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DISCUSSION PAPER

On the Integration of Carbon Capture and Storage into the International Climate Regime

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ABSTRACT

As GHG emissions did not decline as anticipated early of the 1990ties Carbon Capture and Storage (CCS) recently gained more and more attention as a climate change mitigation option. However, CO_2 suppressed in geological reservoirs is likely to lead to future releases of the CO_2 stored. This "non-permanence" must be considered if an environmentally sound policy is desired. Against this background, the present article analyses a potential integration of CCS in the international climate regime. It is based on existing rules and modalities regarding non-permanence of sequestration in the Land use, Land-use change and Forestry (LULUCF) sector. Interestingly, the experience from LULUCF has almost completely been neglected during the discussion on CCS.

We argue that CCS can only be accounted for in a transparent and comprehensive way, if it is considered a "removal" (or "sink") activity. This is, however, incompatible with the current UNFCCC rules and definitions. Consequently, they would have to be changed. Accounting and problems of cross-border projects are discussed. They arise due to the potential geographical separation of capture and storage site. Furthermore, an economic analysis is conducted considering the consequences of non-permanent storage. We apply the tCER approach for LULUCF projects which has already been agreed upon during the international climate negotiations. It may thus form the basis for CCS, too. The study suggests that CCS is probably not as attractive as widely claimed.

Key Words: Carbon Dioxide Capture and Storage, Permanence, Sequestration, LULUCF, Climate Policy

JEL-Classification: Q 25, Q 28, Q 38, Q 48

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Introduction

In order to reduce the adverse effects of human induced climate change the international community agreed inter alia to work towards a stabilization of the greenhouse gas concentration in the atmosphere. For this, two different options are available: reduction of GHG emissions at the source or increasing removal of GHG emissions by sinks. Regarding emission reductions options, the focus of climate policy has been on improving (energy) efficiency on both the supply and demand side, fuel switch to less carbon intensive fuels and change of industrial processes. Sinks enhancement options, which have been seriously considered so far by climate policy, are mainly restricted to the activities enhancing sequestration of carbon dioxide in the terrestrial biosphere. This issue is referred to as Land Use, Land-use change and Forestry (LULUCF).[1] LULUCF has been one of the most contentious and complicated issues in the international climate change negotiations which have been used to renegotiate the emission reduction targets decided at Kyoto (Jung, 2004).

Today, there are increasing problems regarding the reduction of GHG emissions, particular in industrialised countries. In the late 1980ties and the early 1990ties it was believed that deep cuts in emissions could be generated by no-regret measures and an increased penetration of renewable energies. No-regret measures on the demand side have failed to materialise; on the contrary efficiency improvements have slowed down during the 1990ties while consumption levels of goods and services continue to increase.

In this context, the issue of carbon dioxide capture at power and industrial plants and its subsequent storage in reservoirs recently entered the political discussion. This option is referred to as carbon capture and storage (CCS). The first ideas on CCS, however, already date back to the 1960s (for a chronology see for example Byrer 2002). Today, a large body of literature exists, which mostly deals with detailed technical aspects or general economic issues.[2] The most attractive characteristic of CCS mentioned frequently in the literature is that it offers a way to achieve deep emission reductions without a radical reorganization of the world energy system away from fossil fuels.[3] The latter explains why especially the coal and petroleum industry have an interest to promote CCS as a climate change mitigation option.

Interestingly, the question regarding the feasibility of integrating CCS into the international climate policy regime has only attracted little attention. Against this background, the present article investigates which implications the integration of CCS into the international climate policy regime would have, if non-permanence of carbon storage is taken into account.
Just as sink enhancement options in the LULUCF area, CCS is also an end of pipe solution characterised by the non-permanence of carbon dioxide storage. Therefore, our analysis of CCS tries to draw conclusions from the experiences and insights gained in the LULUCF discussion. Interestingly, the two lines of research (CCS and LULUCF) have co-existed relatively unconnected so far.

The paper is structured as follows. The next section gives a brief overview of the different options for CCS. In the subsequent section different aspects, which have to be considered when analyzing CCS are discussed. Starting with a review of the LULUCF rules, section four describes the technicalities of a potential integration of CCS into the international climate policy regime, based on the existing LULUCF approaches accounting for non-permanence.

[1] The revised 1996 IPCC Inventory Guidelines also consider storage of CO_2 in long-lasting petroleum products such as bitumen and lubricants.
[2] An overview of costs and the most important aspects of CCS is given below.
[3] See for example Keith and Parson (2000)

Following, it examines economic implications of non-permanence using the concept of temporary carbon credits applied to CCS. Sections five concludes.

Overview of CCS options

Carbon Dioxide Capture and Storage (CCS) consists mainly of three different elements: the capture at the site of formation, the transport to the storage site, and the storage of the CO_2 in the reservoir. There are different technological alternatives for each of these elements which can generally be combined as depicted in Figure 1.

In the following, we briefly describe the most important options available for capture, transport and storage of CO_2, and give an overview of estimates regarding costs and storage potentials. The main focus lies on storage as this is the most important issue regarding non-permanence.

Capture

The most suitable sources for CO_2 capture are large point sources such as industrial facilities or power plants.[4] Depending on the process considered, capture of carbon dioxide in the industrial sector is a well mastered process. Often the CO_2 must be removed during a certain production step in order to be able to continue downstream operation / business. For example, CO_2 must be removed after the water gas shift reaction during ammonia production as otherwise the catalyst for the ammonia synthesis would be poisoned (Bakemeier et al. 1996, p. 182-183). A single large ammonia plant releases up to 700,000 t CO_2 / a into the atmosphere. Also natural gas must often be treated at the well site as impurities may cause problems during production and transportation. CO_2 must sometimes also be removed to increase methane concentration prior to sales (Hammer et al. 1996, p. 80, 88-95).

The bulk potential[5] for CO_2 capture, however, can be found in power plants. In this case, the plants experience a considerable energy penalty. Efficiency may decrease by about ten percentage points (IEA 1994) which must be taken into account when analysing the economics of CCS. Depending on the process considered, different technical options for increasing the CO_2 concentration in the flue gas exist (see Figure 1), which differ regarding market maturity. (For more details see for example GHGT6, 2002.)

Transport

Transport of CO_2 is fully mastered as there are not too many differences compared to transporting other gases. Experience with CO_2 transport via pipelines already exists especially in the USA (Gale and Davison 2004). The alternative is to transport carbon dioxide by ship, especially if transport distances are longer. (Wildenborg, van Meer, 2002). Prior to transportation, compression is generally required resulting in an additional energy penalty, which is, however, much smaller than the penalty for capture.

[4] However, Ha-Duong and Keith (2002) and (Lackner et al. no year) have also proposed to capture CO_2 directly from the air, showing that this might become a feasible option in the future.

