020. However considering CCS technology is in a demonstration stage, and the long lead times required to build and commence operating CCS, such an approach would lead to very unrealistic potentials. The IEA Roadmap can be considered an optimistic but still realistic scenario, and therefore appropriate to use as a basis for the CCS MAC in 2020.

We used the following steps to build our MAC (see also Annex B):

1. Retrieve CCS deployment projections from the IEA Roadmap, i.e. by world region and broad sectors.
2. Retrieve information on on-going and planned CCS projects in developing countries.
3. Reconcile 1) and 2) in order to identify CCS potentials by country and sector (assumptions explained below).

The Roadmap projects that China, India and non OECD countries might contribute to CCS deployment with 50 projects that count an abatement potential of 116 $MtCO_2eq$/yr in the power, industry and upstream sectors. Although costs per region are unavailable in the document, global CCS cost ranges are presented for the different power and industrial activities.

Country specific information related to on-going and planned CCS projects has been collected and reconciled with the IEA Roadmap projections on the deployment of this technology. Three main databases are used for this purpose. NETL (2010) and IEA/CSLF(2010) compile ongoing and announced CCS projects. The planned CO_2 storage quantity per year per project is presented and some investment data are available. Projects in Annex-I and non-Annex-I countries are both included in these lists. Zakkour et al. (2010) presents the CCS potential in coal-to-liquids (CTL) plants and a breakdown of CCS potential in ammonia, natural gas processing (NGP) and ethylene oxide industries. After mapping the high CO_2 purity industries, these authors extrapolate current emissions up to 2020 and assess the number of CCS projects that might be implemented globally in each industry by 2020. Taking into account the CCS project lists and the deployment scenarios presented by Zakkour et al. (2010) and the IEA CCS Roadmap, we identify costs and potentials for CCS by sector and country. First, we proceed to locate the CCS to be deployed in the power sector and then in industry.

In the power sector*,* IEA CCS roadmap projects that 19 $MtCO_2$/yr may be avoided in China, India and other non-OECD countries. From this amount of carbon, 68% will be removed in China and India by the implementation of six projects. Other non-OECD countries contribute to the remaining carbon reduction by implementing four projects.

In order to geographically locate the potential for CCS projects by 2020, data from NETL and IEA are considered (NETL 2010;IEA-G8, 2010). From these lists, China presents six large scale capture projects with an abatement potential of at least 1 $MtCO_2$/yr, which add up to 10 $MtCO_2$/yr. Smaller projects are also mentioned, however their contribution to the abatement potential is negligible. Accounting for the total carbon expected to be captured by CCS in 2020 (IEA, 2009), we assume that if China and India are to capture 13 $MtCO_2$/yr, India may contribute 3 $MtCO_2$/yr. India's relative contribution corresponds with the results obtained for the CCS scenario presented by ECN (Bakker et al., 2007) on total expected CCS deployment in the power sector in China and India by 2020 (84% and 16% respectively).

For the other non-OECD countries, we intend to allocate to countries the remaining abatement potential of 6 $MtCO_2$/yr. Announced projects found in Abu Dhabi HPAD power plant amount to 1.7 $MtCO_2$/yr, although it is uncertain whether this project will be implemented. Lack of data on additional projects drove us to assume that the remaining 4.3 $MtCO_2$/yr to be captured are located in other developing countries, here referred as to "rest of non-OECD countries".[11]

The IEA scenario suggests that by 2020 global CCS projects in chemical industry and natural gas processing (NGP) may contribute to 11% and 41% respectively of the industrial and upstream avoided emissions. In China and India and in non-OECD countries, a number of 25 and 15 projects avoiding a total of 68 $MtCO_2$/yr and 29 $MtCO_2$/yr may be implemented (IEA 2009).

Assuming a similar industrial categorization to the one presented by Zakkour et al. (2010) and IEA (2009) (ammonia industry, ethylene oxide industry, iron & steel subsector and NGP), we cross-checked the CCS project lists (NETL 2010; IEA/CSLF, 2010; GCCSI, 2009), as well as information available from Zakkour et al. (2010) work in order to geographically locate the potential for CCS. The following results are obtained:

