

Risk governance for geological storage of CO₂ under the Clean Development Mechanism

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Managing local and global risks from the geological storage of CO₂ under the Clean Development Mechanism (CDM) presents three main challenges. First, the CDM procedures must be adapted to the specifics of the technology. Second, storage must last far longer than the crediting period, leaving questions about the management of long-term risks. Third, management of local environmental, health and safety risks falls largely outside the CDM governance framework. CDM procedures could be adapted to successfully manage the short-term global risk of carbon dioxide re-entering the atmosphere during the CDM crediting period, but local environmental, health and safety risks and long-term global risk cannot be ensured under existing structures. To better manage these risks, the implications for the CDM are: (1) to provide guidance on site characterization requirements, and have an independent auditor verify that the proposed geological storage site has a high likelihood of safely containing the injected carbon dioxide; (2) to require that carbon capture and storage (CCS) project design documents specify post-crediting-period commitments; and (3) to support CCS specific capacity building. But because CDM governance is designed to strike a balance between respecting host country sovereignty and ensuring high-quality emission reduction credits, some limitations to risk management of geological storage under the CDM remain. These limitations should be weighed against the potential benefits of including CCS in the CDM.

Keywords: capacity building; carbon capture and storage (CCS); Clean Development Mechanism (CDM); geological storage; risk governance; seepage; site characterization; technology transfer; time

La gestion des risques à échelle locale et globale du stockage géologique du CO₂ sous le Mécanisme pour un Développement Propre (MDP) présente trois principaux défis. D'abord, les procédures du MDP doivent être adaptées aux spécificités de la technologie. Ensuite, le stockage doit durer beaucoup plus longtemps que la durée du projet, laissant les questions relatives à la gestion des risques à long-terme. Enfin, la gestion des risques locaux liés à l'environnement, la santé et la sécurité se situent largement en dehors du cadre de gouvernance du MDP. Les procédures du MDP pourraient être adaptées pour gérer avec succès le risque global à court terme de réémission atmosphérique de dioxyde de carbone pendant la durée du projet, cependant les risques liés à l'environnement, la santé et la sécurité et le risque global à long terme ne peuvent pas être adressés dans le cadre des structures actuelles. Dans la perspective d'une meilleure gestion du risque, les questions pour le MDP sont: (1) d'apporter des lignes directrices sur les besoins en terme de caractérisation du site et faire en sorte qu'un auditeur indépendant vérifie que l'aptitude du site de stockage géologique à contenir avec sûreté le dioxyde de carbone injecté soit élevé; (2) d'exiger que les documents du projet de CSC spécifient les engagements au-delà de la durée du projet; et, (3) soutenir le renforcement des capacités spécifiquement liées à la CSC. Mais du fait que la gouvernance du MDP soit conçue pour créer un équilibre entre le respect de la souveraineté des pays hôtes tout en assurant la bonne qualité des crédits de réduction d'émissions, certaines restrictions dans la gestion du risque du stockage géologique dans le cadre du MDP restent de fait. Ces restrictions pourraient être comparées avec les avantages potentiels d'une inclusion de la CSC dans le MDP.

Mots clés: capture et stockage de carbone (CSC); caractérisation des sites; échelle de temps; gouvernance des risques; infiltration; Mécanisme pour un Développement Propre; renforcement des capacités; stockage géologique; transfert de technologies

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1. Introduction

Can an emerging technology be safely deployed simultaneously in the developed and developing worlds? This fundamental question underlies the debate over whether to include carbon dioxide capture and geological storage (CCS) projects in the Clean Development Mechanism (CDM). CCS projects collect carbon dioxide (CO₂) at industrial facilities or electric power plants and inject it into deep geological formations for permanent storage. The technology is not yet widely deployed, with only four commercial-scale operations worldwide,¹ but it has the potential to be a major tool for reducing greenhouse gases. Researchers project that CCS could supply 15–55% of the emissions reductions necessary to stabilize atmospheric concentrations of CO₂ (IPCC, 2005).

The Kyoto Protocol instituted the Clean Development Mechanism (CDM) to give developed countries the flexibility to carry out greenhouse gas (GHG) emission reduction projects in developing countries while promoting sustainable development (UNFCCC, 1998). The United Nations Framework Convention on Climate Change (UNFCCC) is weighing the risks and benefits of including CCS in the CDM through a formalized process of consultation and negotiation that started in 2005 and is slated for a decision in 2008 (UNFCCC, 2006a, p. 6). So far, two CCS projects have been submitted to the CDM;² these are on hold pending the outcome of this process. See Table 1 for a timeline of milestones for consideration of CCS in the CDM.

The hope is that CDM credits could make it economic for developing countries to include CCS technology when building new energy infrastructure, resulting in increased energy services and economic growth without additional GHG emissions. Short-term CCS potential lies in industrial processes that generate a concentrated CO₂ stream, such as natural gas, ammonia, or hydrogen production. Analysis by the International Energy Agency shows that in developing countries there is technical potential for emission reductions of over 250 million tons per year from these near-term CCS opportunities (Philibert et al., 2007). Costs will vary according to the composition of the CO₂ stream, the characteristics of the geological reservoir and its distance from the CO₂ source, but generally, current CDM credit prices could bring some projects to market, most probably those associated with natural gas production, where CO₂ must be removed before the gas can be marketed.³

Long-term CCS potential lies in fossil-fired electric power generation, especially for rapidly developing countries, such as China and India, that have large coal deposits and a rapidly increasing demand for electricity. Deploying CCS in developing countries where coal-fired generation is projected to increase significantly over the coming decades could make an important contribution to stabilizing atmospheric CO₂ levels; however, the prioritization of economic development and energy security, plus strong financial constraints, are significant obstacles to deployment. Project-based mechanisms for cooperation between developed and developing countries can help overcome these obstacles (Vallentin, 2007). The CDM is one potential mechanism to promote this technology transfer, and CCS projects fit the profile of project types likely to result in successful technology transfer (Haïtes et al., 2006). Technology transfer and CCS capacity building are important because in the long term (post-2050), more than half of worldwide technical CCS potential will be found in what we now call the developing world (Philibert et al., 2007).