[5] in terms of quantity and neglecting costs

Storage

Theoretically, options for using CO_2 in industrial processes, as for example urea or methanol production, refrigeration or beverage carbonisation would have to be considered, too. However, they are neglected as the potential in terms of tonnes stored is not significant compared to the capture potential. Furthermore, the storage time in these products is very short (OECD/IEA 2003b).

Carbon dioxide can either be stored in geological formations (onshore and offshore), such as depleted oil or gas reservoirs and underground water-filled strata (aquifers)[6] as well as in deep-unminable coal beds used for methane production (OECD/IEA 2003a). The idea of the latter is to inject CO_2 into coal-beds which are unattractive for mining, also called Enhanced Coal-Bed Methane Recovery (ECBM). With the adsorption of CO_2 in the coal, an additional amount of methane is released from the coal, thus increasing the methane production rate. While little experience exists with ECBM, CO_2 injection into oil fields has already been applied for some years to enhance oil production (Enhanced Oil Recovery, EOR). EOR is one of the few storage options which is economically viable today, especially when oil prices are high. Contrary to EOR, Enhanced Gas Recovery (EGR) is not yet a commercially viable technology (OECD/IEA 2003b).

Another storage options is the injection of CO_2 into the ocean. This may either be done in shallow waters or in the deep ocean. One option is the injection into deep waters with the sinking CO_2 forming a lake at the bottom of the ocean, thus limiting the spatial extent, while the other option is the dispersion/dilution in water body to minimize the degree of impact (Ohsumi 2002).
In the latter case the retention time, which is a function of the depth of injection, is limited, while in the lake scenario it will be rather long. However, for both options little is known about the environmental implications. Local increase in pH-values may harm the maritime ecosystem considerably. As it seems unlikely that ocean sequestration will become a politically relevant option in the near future, it is not further considered in this paper.[7]

Mineralization of CO_2 by reaction of magnesium and calcium silicates with CO_2 into carbonates is attractive from the point of view of permanence. As the carbonate product is thermodynamically favoured, the carbon remains sequestered in a solid state. The storage capacity exceeds all possible CO_2 emissions from (known) fossil fuel reserves and the minerals in question exist throughout the world. However, due to the large amounts of solid waste generated and the relatively high costs, this option will probably not be suitable for large scale application (Gielen 2003).

[6] An important project worthwhile to be mentioned is the so-called SACS-Project in the Sleipner-Field in the North Sea. CO_2 from natural gas sequestered in an aquifer formation in the North Sea. (For further information see: http://www.iku.sintef.no/projects/IK23430000)

[7] Iron fertilisation of oceans has also been proposed. However, as for the CO_2 disposal at sea, we do not consider this option due to its limited potential and support.

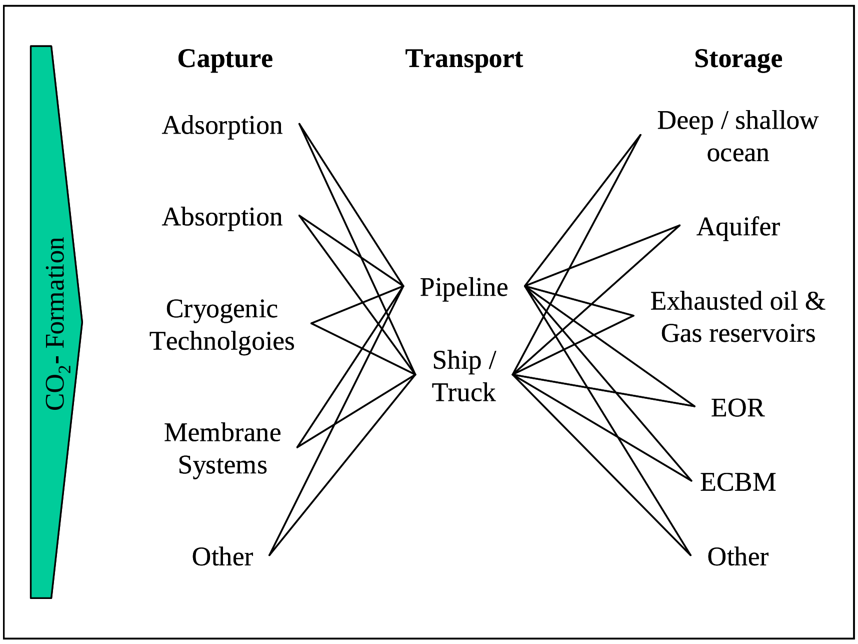

Figure 1: The full chain of capture, transport and storage options

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Characteristics of CCS

Existing regulation and public awareness

Regarding existing regulation, different levels can be distinguished: The international, regional and national legislation. However, the understanding on what might be applicable to CCS seems to differ. While Espie (2004, p. 15) states that a considerable volume of legislation exists that is directly relevant to CO_2 capture and storage, Freund (2004, p. 11) concludes that there is a lack of regulations specifically addressing CO_2 storage. What seems clear is that CCS was generally not anticipated when legislation was elaborated (Thomson 2004, p. 23). As “interpretation is to some extent an art, not an exact science” (Thomson 2004, p. 5), technical discussions on the “right” interpretation and applicable law may render it impossible to have cross-border or national projects in the near future. EOR, which is practised for years, may be an exception. The so-called Weyburn project (IEA 2004) is one example for a large cross-border EOR project. However, it does not take place under a project-based mechanism of the Kyoto Protocol (see discussion below).

With regard to public awareness, Lee (2004, p. 25 – 26) points out that the interest is low to non-existing, although some NGOs are becoming sceptical. “However, it is still to early to assess the level of public sceptism...”. Thus, this aspect has to be analysed in the near future. It can be expected that the NIMBY problem (“Not In My Backyard”) will become relevant for CCS, thus, leading to additional costs and barriers of this mitigation option. Analogies to or lessons learnt from other environmental problems with a clear long-term perspective such as nuclear waste repositories may help to deal with the aspect more appropriately.

Costs of capture, transport and storage

When looking at costs of CCS, one has to include the costs of the full chain from capture to storage to be able to compare it with other emission reduction options.[8] The cost of CCS does, therefore, consist of:

$$C_{CCS} = C_{capture} + C_{transportation} + C_{storage}$$

The costs for CO_2 capture (€/tCO_2) vary with the plant characteristics and capture process applied. Table 1 shows rough cost estimates for full-scale power and industrial plants given by Hendriks et al. (2004) and VGB (2004).[9] Costs for CO_2 capture at power stations of the sources used here lie in the range of 24-52 €/tCO2. Due to the higher CO_2 concentration in the flue gas, capture in coal-fired power plants involves a lower penalty than in natural gas-fired ones. However, whenever talking about costs, the baseline plant used to calculate the emission reduction costs is of crucial importance. For detailed discussion of this issue see Anderson et al. (2003).