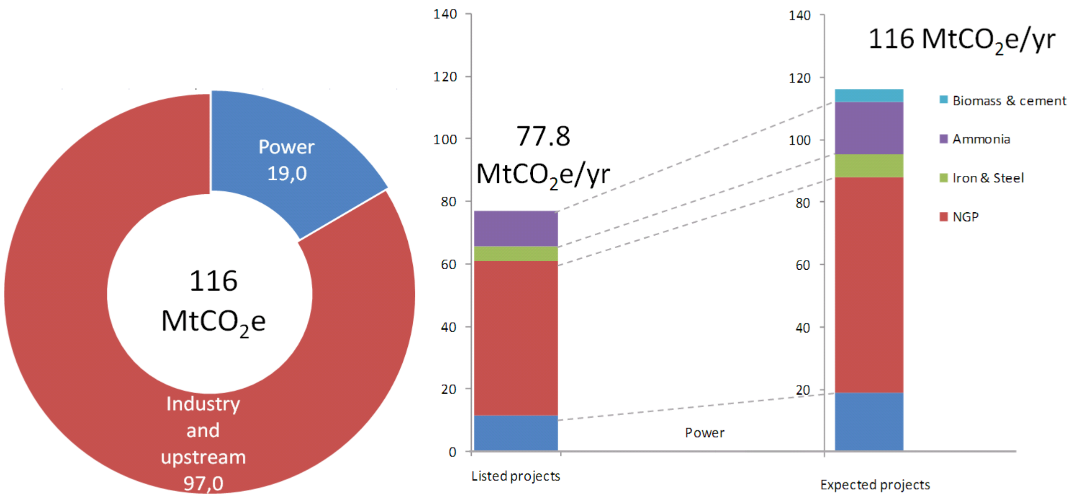
- Ammonia industries: India and China present an abatement potential of 1.1 $MtCO_2$/yr and 10 $MtCO_2$/yr respectively;
- Ethylene oxide: Lack of data inhibited identifying individual projects. Moreover, Zakkour et al. (2010) suggest low interest from this industry to implement CCS, hence only one (1 $MtCO_2$/yr) CCS project is expected by 2020 and we assume, based on the inventory of CO_2 sources, that it might take place in an Annex-I country;
- Iron and steel: A project of 5 $MtCO_2$/yr is planned in the United Arab Emirates;
- NGP: Several projects might take place in Saudi Arabia (17 $MtCO_2$/yr), Libya (11.5 $MtCO_2$/yr), China (8.3 $MtCO_2$/yr), United Arab Emirates (7.7 $MtCO_2$/yr), Malaysia (3 $MtCO_2$/yr) and Algeria (1.5 $MtCO_2$/yr).

The ongoing and announced projects in the industry and upstream sectors located in China, India and non-OECD present a potential of 65.1 $MtCO_2$/yr, which compares to 97 $MtCO_2$/yr projected in the CCS Roadmap.

For the sectors power and industrial & upstream, we notice that approximately 30% of the expectations by the IEA are derived from unlisted projects, i.e. those not yet existing. We assume that this missing number of projects take place in other non-OECD countries not listed in the CCS projects databases and all abatement values are corrected by this additional 30%. In some cases, this 30% correction leads to abatement values higher than those presented by Zakkour et al. (2010) for a specific industry. We set Zakkour et al. (2010) values as an upper abatement limit per industrial activity, hence, if applicable, the exceeding carbon abatement value from power sector or any industrial activity originated by the correction is assumed to shift to other industries

[11] The CCS in CDM assessment in Chapter 6 will be based on a MAC for the entire developing world, therefore this assumption has no impact on the assessment.

that might play a role in CCS by 2020, such as biomass and cement (See Figure 5.3). Specific figures for CCS abatement potentials and costs are presented in Annex A and integrated into the cost curve in this chapter.



(a) (b) (c)

Figure 5.3 *CCS 2020 Abatement potential in developing countries IEA, 2009 (a), listed projects (b) and our assessment (c).*[12]

The IEA CCS roadmap does not include CCS in CTL plants before 2020. Zakkour et al. (2010) estimates CTL emissions in China to be 3.6 $MtCO_2eq/yr$ and in South Africa 24 $MtCO_2eq/yr$. In addition to the potential of CTL, the role of EOR is another important factor in the deployment of CCS in developing countries. Therefore we use three scenarios for our abatement cost curves:

1. IEA base case: Inclusion of CCS in power sector, ammonia, NGP, iron and steel, biomass and cement industries, corresponding to the IEA CCS Roadmap.
2. IEA base case + CTL: Includes the deployment of CCS in CTL industry.
3. IEA base case + CTL + EOR: The use of CO_2 for EOR exclusively in North Africa and Arabic countries[13] regions from the industries expressed in previous scenarios. In this scenario we assume that EOR reduces the abatement cost for CCS projects in those countries by 20$/ton CO_2[14].

[12] Due to lack of data we had to include biomass and cement in one category. Though very different in nature, the capture costs are likely to be high, and therefore the impact on the CCS in CDM assessment is low.

[13] This regions covers 57% of the non-Annex I CCS potential.

[14] This is based on market prices for CO_2 in EOR operations by Steidtmann (2007) and ARI (2010) who report prices between $10 and 24. As these prices refer to relatively low oil prices, $20 per tonne of CO_2 for 2020 can be considered conservative.

Figure 5.4 shows the abatement cost curves for CCS in developing countries in 2020 for these three scenarios.