Inclusion of CCS in the CDM is controversial. At the December 2007 UNFCCC Conference in Bali, CCS Working Group members reached no agreement on the issues under consideration (IISD Reporting Service, 2007). In fact, some observers even question the efficacy of the CDM itself, noting that while it has accomplished the political objectives of engaging developing countries in the climate change debate, it has been inefficient both as a market and as a subsidy

Appendix

TABLE 1 Timeline of milestones for carbon capture and storage (CCS) in the Clean Development Mechanism (CDM)

Date	Milestone	Meeting	Location
January, 2005	Proposed CCS projects in Vietnam (NM0167) and Malaysia (NM 0168) submitted to CDM Executive Board		
November, 2005	Decision to organize a workshop on CCS as CDM project activities (FCCC/KP/CMP/2005/8/Add.1)	COP/MOP 1	Montreal, Canada
May, 2006	Workshop report on CCS as CDM project activities (FCCC/FP/CMP/2006/3)	CCS Workshop	Bonn, Germany
September, 2006	Draft Recommendation on CCS as CDM project Activities. Concluded that CCS could not be approved in the CDM until certain policy and technical issues were resolved (Meth Panel 22 nd meeting report Annex 12)	CDM Meth Panel 22 nd meeting	
November, 2006	Call for further guidance on CCS as CDM project activities. Invitation for parties and observer NGOs to submit information on a list of specific questions. (FCCC/KP/CMP/2006/L.8)	COP/MOP 2	Nairobi, Kenya
May, 2007	Submissions to UNFCCC Secretariat on CCS from 6 observer NGOs and 2 nonobserver NGOs ^a		
September, 2007	Submissions to UNFCCC Secretariat on CCS from Parties to the Kyoto Protocol ^b		
December, 2007	Considered submissions by NGOs and parties on CCS as CDM project activities. Invited parties, IGOs and NGOs to submit their views on additional issues reflecting the informal discussions at SBSTA 27 by 16 June 2008. Requested the secretariat to prepare a synthesis report on all submissions regarding CCS as CDM project activities. (FCCC/SBSTA/2007/L.19)	SBSTA 27	Bali, Indonesia
April, 2008	Synthesis report issued (FCCC/SBSTA/2008/INF.1)		
June, 2008	Considered Synthesis report and conclusions proposed by the chair. Did not agree to adopt these conclusions. (FCCC/SBSTA/2008/06)	SBSTA 28	Bonn, Germany
December, 2008	Scheduled to consider synthesis report and decide whether to include CCS as CDM project activities	COP/MOP 4	

^a Submissions from Greenpeace, the International Emissions Trading Association (IETA), International Petroleum Industry Environmental Conservation Association (IPIECA), International Risk Governance Council (IRGC), World Coal Institute (WCI), World Wildlife Fund (WWF), The Bellona Foundation, and the Norwegian Forum for Environment and Development can be found at http://unfccc.int/parties_and_observers/ngo/items/3689.php

^b Submissions were received from Canada, Japan, Korea, Norway, Portugal (supported by Albania, Bosnia and Herzegovina, Croatia, the former Yugoslav Republic of Macedonia, Serbia, Turkey and Ukraine), and Saudi Arabia. Submissions can be downloaded from [http://unfccc.int/documentation/documents/advanced_search/items/3594.php?such=j&meeting=%22\(SBSTA\),+Twenty-seventh+session%22&sorted=agenda#beg](http://unfccc.int/documentation/documents/advanced_search/items/3594.php?such=j&meeting=%22(SBSTA),+Twenty-seventh+session%22&sorted=agenda#beg)

(Wara, 2007). The divergent stakeholder perspectives can be seen in recent submissions from non-governmental organizations to the UNFCCC on the subject of the inclusion of CCS in the CDM.⁴ In general, these disagreements fall into six general themes:

1. Is CCS sustainable development?
2. Should CCS projects that include oil or gas production be allowed?
3. Would CCS projects displace renewable energy projects or forestry projects?
4. Would large volumes of CCS credits distort the CDM market?
5. Is the CDM the best incentive structure to promote CCS technology transfer?
6. Can the risk of CO₂ escaping from the geological storage reservoir be adequately managed under the CDM?

This article examines only the last question: managing the risk of leakage from geological storage under the CDM. In this article, the term *seepage* refers to CO₂ that migrates from the intended geological storage reservoir to another subsurface zone or back into the atmosphere. This differs from the CDM's usage of the term *leakage* to refer to emissions caused by a project that occur outside the project boundaries (UNFCCC, 2006b). Seepage risks were the primary focus of the UNFCCC's call for further guidance after the Nairobi meeting in 2006 (UNFCCC, 2006a). The potential for seepage drives issues related to site selection, monitoring, remediation, emissions accounting, site closure requirements, and long-term liability. Developing modalities and procedures to manage the risks of seepage will not untangle the political and ideological threads that dominate the current discussion of CCS in the CDM (de Coninck, 2008), but it can help clarify the debate. And regardless of what path global climate change governance follows post-2012, adequately managing seepage risk from the geological storage of CO₂ in developing countries will involve concerns similar to those considered here.