Table 2, which includes the emission avoidance costs for industrial plants illustrates that significantly lower costs are only achieved in capture of CO_2 with ammonia and hydrogen production.

The costs in the literature vary greatly with assumptions on factors like electric efficiencies, plant size and type of plant chosen. Furthermore, power plants as well as the CO_2 capture technologies are continuously developing, which has to be considered in the calculation of emission avoidance costs.

Table 1: Examples of costs estimates for power plants with CO_2 capture (€/t CO_2)

Type of capture technology	**Pre-combustion**		**Post-combustion**	
Fossil fuel	**Natural Gas**	**Coal**	**Natural Gas**	**Coal**
VGB (2004)	39-48	24-37	32-52	47
Hendriks et al. (2004)	43	26	30- 37	29

Table 2: Typical costs of CO_2 capture for industrial plants, Hendriks et al. (2004) (in €/t CO_2)

Source	**Cement plants**	**Iron and steel plants**	**Ammonia plants (flue gas)**	**Ammonia plants (pure CO2)**	**Refineries**	**Hydrogen (flue gas)**	**Hydrogen (pure CO2)**	**Petrochem ical plants**
Hendriks et al. (2004)	28	29	36	3	29-42	36	3	32-26

[8] Additionally, one will have to consider the monitoring cost, which will accrue over long-term periods in the future.
[9] The literature on capture costs is extensive. Further examples of studies dealing with capture costs are Audus 2000, Condorelli et al. (1991), Herzog (1999), David and Herzog (2001), Freund and Davison (2002), Göttlicher and Pruschek (1999), Reimer et al. (1999), Rubin and Rao (2002), Simbeck (1998), and Smelser (1991).

Transportation costs by pipeline vary not only with the transportation distance, but also with the amount transported, the pressure of CO_2, pipeline diameter, and country regulations. Per 100 km pipeline, the cost estimates range from 1-6 €/t CO_2, with decreasing costs for larger throughputs (Hendriks et al. 2004, Freund and Davison 2002). Transport of CO_2 by ship vessels will be cheaper over longer transportation distances (Freund and Davison 2002). There may even be synergies with seaborne transportation of liquefied natural gas (LNG). After unloading the freight at the port of destination, ships may load CO_2 on the way back to the gas field which may subsequently be suppressed there.

Storage costs reported in the literature are mainly based on the technical investment to be made, as for example the drilling of wells and operation costs. Hendriks et al. (2004) estimates costs for storage in aquifers, natural gas and empty oil fields to 1 to 11 €/tCO_2, varying with depth and permeability as well as the type of the storage reservoir. For EOR and ECBM, the cost range is from -10 to 30 €/tCO_2. Table 3 gives an overview of storage costs of different geological reservoirs with varying storage depths.[10]

Table 3: Storage costs by depths of reservoir (in €/tCO_2), given by Hendriks et al. (2004)

	Depth of storage (m)		
	1000	2000	3000
Aquifer onshore	2	3	6
Aquifer offshore	5	7	11
Natural gas field onshore	1	2	4
Natural gas field offshore	4	6	8
Empty oil field onshore	1	2	4
Empty oil field offshore	4	6	8
	Low	**Medium**	**High**
EOR onshore	-10	0	10
EOR offshore	-10	3	20
ECBM	0	10	30

Capture costs seem to make up the biggest portion of CCS costs. Theoretically possible combinations of the different capture, transport[11] and storage options, when based on the cost estimates reported above, may range from profitable values of minus 3 (e.g. Ammonia/hydrogen capture, low transport costs, with EOR at 1000m) to 106 €/t CO_2 (most expensive post-combustion natural gas estimate, high transport costs and high ECBM costs). Van Bergen et al. (2004) present early opportunities for CO_2 EOR and CO_2 ECBM. They consider combinations of high purity industrial point sources with more than 100,000 tonnes of CO_2 per year and a distance of not more than 100 km from the reservoir as early opportunities. For the ECBM projects they find net sequestration costs between 8 and 11 € / t CO_2.

[10] Further storage cost estimates can be found in e.g. Gupta et al. (2002), Hendriks et al (2001), Reeves and Schoeling (2001), Smith et al. (2001), as well as Wildenborg and Van der Meer (2002).

[11] Assuming a transportation of 400 km by pipeline

Technical potential for storing carbon dioxide

Apart from costs, the technical potential, i.e. the size of the reservoirs available, is a major determinant regarding the relevance of CCS as a mitigation option. Various figures have been published (Grimston et al. 2001, p. 161, IEA 2001, p. 17). However, the most detailed and most recent data is given by Hendriks et al. (2004), which is presented in Table 4.

As can be seen, there is still relatively high uncertainty regarding the storage capacity. Global potential is in the range of about 476 to 5880 Gt of CO_2 with a best estimate of 1660 Gt. The geographical distribution of the possible storage capacity depends on the type of reservoir. Saline aquifers seem to be distributed most evenly. With regard to the use of CCS in the international climate policy regime it becomes obvious that the majority of the worldwide storage potential is located in non Annex-I countries. This should be kept in mind when discussing the consideration of CCS under the project-based mechanisms and its environmental integrity.

Table 4: Storage potential (Gt CO_2)