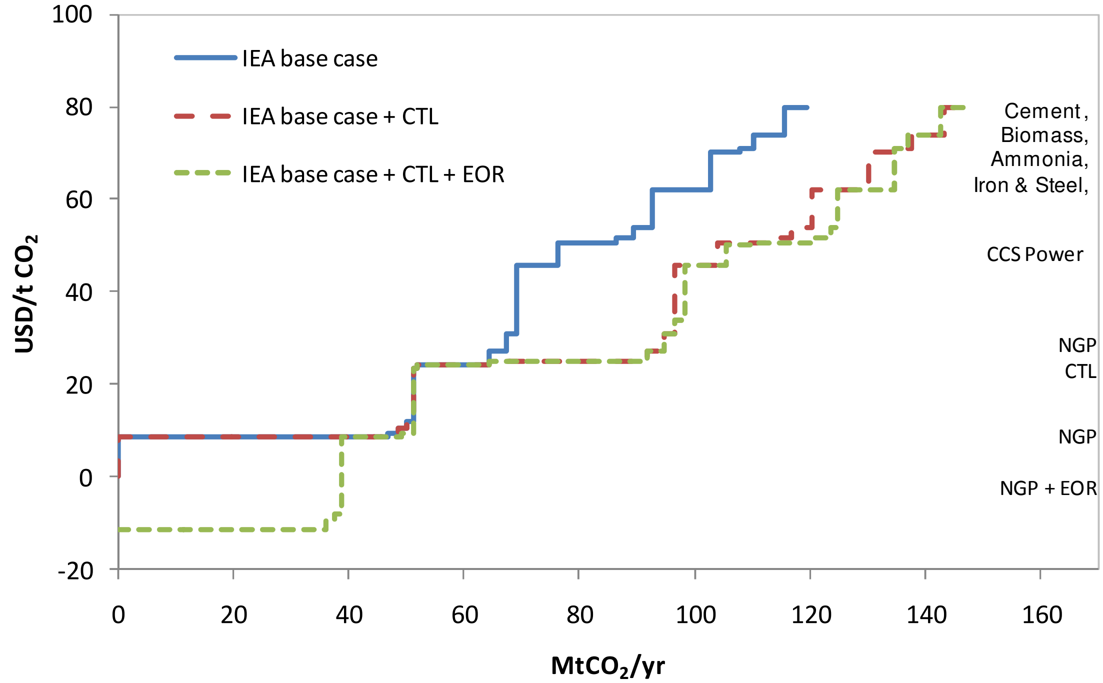


Figure 5.4 *CCS abatement cost curve for power and industrial sectors in developing countries in 2020.In the right hand side of the figure it is broadly indicated which sector are represented in the figure. See Annex A for all cost and potential figures.*

6 Assessment of market impact

The supply curve for carbon credits from CCS projects in 2020 developed in Chapter 5 is the basis for the market impact assessment. We focus on the CDM market, in accordance with the primary aim of this paper, but will also look at broader implications. The assessment is built up of a number of components: supply and demand of credits, theoretical considerations, CDM market dynamics, carbon market scenarios and the impact assessment.

6.1 Credit supply and demand potential

The analysis in Chapter 5 has shown the total potential for CCS projects to be approximately 120-150 $MtCO_2$ in 2020, with the potential up to $30/$tCO_2$[15] estimated to be 70-100 $MtCO_2$. This is mainly related to 'early opportunities' in natural gas processing and ammonia production.

The supply curve for other project types eligible under the CDM is shown in Section 6.3, Figure 6.2. It includes four scenarios for the market potential of CDM projects, based on uncertainties related to CDM regulations (strictness of additionality testing, procedures), and deployment rates of technologies (see Bakker et al., 2007). In each of the scenarios there is a large no-regret potential (800 – 1700 $MtCO_2$ eq). However, the most pessimistic scenario includes approximately 50% lower abatement potential up to $30/$tCO_2$ than the most optimistic scenario (1600 and 3200 $MtCO_2$-eq respectively).

Projecting the demand for CERs in 2020 is close to impossible, due to the uncertainties mentioned in Section 4.4. The demand from companies under the ETS, projected to be up to approximately 200 $MtCO_2$-eq/yr (World Bank, 2010) in phase three, based on the maximum permissible offset amount, could be taken as the lowest level of demand. In addition, EU Member States are likely to remain buyers of CERs.

Based on a range of published studies on the post-2012 carbon market under varying assumptions, UNFCCC (2008) provides a CER demand estimate of 500 – 1700 million/yr in 2020. The lower figure of this range may correspond to the EU demand. Figures in a similar range are reported by New Carbon Finance (Carbon Finance Online, 2008), which estimate a CER demand of 410 – 2300 million/yr. The high figure corresponds to the potential demand from the US, Canada, Japan and Australia (in addition to the EU), i.e. if all significant developed country buyers would use the CDM as part of a their strategy to comply with their targets.

6.2 CDM market dynamics

Basic economic analysis suggests that a well-functioning market can be described by a supply and demand curve. The point where these curves meet gives the break-even or market price and quantity. A change in the supply or demand curve would then result in a market price change, as shown in the figure below.

[15] This figure for the cut-off point for the CDM relevant abatement potential is also used in Bakker et al. (2010).