We present an overview of geological storage risks and CDM governance, and then look at the unique challenges that emerge when CDM governance is overlain onto the full life-cycle risk profile of a geological storage project, and discuss policy alternatives to address these challenges. Finally, we discuss the wider context, including the CDM's potential role in the early deployment phase of CCS, the relative competence of risk management under the CDM compared with other potential mechanisms for the transfer of CCS technology to developing countries, and the tradeoffs between the risks and benefits of including CCS in the CDM.

2. Geological storage risks

CCS projects consist of three components; CO₂ capture, transportation, and geological storage. It is the risks associated with geological storage that present new challenges: risks associated with the above-ground components are well understood and managed successfully in other industrial settings (IEA GHG R&D Programme, 2007). The risks associated with geological storage stem largely from the potential for CO₂ to migrate from the intended geological storage reservoir to another subsurface zone or to escape back into the atmosphere.

Geological storage risks can be local or global. Local risks include the environmental, health or safety impacts of seepage, risks to groundwater quality, and risks due to quantity effects (Wilson et al., 2003). Global risk could arise if seepage from geological storage undermined climate change goals. Geological storage needs to last for hundreds (Pacala, 2002) to thousands (IPCC, 2005) of years for CCS to effectively contribute to stabilizing atmospheric CO₂ levels. CDM governance needs to ensure that both local and global risks of geological storage projects are adequately managed.

Features, events and processes that could lead to seepage are reasonably well understood. Geological features, such as faults or heterogeneity of the confining layer, could provide pathways

for seepage, as could anthropomorphic features, such as wells (IPCC, 2005). Most researchers believe that the risk of seepage at well-chosen, well-operated sites is extremely low (IPCC, 2005); however, seepage probabilities and rates are not yet quantifiable and will vary by site. Project developers, regulators and researchers lack broad worldwide experience with geological storage in a variety of geological and geographical settings. Despite the uncertainty, a general understanding of storage processes and reservoir characteristics can help to structure policy choices to manage risk. Risk of seepage will be site-specific and tied to: geological features and past use; the volume of CO₂ injected and the resulting reservoir pressure; and reservoir location and type.

Generalized risk profiles (see Figure 2) suggest that seepage risk may rise as injection progresses, reservoir pressure increases, and the plume expands. Seepage risk is generally expected to peak around the time that injection ends, and then gradually decay for decades or centuries, as secondary trapping mechanisms (such as dissolution, capillary trapping and mineralization) immobilize the CO₂ (Benson, 2007). Sites that do not follow this profile, for example sites with significant seepage early in the project, would be discovered through monitoring and either remediated or abandoned. Risk from seepage will also vary by geological storage reservoir location and type, as shown in Table 2. Local and global risks are diminished at offshore locations because no communities will be living atop the storage reservoir, and the ocean could attenuate any seepage. Oil and gas reservoirs are vulnerable to seepage through the many wells that have penetrated the confining layer; saline reservoirs may be vulnerable to geological uncertainty, as they lack the extensive history of geological characterization accumulated for oil and gas reservoirs.

Ongoing research and demonstration projects will improve our understanding of geological storage risks. Australia, Canada, the EU, and the USA all have active CCS research and development programmes in place, and several commercial-scale pilot projects (injecting at least 1 million tons of CO₂ per year) are scheduled for the next few years.¹ Therefore, geological storage risk governance will need to incorporate technical data and experience from early commercial-scale projects as it becomes available, and regularly access top international expertise to refine regulatory requirements (Wilson et al., 2008).

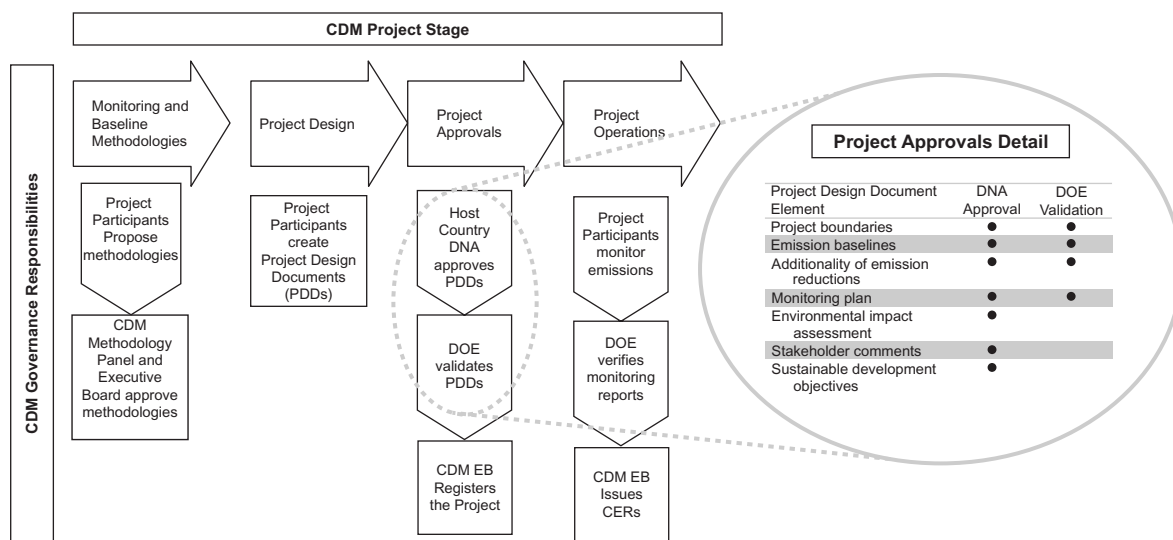
TABLE 2 Seepage risk varies by reservoir location and type