	Onshore					Offshore				
	Remaining Oil Fields	Depleted Oil Fields	Remaining Gas Fields	Depleted Gas Fields	ECBM	Remaining Oil Fields	Depleted Oil Fields	Remaining Gas Fields	Depleted Gas Fields	Aquifers
Canada	0.0 - 3.1	0.7 – 1.5	6.6 - 10.2	0.1 - 8.1	0.0 - 51.0	0.0 - 3.2	0.0 - 0.0	0.7 - 1.3	0.0 - 0.0	2.2 - 77.7
U.S.A.	0.8 - 44.5	2.5 – 4.9	6.0 - 15.3	1.8 - 7.7	0.0 - 190.2	0.1 - 4.8	1.0 - 5.4	0.7 - 1.4	1.2 - 1.9	2.2 - 77.6
Central Am.	0.1 - 14.5	0.5 – 1.0	0.8 - 4.4	0.2 - 1.2	0.0 - 0.0	0.2 - 20.5	2.1 - 11.2	5.6 - 26.7	1.3 - 1.8	0.9 - 32.7
South Am.	0.7 - 53.8	2.3 – 4.5	8.7 - 49.4	0.2 - 17.6	0.0 - 11.7	0.3 - 52.4	2.1 - 11.2	3.6 - 60.4	0.4 - 0.9	2.9 - 103.4
Northern Afr.	0.4 - 23.8	1.2 – 2.4	13.8 - 42.6	0.1 - 19.4	0.0 - 0.0	0.1 - 6.4	0.9 - 4.8	1.5 - 9.8	0.1 - 0.2	1.7 - 60.5
Western Afr.	0.1 - 17.8	0.2 – 0.3	1.1 - 6.7	0.1 - 2.7	0.0 - 1.3	0.4 - 67.4	2.6 - 13.9	4.7 - 28.5	0.4 - 0.9	1.9 - 68.0
Eastern Afr.	0.0 - 0.2	0.0 – 0.0	0.1 - 1.3	0.0 - 0.4	0.0 - 0.0	0.0 - 0.6	0.0 - 0.0	0.2 - 4.0	0.0 - 0.0	0.7 - 24.6
Southern Afr.	0.0 - 0.6	0.0 – 0.0	0.0 - 0.2	0.0 - 0.1	0.0 - 44.6	0.0 - 10.6	0.2 - 1.0	0.5 - 4.5	0.0 - 0.0	1.8 - 63.1
Western Eur.	0.0 - 1.1	0.1 – 0.2	4.7 - 16.9	0.2 - 10.4	0.0 - 5.7	0.3 - 39.9	3.4 - 18.2	12.9 - 111.9	10.3 - 13.3	0.9 - 31.7
Eastern Eur.	0.1 - 5.1	0.3 – 0.6	2.9 - 6.6	0.0 - 3.9	0.0 - 4.2	0.0 - 0.0	0.0 - 0.0	0.0 - 0.0	0.0 - 0.0	0.4 - 15.2
Former S.U.	1.7 - 132.4	4.8 – 9.6	71.0 - 331.5	0.3 - 126.3	0.0 - 150.1	0.2 - 19.3	1.7 - 9.0	24.0 - 287.3	2.1 - 5.3	4.1 - 148.5
Middle East	5.1 - 405.8	7.9 - 15.7	92.3 - 372.6	0.3 - 168.1	0.0 - 0.0	0.8 - 61.1	3.4 - 18.4	69.9 - 116.3	0.7 - 1.4	1.2 - 43.6
Southern Asia	0.0 - 2.1	0.1 – 0.2	3.9 - 24.0	0.2 - 9.5	0.0 - 11.9	0.1 - 3.0	0.4 - 2.3	1.3 - 12.9	0.6 - 1.2	2.7 - 95.5
Eastern Asia	0.2 - 23.0	1.0 – 2.0	3.9 - 23.5	0.1 - 7.8	0.0 - 840.7	0.0 - 3.4	0.4 - 2.2	0.2 - 1.0	0.1 - 0.1	1.7 - 60.3
South East. Asia	0.1 - 6.0	0.6 – 1.2	2.8 - 17.9	0.1 - 7.0	0.0 - 113.9	0.1 - 10.9	1.3 - 6.7	16.5 - 61.3	2.6 - 4.4	0.8 - 28.8
Oceania	0.0 - 0.2	0.0 – 0.0	0.1 - 0.5	0.0 - 0.2	0.0 - 54.1	0.0 - 5.0	0.5 - 2.6	6.9 - 39.9	0.3 - 0.8	3.5 - 126.3
Japan	0.0 - 0.0	0.0 – 0.0	0.0 - 0.0	0.0 - 0.0	0.0 - 0.5	0.0 - 0.0	0.0 - 0.0	0.0 - 0.0	0.0 - 0.0	0.2 - 8.4
Greenland	0.0 - 0.0	0.0 – 0.0	0.0 - 1.5	0.1 - 0.3	0.0 - 0.0	0.0 - 0.0	0.0 - 0.0	0.0 - 10.4	0.0 - 0.0	0.4 - 15.0
Total Annex-1 *)	2,6 - 186,2	8,4 – 16,8	91,2 - 382	2,5 - 156,7	0 - 401,7	0,6 - 67,2	6,1 - 32,6	38,3 - 412,3	13,6 - 20,5	10,4 - 374,1
Total non Annex-1 *)	6,4 - 547,8	13,6 - 27,2	127,8 - 543	1,5 - 234,3	0 - 1078,3	2,4 - 240,8	13,9 - 74,4	110,7 - 365,7	6,4 - 11,5	19,6 - 706,9
Total	**9 - 734**	**22 – 44**	**219 - 925**	**4 - 391**	**0 - 1480**	**3 - 308**	**20 - 107**	**149 - 778**	**20 - 32**	**30 - 1081**

Based on: Hendriks et al. (2004, p. 48); *) Estimate based on own calculation (for example, Former S.U. may include both Annex-I and non Annex-I countries)

Permanence

Most storage options have in common that they are non-permanent, i.e. carbon dioxide re-enters the atmosphere after it has been injected into a reservoir. Exact rates at which CO_2 might be released from the reservoirs are still unknown. Research is devoted to this question in the framework of the pilot projects implemented.

When analyzing CCS, it is essential to account for this potential release of carbon dioxide back to the atmosphere as well as its economic and environmental consequences. Lately, some research has addressed this issue by analyzing the effects of different release rates[12] on future GHG concentration, searching for what could be an ”acceptable” release rate. The answer to this question depends heavily on the amount by which carbon dioxide storage is relied upon as a mitigation strategy (Hawkins 2004). If huge amounts of carbon would be stored over a long period of time, e.g. the next hundred to two hundred years, rates of CO_2 releases must be very low for them not to become a substantial proportion of emissions in the future, thus making any stabilization targets impossible to reach. Thus, one may enter a vicious cycle - although with best of intentions - by promoting CCS in order to cut emissions (see Figure 2).

While no solid evidence exists on what release rate might be realistic if CCS applied at a global scale, this question is of main concern when talking about the viability of this mitigation option. In general, the literature seems to agree that rates should not be greater than 0.1 % (Dooley and Wise 2002, Pacala 2002, Hepple and Benson 2002, Ha-Duong 2003).