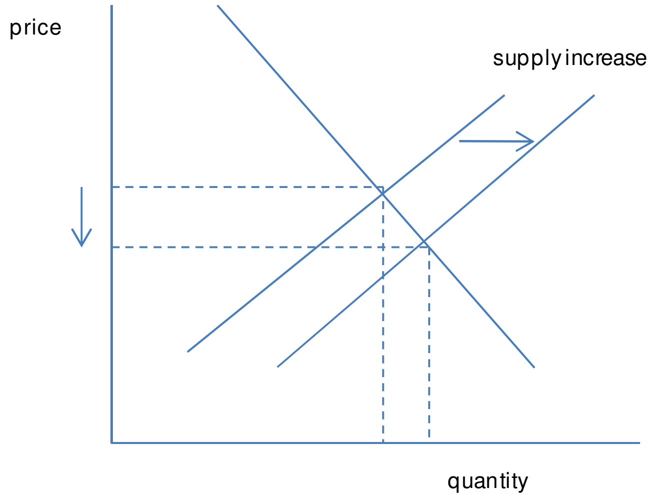


Figure 6.1 *Market price impacts of a supply increase in a theoretical economic model*

For the CDM market, Zakkour et al (2010) used this approach to assess the market impact of CCS on the CDM. To this end, they assume a CER demand of 2.1 billion in 2020. The potential impact of CCS on the CER price would be up to \$30/tCO_2. This rather significant potential impact is caused by the fact that the supply curve is very steep around the 2.1 billion CERs, which implies that at relatively small additional supply can result in a large decrease in price. The authors add, however, that such an impact is likely to be an overestimation of the real impact.

We feel there is reason to think the CDM market may not follow basic economic logic for the following reasons:

- The supply curve of CDM projects (see Figure 6.2) suggests there is a large negative cost potential that could cover the current demand for CERs (approximately 200 MtCO_2 eq/yr), predicting a CER price of 0 \$/tCO_2 eq.
- The current CDM project portfolio does not 'follow' the GHG abatement cost curve, but includes many different project types, ranging from negative cost options such as industrial energy efficiency, to low cost industrial gas projects, to more expensive options such as renewables (Castro, 2010). It should be noted that an explanation for this could be that the MAC is not representative of the CDM market, rather than it being a limitation of the theory. The limitations of the MAC could include incomplete or inaccurate data or sectoral coverage, or assumptions / calculation methodologies that are not representative of the 'real' situation, e.g. the negative cost options might face barriers in practice.
- The CER price is currently almost fully determined by the EUA price in the European Emission Trading Scheme (ETS), with the CER price approximately € 1-2 below the EUA price (Point Carbon, 2010). In this scheme a limited numbers of CERs can be used by European companies to comply with their emission caps (see Section 6.1), and the expectation is that the maximum permissible number of CERs will be used, as buying these credits is cheaper than achieving the reductions in the ETS installations.

On the other hand, in 2010 the market has responded to possible reductions in short-term supply (HFC projects have been put on hold since September 2010 with CER price ups as a result) and increases (e.g. a 3 million CER issuance resulted in downward pressure on the CER price) (Point Carbon, 2010).

These observations show the current CDM market dynamics. It is uncertain to what extent the CDM market in 2020 will behave like a liquid and mature market.

6.3 CDM market impact of CCS

In order to assess the potential impact of CCS on the CDM market, the uncertainties regarding demand and supply discussed in the previous sections have to be taken into account. We us the following approach:

1) Develop quantitative supply and demand scenarios:
   - Retrieve four realistic scenarios for the supply of CERs without CCS (see Section 6.1 and Figure 6.2);
   - Use two CER demand scenarios (see Section 6.1 and Figure 6.2)
2) Develop four scenarios for the more qualitative uncertainties:
   - Two scenarios for the relation between the CDM and other carbon market mechanisms (see Section 4.4 and below);
   - Two scenarios with regard to the CDM market dynamics (see Section 6.2 and below).
3) Add the CCS MAC (Section 5.3) to the supply scenarios, which in each of the four qualitative scenarios of step 2 results in possible market impacts.

Step 1
Figure 6.2 shows the market potential for CER generation from currently eligible project types. The demand estimates are also indicated in the figure.