		Reservoir location and type				
		Onshore		Offshore		
		Oil/Gas	Saline	Oil/Gas	Saline	
Seepage risk potential	Impacts	Human health	●	●		
		Ecosystems	●	●	●	●
		Drinking water	●	●		
		Fluid displacement	●	●	●	●
		Atmosphere	●	●		
	Vulnerabilities	Wells	●		●	
		Faults	●	●	●	●
		Geological uncertainty		●		●

3. CDM risk governance

The purpose of CDM governance is to ensure accurate accounting of emissions reductions, protecting the integrity of the carbon market. From a risk management perspective, this translates into the management of global risk during the CDM crediting period, assuming that modalities and procedures are adapted to the specifics of geological storage. CDM governance involves UN bodies, regulators from the country where the project takes place (the host country), and private actors, each with distinct responsibilities. The CDM governance process begins with the approval of baseline and monitoring methodologies and continues through the issuance of certified emission reductions (CERs) for the final crediting period (a maximum of 21 years after project operation begins for most projects; 60 years for afforestation and reforestation). Figure 1 illustrates the CDM process. See Table 3 for more detail on the actors and their roles.

The focus on emission accounting can be seen in the attention to baseline and monitoring methodologies at the start of a project, as well as in the project approvals stage, where project design elements associated with emissions accounting (such as project boundaries, baseline, and monitoring plans) are subject to dual approval from both the host country regulator and an independent auditor (the designated operational entity (DOE) – an auditor certified by the CDM EB and hired by CDM project participants). Other elements of the project design, such as environmental impact analysis, stakeholder consultation and sustainability objectives, are left to the sole approval of the host country as a matter of national sovereignty.



Acronyms: CER – certified emission reduction; DNA – designated national authority (host country regulator); DOE – designated operational entity (independent auditor); PDD – project design document.

FIGURE 1 The Clean Development Mechanism (CDM) governance process. Rules focus on emission accounting, with baseline and monitoring methodology requirements and dual approvals of project design elements associated with emissions accounting, such as project boundaries, baseline, and monitoring plans. Elements related to environmental impacts or sustainable development objectives receive less oversight.

TABLE 3 The Clean Development Mechanism (CDM) risk governance structure

Risk governance actor	Description	Role	Responsibilities
Project participants	Private parties, including the project operator and any partners	Proposes new baseline and monitoring methodologies	Structures the framework for accurate emissions accounting during the crediting period
		Creates project design documents (PDDs)	Environmental Impact Assessment (EIA) Stakeholder consultations Site-specific plans for monitoring and remediation Site-specific plans for emissions accounting (project boundaries, baseline, and additionality) Demonstrates how the project will contribute to sustainable development ^a
		Project operations	Implements project as approved in PDD Submits annual monitoring reports Corporate Environmental Management Systems and Industry Best Practices guidelines supplement CDM governance
Designated national authority (DNA)	Host country national regulator	Approves PDD	Approval lays the groundwork for how all aspects of local and global CCS risks will be managed Sole authority to approve EIA and vouch for sustainable development credentials
Designated operational entity (DOE)	Independent auditor accredited by the CDM EB, hired by project participants	Validates PDD	Vouches for the accuracy of project boundaries, baselines, and additionality in the PDD Reviews DNA approvals of EIA and sustainability to make sure submission is complete
		Verifies annual monitoring reports	Vouches for accuracy of monitoring data
CDM Executive Board (CDM EB)	United Nations body	Approves baseline and monitoring methodologies	Establishes the framework for accurate emissions accounting during the crediting period
		Registers each project	Final layer of project oversight. Can challenge or reject a project
		Issues CERs	Ultimate guardian of short-term global seepage risk

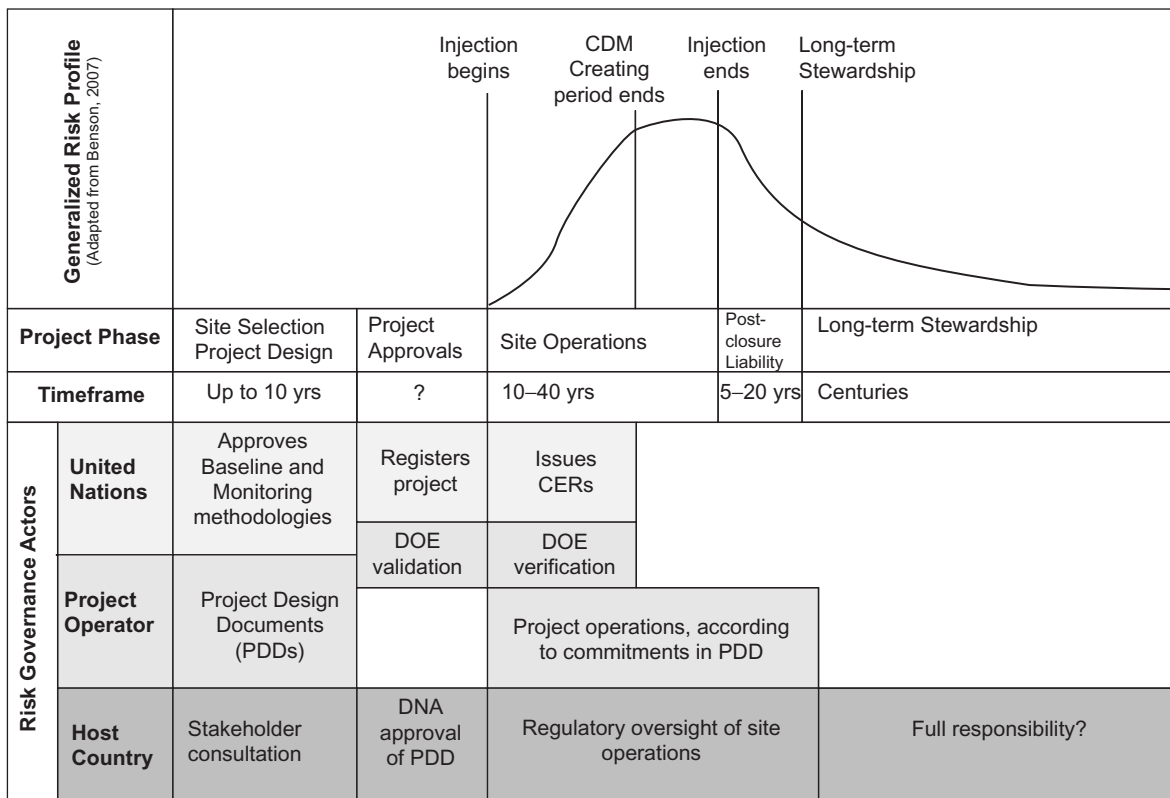
^a Sustainable development is not a risk management issue *per se*, but it is important to understanding the dynamics of the approvals process.