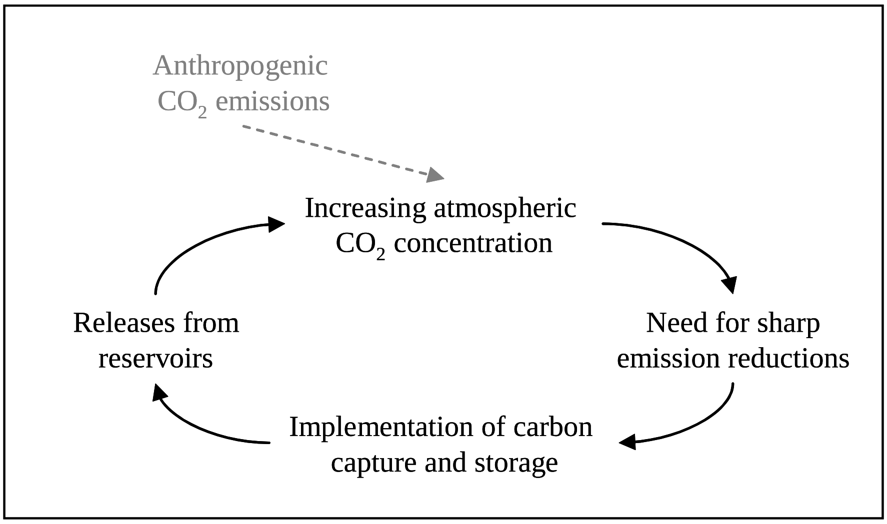

Figure 2: Possible vicious cycle started by promoting CCS

[12] We do not apply the widely used term leakage, but rather refer to *releases* of CO_2 or escaped CO_2, because the term leakage is defined in the legal texts of project-based mechanisms of the Kyoto Protocol as the emissions resulting from the project activity outside the project boundaries of the (JI/CDM) project. De Conninck (2004) proposes to use the term leakage for the emissions resulting from capture, transport and injection, which should not be confused with releases of CO_2 from a geological reservoir (escaped CO_2). Heafali et al. (2004) try to avoid the confusion of the terms by calling the released CO_2 from the reservoir “leaked CO_2” or “escaped CO_2” while losses during transport and processing are labelled “fugitive emissions” according to the IPCC 1996 national GHG inventory guidelines.

Hawkins (2004) comes to the conclusion that the current use of fossil fuels can be thought of as a 0.1 % release rate of the total resources stored underground. He demonstrates that with CCS as the exclusive mitigation option for the next two hundred years even low release rates of 0.01 % would lead to emissions from storage in the year 2200 which would make up 100 % of the allowed global budget for that year for stabilization targets of 450 ppm, and 20% of 750 ppm. Herzog, Caldeira and Reilly (2003) look at the problem of released CO_2 from a different angle. First, they emphasize that all carbon mitigation options are somehow temporary, since a ton of carbon mitigated today might just be emitted in the future (temporal leakage) due to the lower price path of fossil fuels in the future. They then calculate the net present value of temporary storage depending on the price paths of carbon over time, coming to the conclusion that CCS has a positive value if carbon prices are constant or capped by a backstop technology. If the latter two conditions are not given, though, carbon storage is not an effective mitigation strategy.

Harvey (2004) and Kirschbaum (2003) study the impacts of temporary storage on the atmospheric concentration of CO_2. They argue that due to the slower increase in CO_2 concentration in a case of large-scale use of temporary storage, the carbon uptake by the natural carbon sinks is reduced as well. The consequence is that for stabilization of the GHG concentration, there is a need for continuous emission reductions and/or a declining sequestration fraction (Harvey 2004). Based on this mechanism, Kirschbaum (2003) shows that temporary storage with sudden release of bigger portions of the stored CO_2 can even have the opposite effect of the one it has supposedly been used for, namely worsen climate change impacts. If one considers this a valid argument, one would also have to reconsider the banking of emissions rights in the international climate regime which leads to a similar temporal pattern of CO_2 emissions.

Next to the risks of increased emissions in the future, geological storage might embody further risks. In this context it should also be mentioned that deep CO_2 well injection may induce seismic activity, which might be too small to be felt, but which may be precursors of larger events (Sminchak et al. 2002, p. 34). Larger amounts of CO_2 escaped from a reservoir (or pipeline during transportation), can be a danger to humans and animals in the area, since it will accumulate in valleys and lead to asphyxiation (Johnston and Santillo 2002).[13]

Whatever release rate of stored CO_2 one might find acceptable, released emissions will always have to be compensated somehow if stabilization of GHG concentrations is the goal. This has to be done either by additional emission reductions or increased CCS, the latter again leading to further releases in the future.[14]

To guarantee that the risks associated with releases of CO_2 back to the atmosphere are accounted for, one has to consider the permanence issue when thinking about an integration of CCS as a mitigation option in the climate policy framework. Interestingly, the discussion on escaping CO_2 has almost not referred to any of the experiences gained from the policy debate

[13] Since CO_2 is heavier than air, a sudden release into the atmosphere would cause the gas to flow near the ground and form a blanket that could be harmful to life. There is uncertainty if such a leaking is to be expected for example from sudden seismic activity. As an example for this health hazard the gas disaster in lakes Nyos and Mononun can be given. In August 1986 an enormous volume of CO_2 was released from lake Nyos and killed 1700 people. Even though the physics were different (CO_2 of magmatic origin) the risks of high CO_2 sequestration became visible. CO_2 stored in aquifers may float over large distances and seep back to the surface. Carbonates simply cannot release significant volumes of CO_2.

[14] Michaelowa (2003) argues that CO_2 emissions may be released expressively in the very distant future in the case where global cooling may become a problem.

on the issue of carbon sequestration in the Land use, Land-use change and Forestry (LULUCF) sector.[15]

Capture and storage options and the international climate regime

To be able to transfer the concept used to account for the non-permanence of carbon storage in the LULUCF area, the rules and modalities regarding LULUCF in the climate regime are briefly described. In the next step, we examine the most important similarities and differences between LULUCF and CCS, before discussing accounting options for CCS which are based on the framework created for accounting of non-permanence in the area of LULUCF.

LULUCF in the Kyoto Protocol

When looking at LULULCF in the climate regime, one has to distinguish between accounting of LULUCF in emission inventories in Annex I countries on the one hand, and in the project-based mechanisms Joint Implementation (JI) and Clean Development Mechanism (CDM) on the other. JI projects are those project activities taking place in countries belonging to Annex I of the UNFCCC, while CDM projects can be implemented in non-Annex I countries (developing countries).[16] Credits generated by these projects are fungible on the international market and can be used by Parties with emission reduction obligations for compliance with their Kyoto targets.

Annex I Inventories

In the national emission inventories, emissions and removals from LULUCF are accounted for on an activity basis. Reporting of afforestation, reforestation and deforestation (ARD) which take place after 1 January 1990 is mandatory for Annex I Parties (Art. 3.3 Kyoto Protocol).

Furthermore, the additional activities cropland management, grazing land management, revegetation and forest management can be accounted for on a voluntary basis (Art. 3.4).

Afforestation, reforestation and deforestation as well as forest management are based on a ”gross-net approach”, meaning that emissions and removals from these activities during the commitment period are considered (net), while they are not included in the base year (gross).[17]

[15] Only Torvanger et al. (2004) mention the issue briefly, but do not go into further details on how to apply the LULUCF rules to CCS.

[16] The term Annex I country is often used to refer to the countries with emission targets under the Kyoto Protocol. This is, however, not exact. “Annex I” refers to the UNFCCC. Parties with emission reduction targets are listed in Annex B of the Kyoto Protocol, therefore labelled Annex B countries. Only two countries (Turkey and Belarus) are an Annex I country, but not listed in Annex B.