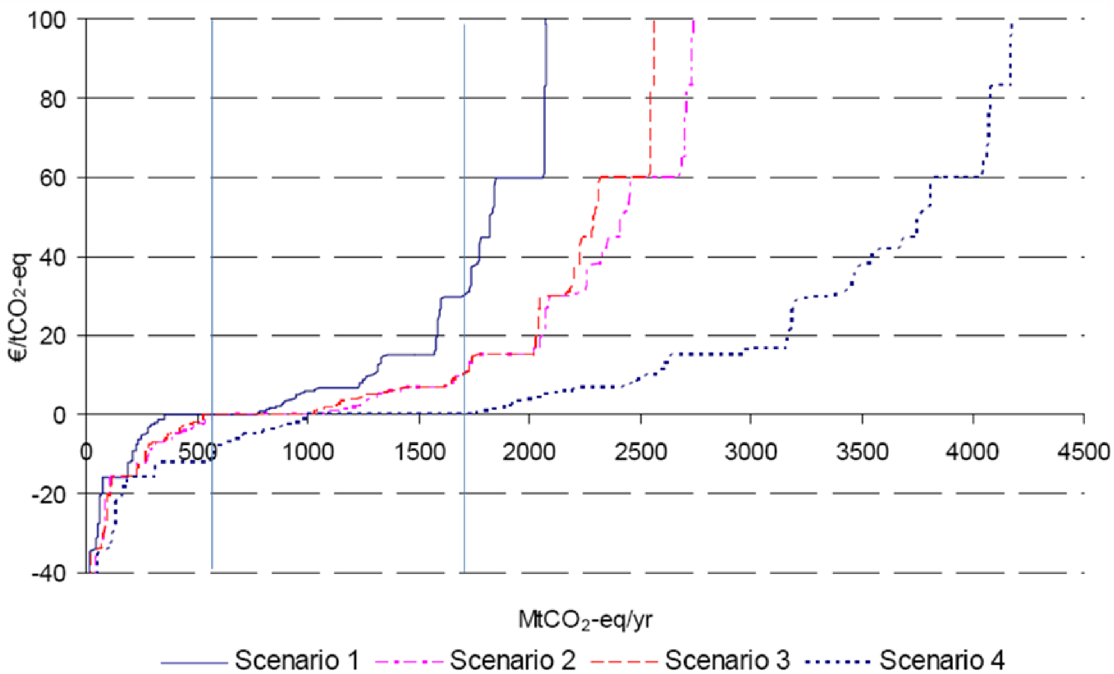


Figure 6.2 *Supply curves for CDM projects in four scenarios (modified from Bakker et al., 2007). The supply scenarios are based on uncertainties related to CDM regulations (strictness of additionality testing, procedures), and deployment rates of technologies (see also Section 6.1). Vertical lines indicate two CER demand scenarios.*

Step 2
To assess the impact of CCS on the CDM market in terms of supply of CERs and the CER price we develop four scenarios, based on the following considerations or variables[16]:

- The role of the CDM versus other possible post-2012 carbon market mechanisms. It is possible that the CDM is used only by the EU, while other developed countries use other mechanisms, which results in a 'fragmented' market. One the other hand, it is possible that the CDM is the only carbon credit mechanism in 2020 and therefore used by all developed countries, thereby covering the full demand for carbon credits ('CDM only'). The demand in these two scenarios is assumed to be fixed (i.e. not dependent on the carbon price) and is depicted in Figure 6.2 by the two vertical lines.
- Market dynamics: the CER price impact depends on the functioning of the market. 'Low responsiveness' refers to the possibility that additional supply potential of credits would have no or a small impact on the CER prices, while in 'high' responsiveness a supply increase has a downward impact on prices.

For the additional supply of credits due to CCS in the CDM we use the two supply curves from Chapter 5 that do not include EOR, as this storage technology is unlikely to be eligible under the CDM[17]. In Table 6.1 we quantify the CDM carbon market impact in ranges based on these two scenarios. The share of the CER supply by CCS is based on the assumption that the CER demand (i.e. 500 or 1700 MtCO_2 eq, see Section 6.1) can be met by a supply of projects that include all project types up to an abatement cost of €30/tCO_2. This assumption is in accordance with the approach used in Bakker et al. (2010) and the analysis by Castro (2010), which shows that the current CDM portfolio includes projects from different abatement cost categories, from negative to $40 per tonne of CO_2 eq, and to a limited extent from higher cost categories.

Step 3
The potential CER price impacts of CCS in case of the 'high responsiveness' / 'CDM only' scenario are based on the supply curves of Figure 6.2. For the low demand scenario of 500 Mt the impact is likely to be zero, as this demand can be met by no-regret options. In practice these options may not be realised due to non-financial barriers (Bakker et al., 2007), however the impact of the low-cost CCS options is not likely to be significant.

For the high demand scenario of 1700 million CERs, there could be a CER price effect. Without CCS the CER market price is estimated to be approximately $36[18] (scenario 1) or $12 (scenario 2 and 3 in Figure 6.2). With CCS (potential 50 Mt up to $30/t$CO_2$) the CER supply could increase, resulting in a downward effect of $0 (scenario 1) or $4 (scenario 2 and 3).

For the Fragmented Market scenario no meaningful CER price impact assessment was possible.

[16] Each variable can have two 'values', which lead to 2 x 2 scenarios (see Table 6.1).
[17] However for other instruments than CDM, EOR could be an eligible technology, therefore it is included in the MACs in Chapter 5.
[18] Using a €/$ ratio of 1.2

Table 6.1 *Potential impacts of CCS on the CDM market*

Market responsiveness	CCS impact	Carbon market 2020	
		Fragmented	CDM only
Low	% of CER supply	14-19%	4-5%
	$/tCO_2$-eq	0	0
High	% of CER supply	14-19%	4-5%
	$/tCO_2$-eq	-	0-4

7 Discussion and conclusions

The CDM is currently the only international climate instrument that could provide an incentive for CCS projects in developing countries. The decision at COP16 in 2010, allowing CCS projects to be in principle eligible under the CDM, provided a number of conditions are met, may encourage the development of CCS projects in Non-Annex I countries. . However, modalities and procedures will have to be drafted, which takes time. It is unclear whether Enhanced Oil Recovery will be developed under the CDM, as: accounting for the emissions of the combustion of the additional fossil fuels may lead to positive emissions, and the economics of EOR projects may be too favourable to pass the additionality test.