4. Risk management challenges for geological storage in the CDM

When the CDM risk governance structure is overlain on the generalized geological storage risk profile over the entire project life-cycle (Figure 2) we see that there is progressively less regulatory oversight as the project progresses. Three main challenges emerge. First, as previous authors have noted, CDM modalities and procedures must be adapted to the specifics of geological storage in order to effectively manage global risk during the crediting period; and, second, storage must last far longer than the crediting period, leaving questions about management of long-term risks (IEA GHG R&D Programme, 2007; Philibert et al., 2007; UNFCCC, 2008). The third challenge is that management of local environmental, health and safety risks will most probably not be subject to international monitoring under the CDM governance framework.

4.1. Adapting CDM procedures to fit geological storage

Significant progress has been made in adapting CDM protocols to the specifics of CCS for the issues comparable to those faced by other types of CDM projects. The development of CDM



Acronyms: CER – Certified emission reduction; DNA – Designated national authority; DOE – Designated operational entity; PDD – Project design document

FIGURE 2 Generalized carbon capture and storage (CCS) seepage risk and the Clean Development Mechanism (CDM) governance structure. There is progressively less oversight as the project progresses.

modalities and procedures for CCS is the subject of ongoing discussions and negotiations through the UN Subsidiary Body for Scientific and Technical Advice (SBSTA) (Watanabe et al., 2007). A comprehensive proposal was prepared for the International Energy Agency (IEA) Greenhouse Gas R&D Programme in May 2007, suggesting common guidance for companies to use when preparing methodologies and project design documents (PDDs) for CCS projects (IEA GHG R&D Programme, 2007). The IEA GHG R&D Programme's guidelines propose a thorough approach to handling baseline, additionality and project boundary issues and a monitoring methodology to meet the standards of the 2006 Intergovernmental Panel on Climate Change (IPCC) *Guidelines for National Greenhouse Gas Inventories* (IPCC, 2006) within the CDM governance framework. Procedures such as these could effectively manage global risk during the crediting period through accurate greenhouse gas (GHG) inventory accounting.

Potential seepage after the crediting period creates special issues for emission accounting and crediting rules for CCS in the CDM. This important topic is the subject of considerable research and negotiation (Heafeli et al., 2004; Bode and Jung, 2006; IEA GHG R&D Programme, 2007; Philibert et al., 2007; Watanabe et al., 2007). A full treatment is beyond the scope of this article, but it should be noted that emission-crediting rules for CCS projects in the CDM will influence risk management activities by assigning responsibility for who must pay for seepage, as discussed further in Section 5.2.

4.2. Risk management after the crediting period

The CDM crediting period will be shorter than the geological storage period (Figure 2), creating responsibilities for project operators and host countries that do not arise in other types of CDM projects. Who will be responsible for continued monitoring (and remediation if necessary) after the crediting period? Long-term liability issues for geological storage have yet to be resolved by any legal system, but most authors envision that, after injection ceases, project operators would retain responsibility for a time period sufficient to demonstrate that storage is stable and is behaving predictably (MCMPR, 2005; de Figueiredo, 2007). After that, geological storage sites would be likely to undergo a structured transition from private to public responsibility, because national governments may be the only entities capable of making credible commitments over sufficiently long time periods. A similar model is probably necessary for CO₂ storage sites created as CDM project activities (Philibert et al., 2007), but it is not clear that developing countries would accept CDM projects that impose additional responsibilities upon them.⁵ SBSTA delegates at the Bali Conference indicated that long-term liability is a key unresolved issue (IISD Reporting Service, 2007).

4.3. Management of local risks

National sovereignty dictates that host country regulators will manage the local environmental, health and safety risks of geological storage projects in the CDM: successful risk management will depend on host county regulatory capacity. In most developed countries, regulatory structures exist that can be adapted to manage the environmental, health and safety risks of geological storage (Wilson et al., 2008), but this is not uniformly true in developing countries.

Local management of local geological storage risks is not unique to the CDM. Governance by national (rather than regional or international) regulators is emerging as the regulatory model in developed countries as well. Deliberations on the inclusion of CCS in the European Union Emissions Trading Scheme (EU ETS) provide a close regulatory analogue, as this framework shares the CDM's basic objective of generating emission reductions for the Kyoto compliance market. Analysis by the European Commission Directorate-General Environment concludes that the IPCC GHG

accounting guidelines and EU ETS requirements would manage the global risks of geological storage, but would not provide regulatory coverage for local environmental, health and safety risks, and would provide only partial coverage for site characterization and environmental impact assessment of CO₂ storage sites (Zakkour, 2007). To cover these gaps, the European Commission has introduced a proposed Directive on the geological storage of carbon dioxide, which delegates the implementation of local environmental, health and safety risk regulation to Member States (European Commission, 2008).