[17] Due to the gross-net approach, the amount of forestry sinks accounted for in their inventories in fact reduces the overall reduction obligations of the Kyoto Protocol. Since targets were fixed before the rules and modalities for sinks were negotiated, countries could decrease their actual emission reduction by increasing eligible forestry options (WBGU 1998, Jung 2004).

Cropland management, grazing land management and revegetation are based on a ”net-net approach”, including emissions and removals of these activities in the base year as well as in the commitment period.[18] If Article 3.3 activities represent a net source of emissions, each Party may use forest management removals to compensate this debit to a maximum of 9 megatons of carbon per year. Further debits may be accounted for by forest management up to an individual, politically agreed limit for each Party, fixed in the so called Appendix Z.[19]

Credits generated from LULUCF activities under Article 3.3 and 3.4 activities are labelled ”removal units” (RMU). RMUs are fungible units in the international market, but cannot be carried over (banked) to the next commitment period.[20] This means, that they have to be used in the commitment period they were created.

Project-based mechanisms

The two project-based mechanisms of the Kyoto Protocol, JI and CDM, include different project activities in the LULUCF area. All LULUCF activities eligible under article 3.3 and 3.4 are possible JI project activities.[21] The credits generated by JI sinks projects are RMUs as in the case of domestic sinks accounting. When transferred to the Annex I country investing into the JI project, they are converted to “Emission Reduction Units“ (ERUs), which are then subtracted from the Assigned Amount Units (AAUs)[22] of the host country. The host country selling the RMU will have to account for any carbon losses in its emission inventory of future commitment periods (seller liability). The host country does not have an incentive to exaggerate the amount of carbon sequestered because the amount of carbon transferred will not be allowed to be emitted in the country itself anymore.

Under the CDM, only afforestation and reforestation are eligible LULUCF activities. The use of credits from LULUCF CDM projects by Annex I Parties is limited to 1% of a country’s 1990 emissions per year. Since non-Annex I Parties do not have an emission reduction target under the Kyoto Protocol, there is an incentive for Parties to exaggerate the emission reductions or carbon sequestration of CDM projects. CDM projects taking place in developing countries are therefore controlled by a complex certification procedure which tries to guarantee that emission reductions or carbon sequestration is real and additional to ”what would have occurred otherwise”.[23]

For addressing non-permanence of forestry projects in the CDM, a system of expiring credits with buyer liability was adopted. After long and very technical negotiations on the issue, Parties agreed on the creation of two different types of expiring credits: ”Temporary Certified Emission Reductions” (tCER), and ”Long-term Certified Emission Reductions” (lCER).[24]

[18] Australia, however, managed to insert an exception into Article 3.7, which allows Annex I Parties with net emissions in 1990 from land-use change and forestry to use a net-net approach, by adding land use emissions to their base year emissions. The latter is a special gift to Australia which had considerable net emissions in the LULUCF sector in 1990.

[19] The main rules on LULUCF can be found in UNFCCC (2001a and b).

[20] See UNFCCC (2001b)

[21] The use of RMUs by a Party is limited, though, by the above described caps which will have to be applied also in the case of JI sink credits.

[22] AAUs are the amount of GHGs a country is allowed to emit (reduction target in % of 1990 emissions)

[23] For a consolidated additionality test introduced in Oct. 2004 see: Report of 16 meeting of the CDM Executive Board, Annex 1 Tool for the demonstration and assessment of additionality, retrievable on: http://cdm.unfccc.int/

[24] The fact, that there is two different credit types is purely due to political reasons.