Even if the CDM would not be able to spur development of CCS projects, other instruments under the carbon market post-2012 may provide incentives for CCS, in addition to non-market instruments such as supported NAMAs. In order to characterise the opportunities for CCS in developing countries, we developed a marginal abatement cost curve. After a review of existing studies related to CCS potentials and scenarios in developing countries, we considered the IEA CCS Roadmap to be the most suitable basis for preparing the CCS MAC in 2020. This Roadmap can be considered an optimistic scenario for CCS, as the technology is still in an early stage (compared to e.g. wind energy) and achieving the projections for 2020 is far from an easy task. However, as it considers ongoing and planned CCS projects up 2017 it is also a realistic scenario.

Using this approach, the potential for CCS deployment in developing countries with abatement costs up to \$30/tCO_2 is estimated to be 70-100 MtCO_2/yr in 2020. The main part of this potential is in natural gas processing in Asian countries. CTL in South Africa may be an important option as well. It should be noted that the uncertainty in these figures is considerable, and is mostly related to the difficulty of making projections of CCS deployment (as done in the IEA Roadmap), to geological storage capacities, and to estimating the abatement costs.

Based on these figures for costs and potentials, we estimate CCS could take 4 – 19% of the CER supply in 2020. To account for all possible uncertainties in this assessment, we used four scenarios for the supply of and two scenarios for the demand for CERs in 2020, and in addition scenarios for the role of CDM in the post-2012 climate regime, and the market responsiveness. This allows to give a complete picture of the possible impacts of CCS on the CDM market. Finally, the CER price impact is estimated to be between 0 and 4 \$/tCO_2, with higher probability (i.e. most of the scenarios) for the lower part of this range.

References

Advanced Resources International (ARI) (2009) *CO_2 storage in depleted oil fields: global application criteria for storage in depleted oil field*. IEA GHG report IEA/CON/08/155.

Bachu, S. (2009) Capacity building in developing economies: building on the APEC and CSLF experience. *Energy Procedia* 1: 4719-4726.

Bakker, S., de Coninck, H., Ba, L., and Zhou, P. (2007a) *Advancing CCS and CDM in Africa: Outcomes of two workshops in Africa*. Report ECN-E-07-079, Petten.

Bakker, S.J.A., Arvanitakis, A.G., Bole, T., Brug, E., van de, Doets, C.E.M., Gilbert, A. (2007b). *Carbon Credit Supply Potential Beyond 2012. A Bottom-Up Assessment of Mitigation Options*. ECN-E–07-090, Energy research Centre of the Netherlands, Amsterdam/Petten.

Bakker, S., H. de Coninck, H. Groenenberg (2010) Progress on including CCS projects in the CDM: Insights on increased awareness, market potential and baseline methodologies *International Journal of Greenhouse Gas Control* 4 (2010) 321–326

BlueNext (2010). Statistics. Closing prices BlueNext Spot EUA 08-12. Available at (03/03/10): http://www.bluenext.eu/

BusinessGreen (2009) South Korea announces multi-billion dollar CCS test programme. Available at (7/10/2010): http://www.businessgreen.com/businessgreen/news/2251371/south-korea-spend-85m-ccs

Carbon Finance Online (2008) *Post-2012 CER demand 'could treble' – NCF*. http://www.carbon-financeonline.com/index.cfm?section=global&action=view&id=10993 (accessed October 28, 2010)

Carlisle, T. (2010). *Gas shortage squeezes crude output*. The National, Wednesday June 30th, 2010.

Castro, P. (2010) *Climate Change Mitigation in Advanced Developing Countries: Empirical Analysis of the Low-hanging Fruit Issue in the Current CDM*. CIS Working Paper No. 54, ISSN 1662-7504, Zurich

Coninck, H. de (2008) Trojan horse or horn of plenty? Reflections on allowing CCS in the CDM. *Energy Policy* 36: 929–936.

Dahowski, R., Li, X., Davidson, C., Wei, N., Dooley, J., and Gentile, R. (2009). A preliminary cost curve assessment of carbon dioxide capture and storage potential in China. *Energy Procedia* 1: 2849-2856.

Deutsche Bank (2008) *Carbon Emissions: It takes CO2 to Contango*. Deutsche Bank AG: London, UK.

G8 (2009) *Joint Statement by G8 Energy Ministers, The European energy commissioner, the energy ministers of Brazil, China, Eqypt, India, Korea, Mexico, Saudi Arabia and South Africa.* Rome, May 24, 2009. Available at (12/11/09): www.g8energy2009.it

GCCSI (2009) *An Ideal Portfolio of CCS Projects and Rationale for Supporting Projects*

Hagemann, M., S. Moltmann, A. Palenberg, E. de Visser, N. Höhne, M. Jung, S. Bakker (2010, forthcoming) *Advancing CCS through insights in the international climate regime*. CATO-2 Deliverable WP2.3-D03.

http://cdm.unfccc.int/public_inputs/inputam0001/Comment_AM0001_Schwank_081004.pdf

http://www.carbontradefinance.com/articles/IETA_GHG_Market_Report_2008%20AAU%20Trading.pdf

http://www.opec.org/home/Press%20Room/EU-OPEC%20presentations/HaddadjiSonatrach%20Algeria.pdf