5. Policy proposals to improve risk governance of geological storage of CO₂ under the CDM

Assuming that CDM modalities and procedures can be adapted to manage short-term global risk, we discuss three policy approaches that have been proposed to improve the management of local risks and long-term risks of geological storage under the CDM:

1. Site characterization studies approved by an independent auditor
2. Explicit post-crediting-period commitments
3. Access to top international CCS expertise.

The following sections discuss each of these proposals, including lessons learned from regulatory analogues, and projected outcomes.

5.1. Oversight of site characterization studies

Diligent site selection and characterization is the single most potent method to minimize all risks of geological storage over the complete project life-cycle (IPCC, 2005; UNFCCC, 2008, para 37). A high-quality site characterization will determine whether the site is suitable for geological storage and form the basis for monitoring and remediation plans. Ensuring that only suitable sites are chosen, and that they are well monitored, will decrease the potential for local environmental, health and safety impacts, and reduce the expense of long-term care. The question is how to achieve this objective under the CDM.

Site characterization consists both of the studies that collect geological, geophysical, geomechanical, geochemical and geographical data about a site, and the risk assessment that uses this data to assess whether the site has a high likelihood of safely containing injected carbon dioxide. While there is general agreement about the types of data that should be collected (European Commission, 2008; UNFCCC, 2008, para 38), no fully integrated risk assessment has yet been carried out for a geological storage project, and there is no consensus yet on the merits and shortcomings of different risk assessment methodologies that are under development (IEA GHG, 2007).

Some current proposals (IEA GHG R&D Programme, 2007), and past practice within the CDM, suggest that site characterization could be placed within the environmental impact assessment, but we believe that this structure is not robust enough to ensure consistent quality. As CDM governance currently stands, international oversight of environmental impact assessments is limited. The host country sets the requirements for the environmental impact assessment, because weighing environmental risks and benefits is considered their sovereign concern. The independent auditor's (DOE) oversight is limited to documenting that an environmental impact assessment was conducted in accordance with the procedures required by the host country (UNFCCC, 2002). This parallels the governance of sustainable development objectives within the CDM, which is left to the discretion

of the host country as a matter of national sovereignty. Furthermore, the CDM provides no monetary incentives for sustainability or environmental objectives: only emissions reductions are rewarded. This arrangement has stymied the sustainable development objectives of the CDM (Ellis et al., 2007). Without any accompanying incentives, site characterization conducted as part of the environmental impact assessment could suffer a similar fate.

CDM governance provides a stronger oversight for the portions of the project design documents that deal with project boundaries, additionality, leakage and monitoring. An independent auditor (the DOE) must validate that these aspects of the project meet approved baseline and monitoring methodologies. If all parties agree that the integrity of site characterization deserves more assurance, site characterization modalities and procedures could be developed for CCS projects that would subject site characterization studies and risk assessment to oversight and approval by both host country regulators and the independent auditor (the DOE) (Philibert et al., 2007). The Clean Development Mechanism Executive Board (CDM EB) could provide guidance on site characterization requirements (Philibert et al., 2007; UNFCCC, 2008), but the quality of site characterization and risk assessment will depend on the details of the modalities and procedures that are negotiated. Host countries may well agree to dual oversight by both the DOE and the DNA (designated national authority, i.e. the host country regulator) of site characterization studies, because these requirements would be largely technical, much like baseline and monitoring requirements. However, risk assessment is a different matter. Host countries may wish to reserve their sole authority about how to use site characterization data for risk assessment, to weigh what is in their best interests, as they do with consideration of environmental impacts or sustainable development objectives.

Efforts to develop site characterization guidelines are under way. The 2006 IPCC inventory guidelines on geological storage of carbon dioxide include a discussion of site characterization (IPCC, 2006), the 2008 EC proposed Directive on the geological storage of carbon dioxide lays out site characterization requirements (European Commission, 2008), the Australian State of Victoria has introduced legislation for a regulatory framework for geological storage that covers site characterization (Parliament of Victoria, 2008), and the US EPA proposed regulations for CO₂ injection wells under the Underground Injection Control Program in July 2008 (US Environmental Protection Agency, 2008). Development of site characterization and risk assessment requirements for CCS projects in the CDM could build upon these efforts.

5.2. Post-crediting-period commitments

To successfully manage long-term risks, CDM procedures would need to explicitly and transparently detail the responsibilities of the project operator and the host country after the final crediting period, including:

- monitoring, reporting, and remediation
- proper site closure
- liability for seepage
- conditions for liability transfer
- contributions to funding for long-term care.

Proposals for up-front liability agreements (Philibert et al., 2007; UNFCCC, 2008) do not acknowledge the fact that CDM governance will probably have limited ability to influence the specifics of post-crediting-period commitments, because they will be bilateral contracts between

project operators and host countries. The IEA guidelines propose that these post-crediting commitments be specified in the Environmental Impact Assessment (IEA GHG R&D Programme, 2007). While the Environmental Impact Assessment may seem like a somewhat awkward vehicle for such vital commitments, the logic of this proposal goes to the heart of the difficulty of governing long-term risks of geological storage under the CDM. The host country's agreements with CCS project operators regarding actions to be taken after the crediting period will be their sovereign concern, as are the assessments of environmental impacts and sustainable development benefits.

A somewhat analogous issue arose during the debate over the inclusion of forestry projects in the CDM. Proper management of the socio-economic impacts of forestry projects, while outside the traditional bounds of CDM project governance, is vital to their success, due to a high public awareness of these projects and their effects (Graichen, 2005). These concerns prompted a requirement that project participants conduct an analysis of socio-economic as well as environmental impacts, and submit documentation of this analysis with project design documents (UNFCCC Decision 19/CP.9). Respect for national sovereignty, however, produced protocols that place authority for design and approval of the socio-economic impact analysis with the host country: the independent auditor's oversight is limited to confirming that the analysis has been conducted. It seems likely that CDM protocols for CCS covering post-crediting-period commitments would be similarly structured.