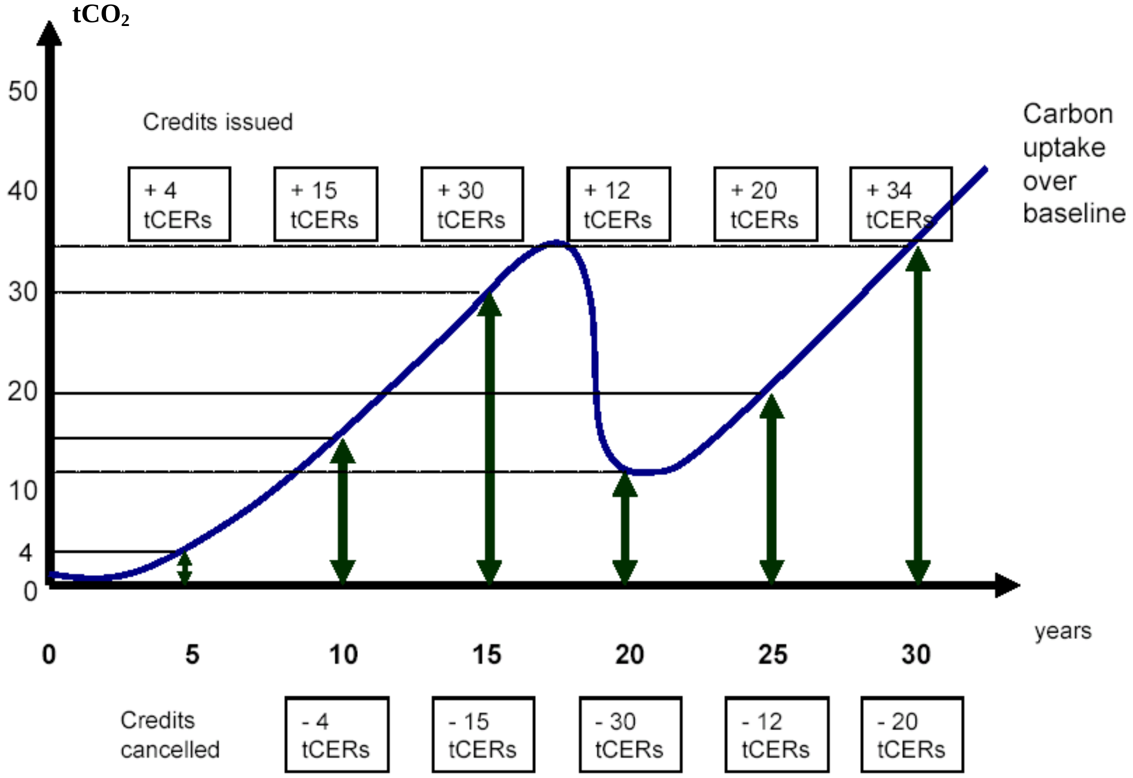

Figure 3: tCER approach for LULUCF projects

Both can be used for meeting Kyoto reduction targets for the commitment period in which they were issued. They cannot be carried over (banked) to a subsequent commitment period. Verification of tCERs and lCERs occurs in five-year intervals. While a tCER expires at the end of the commitment period subsequent to the commitment period for which it was issued, a lCER is valid until the end of the project's crediting period (UNFCCC 2003, Dutschke et al 2004).[25] In terms of the amount of carbon credited, these two approaches render the same result.[26] Thus, in the following, we will focus on the tCER approach, which is probably the easier one to understand. In the tCER approach represented in Figure 3, four temporary credits with a five year validity are issued at the first verification (year 5) for the sequestration of four tons of CO_2. These four credits expire at the end of the next commitment period (year 10). The same amount of tCERs can be issued for use in the following commitment period, if the carbon remains sequestered. In our figure, however, not only the four tons of CO_2 have remained sequestered, but also additional 11 t of CO_2 have been taken up in the biomass. In general, the amount of tCERs issued will increase by the amount by which sequestration has increased compared to the last verification. If, on the contrary, there has been a release of carbon e.g. deforestation, as illustrated for year 20 in Figure 4, the amount of renewed tCERs will be lower to this extend. The option of renewing tCERs if carbon remains sequestered makes it possible to create a chain of tCERs. Since the maximum crediting period for LULUCF is 60 years[27], a chain of maximum 12 tCERs with 5 year validity can be created, thus, representing a credit with a validity of 60 years. The temporary nature of the tCER will

[25] In case a renewable crediting period was chosen, the lCER expires at the end of the last crediting period of the project activity. Considering the available options for the length of the crediting period, the maximum validity of a lCER can be 60 years.
[26] Differences can be found rather in the resulting procedural consequences due to the different length of validity.
[27] The length of the crediting period can be chosen to be either 30 years with no renewal or 20 years with the option of two renewals.

result in a lower price obtained on the market compared to permanent credits as the temporary credit must be replaced by a new one after its expiration.

Harvested wood products

The accounting approach for LULUCF in the first commitment period assumes that all carbon removed from a forest is emitted in the year of removal and in the country where the wood was harvested (IPCC default method). Thus, the wood product pool, called harvested wood products (HWP), was excluded from accounting, while discussions on approaches how to include this pool in later commitment periods are continuing.[28] The issue of harvested wood products is interesting with respect to CCS, because here as well capture and storage are treated as two separated processes which can take place in different locations. This implies that the stored carbon has to be traced when crossing country borders, which has implications for inventory practises (Pingoud et al. 2004, Martino 2004). Discussions on how to account for HWP are therefore highly relevant for accounting issues related to CCS and vice versa. Both topics should be treated consistently.

Differences and similarities between LULUCF and CCS

As CCS and LULUCF are both activities sequestering and storing carbon temporarily after it has been produced, the basic concept underlying both is very similar. However, some differences can be found, which are summarized in Table 5.
First, while trees take up carbon from the atmosphere, the carbon dioxide capture process is located at the stack of a point source e.g. a power plant. The importance of this difference will be discussed below. Furthermore, the pattern of sequestration is rather the opposite of the one in projects accumulating carbon in biomass. While the latter is characterized by a slow uptake, the uptake in CCS could be considered as immediate. Releases of CO_2 from biomass are relatively fast (at least if the storage of CO_2 in wood products is neglected as in the IPCC default approach), while for CCS CO_2 reelases are probable in the form of slow seepages in most of the cases. Furthermore, time frames of storage in geological formations – assuming low release rates – will be far beyond any human time horizon, while most forestry options have time horizons which are much shorter. While CO_2 in biomass is monitored and measured in a stock-based approach, the monitoring of CCS will have to focus on fluxes. The main problem arising from CCS compared to the current accounting of LULUCF is that CO_2 capture can take place in a different location than CO_2 storage. This has wide ranging implications for accounting of CCS activities in the international climate regime, an issue dealt with in this article.

[28] For the latest discussions see the report on the UNFCCC workshop harvested wood products at: http://unfccc.int/sessions/workshop/300804/index.html

Table 5: Differences between LULUCF and CCS

	LULUCF	CCS
Uptake	From the atmosphere	From a point source[29]
	Slowly	Immediately
Release of CO2	Fast release (if not accounting for harvested-wood products)	Slow release (sudden release only in case of accident)
	Due to natural and human disturbances	Factors mainly natural, e.g. characteristic of reservoir
Ancillary benefits	Negative and/or positive, e.g. wood, biodiversity (depending on project)	None or only negative
Time frames	Hundreds years or less	Many thousand years (in some cases permanent)
Monitoring	Carbon stocks (biomass)	CO2 fluxes
Sequestration and storage	Cannot be separated (if not accounting for harvested-wood products)	Capture can take place in different location than storage
	Project encompasses capture and storage at the same time	Project consists of a capture and a storage element

Geological storage

Based on our description of LULUCF accounting in the climate regime and the specific characteristics of CCS, we now examine implications of different accounting options for geological carbon storage against the background of non-permanence.

Annex I Inventories

The most comprehensive analysis of the consideration of CCS in the climate policy regime is provided by Haefeli et al. (2004). Regarding the treatment of CCS in Annex I inventories two different options for accounting of CCS[30] (Haefeli et al. 2004) are mentioned; accounting as a

1. removal activity (sink) or an
2. emissions reduction (at the source).

In the first case, CO_2 is considered as emitted into the atmosphere although it has been removed at the stack. The second option deals with the captured CO_2 as if it had never been emitted. An adjustment of emission factors is likely to be required in this case. The two options are visualised in Figures 4 and 5 and explained in more detail below.

As the term sink is defined by the UNFCCC as "any process, activity or mechanism which removes a greenhouse gas, an aerosol or a precursor of a greenhouse gas from the atmosphere" (Article 1.8 UNFCCC), this legal definition does not apply to the process of CCS, since this option mainly refers to capture of CO_2 from point sources and not the atmosphere.[31] To be consistent with the UNFCCC definition and also with the methodologies

[29] Remember that theoretically, CO_2 may also be captured from the air.
[30] For both approaches, special rules for the treatment of biomass would be required (Haefeli et al. 2004).
[31] We also try to avoid the use the word sink when referring to CCS and apply the term "sequestration activity" to address both CCS and LULUCF.

of the IPCC inventory guidelines, it has been argued that CCS should be considered an emission reduction rather than a removal activity (DeConninck 2004).