IEA (2009) *Technology Roadmaps. Carbon capture and storage*. Paris

IEA/CSLF (2010). *Report to the Muskoka 2010 G8 Summit Carbon capture and storage. Progress and Next Steps*. 2010

IETA (2009) *Impact of AAUs on the international negotiations and carbon markets. International Emission Trading Association*, Geneva. Available at (04/03/2010) http://www.ieta.org/ieta/www/pages/download.php?docID=3311

Indonesia CCS Study Working Group, 2009. Understanding carbon capture and storage potential in Indonesia. Available at (23/11/2010) http://www.decc.gov.uk/assets/decc/what%20we%20do/uk%20energy%20supply/energy%20mix/carbon%20capture%20and%20storage/1_20100111133127_e_@@_ccspotentialindonesia.pdf

KPMG (2009) CDM market update – *power and utilities*. Issue 1, October 2009. Available at (03/03/10) http://www.kpmg.de/docs/Sustainability_CDM_Market_Update_China_10-2009.pdf

NETL (2010) *CCS projects list*. www.netl.doe.gov/technologies/carbon_seq/database/NETL%2520CCS%2520Projects%2520List.xls

NZEC (2008) *China-UK Near Zero Emissions Coal Initiative*. Available at (12/11/09): - http://www.nzec.info/en/assets/Presentations/Brochure/NZEC-Design.pdf

OPEC (2009). *The In-Salah CCS Experience Sonatrach, Algeria. EU-OPEC Roundtable on Carbon Dioxide and Storage. Prospects of CCS in OPEC member countries and the EU*. Available at (26/11/2009):

Point Carbon (2010) *CDM and JI monitor*, various issues in 2010, www.pointcarbon.com

Power-Gen (2010) *Masdar completes prequalification process for carbon capture project. Power-Gen worldwide.* Available at (7/10/2010): http://www.powergenworldwide.com/index/display/articledisplay/6996031490/articles/powergenworldwide/Business/contracts-and-projects/2010/05/masdar-completes_prequalification.html

Qian, J., Peridas, G., Chen, J., and Qiu, Y. (2009) *Identifying near-term opportunities for carbon capture and sequestration (CCS) in China*. Natural Resources Defense Council. Available at (23/11/2009): http://www.nrdc.org/international/chinaccs/files/fchinaccs.pdf

Ramming, I. (2008). *AAU trading and the impact on Kyoto and EU emissions trading. Before the flood or storm in a tea-cup?* Greenhouse gas market report 2008, 34. International Emissions Trading Association. Available at (03/03/2008):

Schwank, O. (2004) *Concerns about CDM projects based on decomposition of HFC-23 emissions from 22 HCFC production sites*. Infras. Available at (12/11/09):

Steidtman, J (2007) *Presentation to the Joint Minerals and Economic Development Committee. Enhance Oil Recovery Institute*, presentation 26 September 2007. eori.uwyo.edu/downloads/JMEDC_JS_070926.ppt

Surridge, T. (2010) *Carbon Capture and Storage in South Africa*. Presented at CCS in Southern Africa Workshop, Gaborone, April 2010. Available at (7/10/2010): http://www.ccs-africa.org/projects/ccs-in-southern-africa/botswana/workshop-programmes-and-presentations/

UNFCCC (2005). *The White Tiger Oil Field Carbon Capture and Storage (CCS) project in Vietnam,* NM0167. Project Design Document. Available at (24/11/2009): http://cdm.unfccc.int/UserManagement/FileStorage/AM6CJE7R0VH1DPTZ79LW4QQ26ZTQ04

UNFCCC (2006a). *Executive Board of the Clean Development Mechanism twenty-fifth meeting report. CDM-EB-50, 19-21st July 2006.* Available at: - (26/11/2009):http://cdm.unfccc.int/Reference/catalogue/document?doc_id=000000488&para_id=para-000055192#para-000055192

UNFCCC (2006b). *The capture of the CO2 from the Liquefied Natural Gas (LNG) complex and its geological storage in the aquifer located in Malaysia,* NM0168. Project Design Document. Available at (24/11/2009): http://cdm.unfccc.int/UserManagement/FileStorage/VK1I5G0CSRZYB8JCSMF1420747JTS7

UNFCCC (2008). Investment and financial flows to address climate change: an update. FCCC/TP/2008/7.

UNFCCC (2009a) *Possible implications of the inclusion of CCS as CDM activities*. Annex 11, Clean Development Mechanism Executive Board Meeting 50.

UNFCCC (2009b) *Further guidance relating to the clean development mechanism.* Decision 2/CMP.5.

UNFCCC (2009c) *Implications of the inclusion of geological carbon dioxide capture and storage as CDM project activities. An assessment. Final report for the UNFCCC*. Annex 4 to Executive Board report 49.