Worldwide, no comprehensive model for funding and administering long-term geological storage site care has yet been developed that could serve as a model for the CDM. The willingness of citizens to accept such responsibilities, and the arrangements for funding and administering long-term site care, are in early stages of consideration in other forums. Discussions on whether to include CCS from Phase II of the EU ETS have identified issues of site closure and liability transfer as significant regulatory gaps (Zakkour, 2007). State legislatures in Texas and Illinois offered state indemnity for long-term liabilities for the proposed (and now cancelled) FutureGen project in the USA. Presumably, the stakeholder consultations required for CDM project design documents should touch on host country public willingness to assume long-term responsibility for CO₂ storage sites, but questions arise over whether civil society institutions are uniformly robust enough to contribute meaningfully (WWF, 2007). International financial and insurance institutions can help design appropriate long-term care funding mechanisms, but the form that these take will be strongly influenced by the requirements put forth by the host country.

CDM governance has limited ability to influence the management of long-term geological storage risks. Climate risk could be managed by attaching liability to the CERs created, as has been done for forestry projects; but, for local risks, the CDM executive board is limited to providing guidance on models for funding and administering long-term care for CO₂ storage sites, and requiring that the post-crediting commitments of the host country and project operator be disclosed in the project design documents.

5.3. Access to top CCS technical expertise

CCS is at a very early stage of deployment, which means that site characterization protocols, monitoring technology, and remediation techniques are rapidly advancing as experience with pilot and early commercial CCS projects grows. This means that CDM modalities and procedures will need to advance the cutting edge on these topics. Therefore, UN bodies and developing countries will need access to state-of-the-science knowledge. To provide the necessary technical prowess for CCS under the CDM, the IEA GHG R&D Programme (2007) proposes that the CDM Executive Board: (1) create a new sectoral scope for CCS; (2) create a working group of CCS

technical experts charged with evaluating proposed CCS baseline and monitoring methodologies, and with defining competencies for auditor certification; and (3) provide technical support for host country regulators in evaluating CCS project design documents. This proposal is analogous to the approach taken for afforestation/reforestation (A/R) in the CDM but, while necessary to support CCS technology in the CDM, by itself it is not sufficient to trigger deployment of CCS in the CDM. The new sectoral scope for A/R and the efforts of the working group have not catalysed wide interest in A/R projects. As of May 2008, 12 A/R methodologies had been approved, but no CERs for A/R projects had been issued.⁶ Hopefully, this imbalance between institutional investment and emission reductions can be avoided for CCS.

It is less clear whether CDM governance can aid the crucial CCS-specific capacity building for host country regulators. Currently, surveys of CDM-related capacity building activities indicate the insufficient institutional capacity of host country regulators to manage climate change programmes as a significant barrier (Nondek and Niederberger, 2005; UNFCCC, 2007). Successfully overcoming this barrier for CCS as CDM project activities may prove challenging because provision of CCS technical support for host country regulators is a very specific 'top-down' mandate, whereas the strategic approach of the Global Environmental Facility (GEF), which has been delegated to coordinate capacity building under the Kyoto Protocol, is to support 'bottom-up' capacity building projects initiated by host countries (GEF, 2003). Efforts are under way, however, including capacity building workshops for CCS in the CDM held in Africa in September 2007, organized by the Energy Research Centre of the Netherlands, and the African non-profit group Environment and Development Action. The Carbon Sequestration Leadership Forum organized three CCS capacity building workshops in 2007, which were reasonably well attended; however, obtaining financing to facilitate participation by regulators from developing countries was noted as a concern (CSLF, 2008).

Despite the difficulties, any decision to include CCS in the CDM should be accompanied by specific plans for both general CCS capacity building and specific technical support for regulators in the host country of proposed CCS projects. Buttressing the technical capabilities of host country regulators to evaluate whether the site characterization and environmental impact assessment are comprehensive, whether monitoring and remediation plans are appropriate, and whether post-crediting-period commitments are adequate, would clearly improve CCS risk management. Ultimately, however, host country regulatory capacity is another aspect of CCS project risk management over which CDM governance has limited control.

6. Discussion and conclusions

6.1. What is the role for developing countries in the early deployment phase of CCS?

The current discussion over inclusion of CCS in the CDM is in part a debate over the role of developing countries in the *early-deployment phase* of CCS. It is often reported that CCS will not be ready for widespread commercial deployment until approximately 2020 (MIT, 2007), but a crucial early-deployment phase lies between now and then, during which a limited number of full-scale CCS projects worldwide will generate the scientific and technical underpinning for widespread deployment (Wilson et al., 2008).

6.2. Can CCS projects through the CDM contribute to the valuable knowledge base that will be built during early deployment?

Realistically, certain types of CCS projects are more likely to be financially viable during the early deployment phase, especially considering the relatively low market price for certified emission

reduction (CER) units.³ Development of modalities and procedures for CCS in the CDM will probably prove to be academic unless project types with lower CO₂ capture costs (such as those associated with natural gas recovery) are allowed. While there is concern about how to handle the greenhouse gas accounting issues for CCS projects associated with hydrocarbon production (additionality), a benefit of allowing these types of projects, thus making CCS within the CDM feasible during the CCS early deployment phase, is that it would enable CCS capacity in the developing and developed worlds to advance in tandem. This arrangement stands to benefit developing countries that gain early adopter advantages, as well as strengthening worldwide development of a general governance framework for CCS by providing experience in a wider variety of geological and institutional situations. While some suggest that CCS be fully vetted in developed countries before it is deployed in the developing world (WWF, 2007), the possibility exists that capabilities could develop in parallel, as long as CDM governance accesses top experts worldwide to design appropriate methodologies and provide state-of-the-science support to host country regulators and to auditors validating and verifying CCS projects.