UNFCCC (2010a). *Decision/CMP.6: Carbon dioxide capture and storage in geological formations as clean development mechanism project activities*. Available on http://unfccc.int/files/meetings/cop_16/application/pdf/cop16_cmp_ccs.pdf

UNFCCC (2010b) *Information provided by the Parties to the Convention relating to the Copenhagen Accord*. http://unfccc.int/home/items/5262.php

URC (2010) *CDM/JI pipeline November 2010*. Available at (01/11/10): http://cdmpipeline.org/overview.htm

US DOE, 2007: *Cost and Performance Baseline for Fossil Energy Plants*, Volume 1: Bituminous Coal and Natural Gas to Electricity, US Department of Energy National Energy Technology Laboratory, Pittsburgh, available at (23/11/2009): www.netl.doe.gov/energy-analyses/pubs/Bituminous%20Baseline_Final%20Report.pdf

World Bank (2010) *State and trends of the carbon market 2010*. Washington, May 2010

WorleyParsons (2009) *Strategic Analysis of the Global Status of Carbon Capture and Storage.* Report 5: Synthesis Report. Global CCS Institute, Canberra.

Zakkour, P., King, E., Cook, G., Maruyama, N., and Rana, S. (2008): *Carbon Dioxide Capture and Storage in the Clean Development Mechanism: Assessing market effects of inclusion.* IEA GHG R&D Programme Technical Study, RN:2008/13, November 2008.

Zheng, Z., Larson, E., Li, Z., Liu, G. and Williams, R. 2010. Near-term mega-scale CCS demonstrations in China. *Energy and Environmental Science*, 3, 1153-1169.

Annex A. CCS MAC data

The data below describe the MAC presented in Chapter 5, which comprises Deliverable D02 of WP2.3 of the CATO-2 programme.

		Potential in 2020	Cost (Scenario 1)	Cost (Scenario 2)	Cost (Scenario 3)
Country		$MtCO_2eq$		USD/t CO_2eq	
China	CCS power	10.0	50.4	50.4	50.4
India	CCS power	3.0	51.8	51.8	51.8
Abu Dhabi	CCS power	1.7	54.0	54.0	34.0
Algeria	NGP	1.5	10.6	10.6	-9.4
Saudi Arabia	NGP	17.0	8.8	8.8	-11.2
UAE	NGP	7.7	8.8	8.8	-11.2
Malaysia	NGP	3.0	27.2	27.2	27.2
China	NGP	8.3	8.8	8.8	8.8
Libya	NGP	11.5	8.8	8.8	-11.2
Indonesia	NGP	12.3	24.4	24.4	24.4
Pakistan	NGP	1.7	9.6	9.6	9.6
Thailand	NGP	1.2	31.0	31.0	31.0
Kazakhstan	NGP	1.2	8.8	8.8	8.8
Iran	NGP	1.1	11.9	11.9	-8.1
Vietnam	NGP	0.7	23.4	23.4	23.4
Argentina	NGP	0.7	8.9	8.9	8.9
Brunei	NGP	0.5	31.0	31.0	31.0
Myanmar	NGP	0.3	8.8	8.8	8.8
Uzbekistan	NGP	0.3	9.4	9.4	9.4
China	*CTL*	*3.6*		*25.0*	25.0
South Africa	*CTL*	*24.0*		*25.0*	25.0
China	Ammonia	10.0	62.0	62.0	62.0
India	Ammonia	1.1	54.0	54.0	54.0
UAE	Iron and steel	5.0	70.0	70.0	50.0
Rest of non-OECD	CCS power	7.3	45.8	45.8	45.8
Rest of non-OECD	Ammonia	5.4	74.0	74.0	74.0
Rest of non-OECD	Iron and steel	2.4	71.0	71.0	71.0
Rest of non-OECD	Biomass (synfuels) and cement	4.0	80.0	80.0	80.0

Annex B. Ongoing and planned CCS projects in developing countries

The table below compares the IEA CCS Roadmap deployment projections with ongoing and planned CCS projects based on NETL (2010), IEA/CSLF (2010).

Sector	Region	Country		Potential [IEA Roadmap] $MtCO_2/yr$	Potential announced for projects $MtCO_2/yr$
Power	China and India			13	
		China	DaGang Huashi Power Plant		2.3
			Harbin Thermal Power Plant		2.7
			Harebin Thermal Power Plant		1.0
			GreenGen IGCC Project		2.0
			IGCC with CO2 capture project		1.0
			Lianyungang IGCC with CO2 capture project		1.0
		India			
	non-OECD			6	
		UAE	Hydrogen Power Abu Dhabi		1.7
Industry (IEA)	China and India			29	
		China	Chemical Plant, Yulin China Identify Dongguan Taiyangzhou		10.0
			NGP new fields (exploratory)		8.3
		India	Indian Farmers Fertiliser Cooperative Plant		1.1
	non-OECD			68	
		Algeria	In Salah Gas Processing Plant		1.5
		Malaysia	LNG Bintulu Plant		3,0
		UAE	Emirates Steel's Mussafah rolling mill, a gas fired power plant, and aluminum smelter		5,0
			NGP fields		7.7
		Libya	NGP new fields (exploratory)		11.5
		Saudi Arabia	NGP new fields (exploratory)		17.0
Industry - CTL		China			3.6
		South Africa			24.0