6.3. How would risk management under other technology transfer mechanisms compare to the CDM?

Our analysis indicates that CDM governance for geological storage faces challenges in managing local environmental, health and safety risks, and in managing long-term global risk by ensuring appropriate post-crediting-period commitments. How would alternate technology transfer mechanisms perform in these areas? Other mechanisms that could promote CCS projects in developing countries include private commercial ventures, such as the BP project at In Salah, Algeria or bi- or tri-lateral projects, such as the EU–UK–China Memorandum of Understanding to develop a CCS demonstration project in China. In terms of managing local environmental, health and safety risks, projects developed under these other mechanisms would be no different from projects under the CDM: local environmental, health and safety risks would be overseen by host country regulators. Likewise, post-crediting-period commitments would be negotiated between project developers and the host government under these alternative mechanisms just as under the CDM. Thus, the CDM may provide better risk management than these alternative technology transfer mechanisms because it can provide greater transparency and at least a minimum requirement that post-crediting-period commitments have been considered rather than ignored. Finally, the CDM provides superior management of short-term global risk because of its well-developed governance structures to accurately account for (and financially reward) CO₂ emissions avoided.

6.4. Can geological storage risks be adequately managed under the CDM?

Existing CDM governance structures could be adapted with modalities and procedures to adequately manage the short-term global risks of geological storage projects. Ultimately, however, CDM governance is designed to strike a balance between respecting host country sovereignty and ensuring high-quality emission reduction credits. As a result, CDM governance faces limitations in its influence over the management of local environmental, health and safety risks, long-term risks, and host country regulatory capacity. Risk management can be improved, with the proposals discussed above, but limitations will remain. CDM decision makers can, however, compensate for some of the uncertainties and limitations of geological storage in the CDM by rejecting sites where host country regulatory capacity is inadequate, and by giving preference to sites that present lower seepage risk, such as offshore sites or sites that have well-characterized geology.

6.5. Tradeoffs

At this point in time, geological storage risk management capabilities may not be as strong in developing countries as in developed countries, but they may be adequate to safely deploy CCS if supplemented by rigorous CDM modalities and procedures. The benefits of pursuing CCS in the CDM, despite the challenges, include the more rapid diffusion of CCS technology into countries with rapidly growing energy demand, and the contribution of transparent project experience to the worldwide knowledge base during the early deployment phase of CCS.

Returning to the larger picture of diverse stakeholders with divergent perceptions of the risks and benefits of CCS in the CDM, it is clear that even if risks of seepage from geological storage can be adequately managed, some stakeholders may object to CCS inclusion in the CDM based on underlying value differences on other issues (de Coninck, 2008). And, realistically, the development of modalities and procedures for CCS will entail certain tradeoffs. But, clearly, CCS projects conducted as CDM project activities would have high visibility, making proper management of local and global seepage risks a high priority. If a geological storage site approved by the CDM were to cause environmental, health or safety problems for the host country, it would damage not just the reputation of the CDM but also the reputation of CCS as a greenhouse gas mitigation technology. CCS is a promising technology that may help to achieve the UNFCCC's goal of preventing dangerous climate change. CDM modalities and procedures for CCS must manage local and global seepage risks rigorously enough to avoid damaging the prospects of this potentially important climate mitigation technology.

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Notes

1. Sleipner in the North Sea, run by StatoilHydro; In Salah in Algeria run by BP, Sonatrach and StatoilHydro; Weyburn in Canada, operated by EnCana; and Snøhvit in the Barents Sea, operated by StatoilHydro. A comprehensive list of commercial and pilot CCS projects is maintained by the International Energy Agency (IEA) at <http://co2captureandstorage.info/co2db.php>
2. The first, in Vietnam, proposes using CO₂ from combined cycle natural gas power plants for enhanced oil recovery in an offshore reservoir (NM 0167). The second, in Indonesia, proposes injecting CO₂ produced as a by-product of natural gas production into an offshore saline reservoir (NM 0168). Reviewers raised concerns over whether the methodologies proposed for these projects were adequate to detect seepage, and whether long-term liability was adequately handled (see http://cdm.unfccc.int/UserManagement/FileStorage/MCFI_PAmethodologies_262044693 and http://cdm.unfccc.int/UserManagement/FileStorage/MCFI_PAmethodologies_477122217).
3. In 2006, average CDM prices were €8.40/tCO₂ (Capoor and Ambrosi, 2007). BP's CCS project at the In Salah gas field reports costs for compression, transportation and injection of approximately €4.50/tCO₂ (Wright, 2007).
4. Submissions from Greenpeace, the International Emissions Trading Association (IETA), the International Petroleum Industry Environmental Conservation Association (IPIECA), the International Risk Governance Council (IRGC), the World Coal Institute (WCI), the World Wildlife Fund (WWF), the Bellona Foundation, and the Norwegian Forum for Environment and Development can be found at http://unfccc.int/parties_and_observers/ngo/items/3689.php
5. Article 8 of the *Measures for Operation and Management of Clean Development Mechanism Projects in China* (Office of National Coordination Committee on Climate Change, 2005) states that: 'implementation of CDM projects must not introduce any new obligation for China'.

6. CDM-approved methodologies are listed at <http://cdm.unfccc.int/methodologies/index.html> and registered projects at <http://cdm.unfccc.int/Projects/projsearch.html>. The CDM pipeline can be found at <http://cdmpipeline.org/cdm-projects-type.htm>.

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