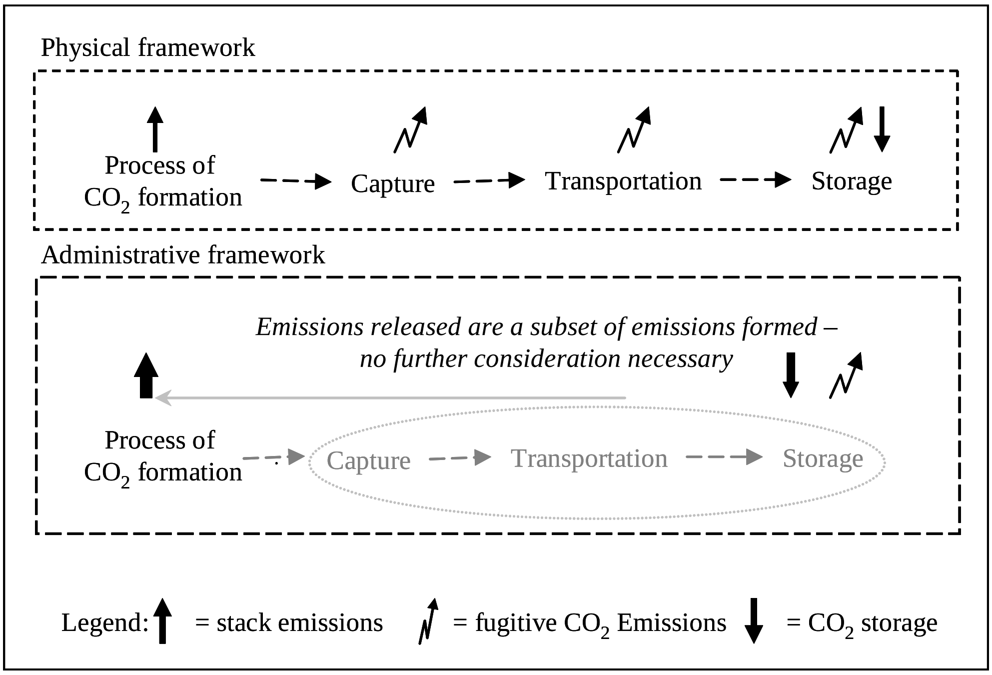

Figure 4: Schematic representation of the ‘removal’- approach

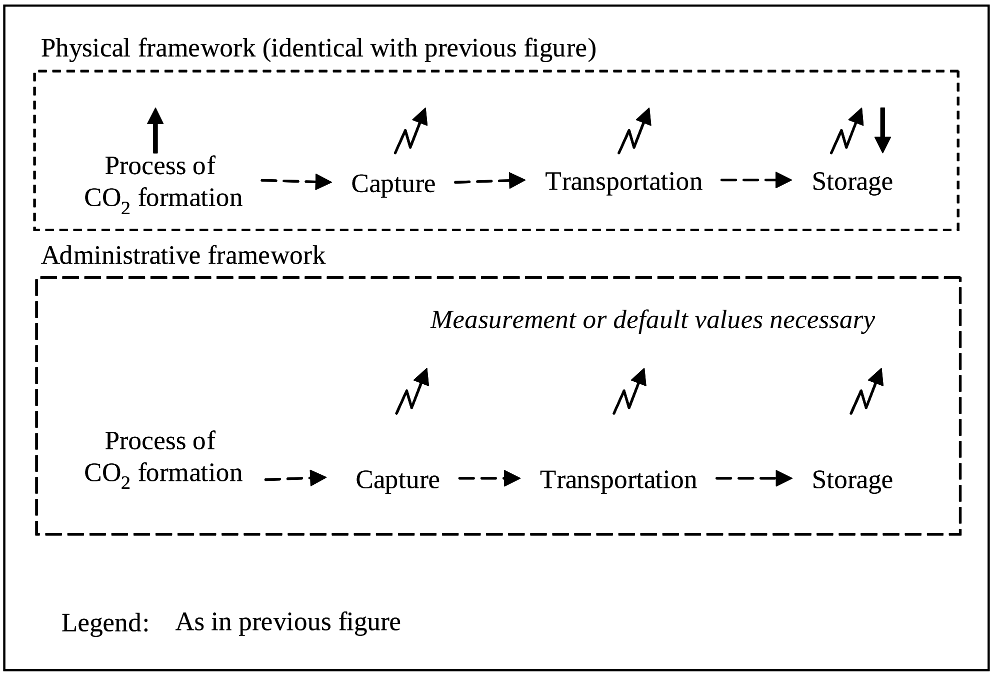

Figure 5: Schematic representation of the “source reduction” approach

Haefeli et al. (2004, p. 20) also discuss the issue of completeness especially with regard to the fugitive emissions. Two approaches are proposed:

a) applying default emission factors for fugitive emissions. This approach does not provide many incentives for high efficiency capture, or to be more precise, to beat the default factor.
b) "deducting the actually injected CO_2 measured at the injection point in a separate step and under a newly created category in the national GHG inventory." This would require a measurement of the quantity of CO_2 injected which may result in additional costs.

From our point of view the issue of fugitive emissions (a and b) is closely related to the treatment of CCS under the inventory rules (1 and 2).

We argue that the removal approach is the better choice if environmental integrity of the CCS is to be ensured.[32] We are aware that this would be linked to a revision of inventory guidelines, and would probably be incompatible with the sinks definition of the UNFCCC. The latter may imply that the inclusion of CCS into the climate regime is generally not possible if non-permanence is to be accounted for appropriately.

Our main arguments for preferring the *removal approach* are as follows:

1. Unexpected events like accidents during transportation or, even worse, wilful release of CO_2 at the high seas could not easily be accounted for under the emission reduction approach.[33] Default values are unlikely to be conservative enough to account for such events. Ex-post measurement of unexpected releases may be complicated and lack incentives for full determination of releases.

2. Cross-border projects with CO_2 stored in a non-Annex I country would raise the question of how emissions released from a non-permanent reservoir would be accounted for. Two options exist:

    a. Releases are considered within the host country's inventory. However, as non-Annex I countries do not have emission targets, this would violate environmental integrity if CO_2 is imported from an Annex B country.

    b. Releases in the storage country are considered within the inventory of the country of origin (capture country). Since the releases would derive from CO_2 that has officially never entered the atmosphere, tracking of CO_2 would be rather difficult. On the other hand, accounting of non-permanence of storage could be done by means of the existing flexible mechanisms and the rules which already have been agreed upon in the context of LULUCF based on the removal approach.[34] This option is discussed below.

Following the removal approach, all emissions that are produced and captured at the stack[35] are considered as being released to the atmosphere and are to be reported in the emission inventory of the country where they have been formed. For each ton of CO_2 which is stored underground, a permit is created. In analogy to the RMU created due to LULUCF activities in

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[32] Here, we are only referring to environmental integrity regarding non-permanence. The consideration of further environmental and health risks are out of the scope of this paper.
[33] An analogy is the treatment of bunker fuels. Though, not released wilfully CO_2 emissions from international maritime transportation are currently not considered under the emissions targets of the Annex-B countries. (For detailed discussion see Bode et al. 2002)
[34] Ignoring the mentioned inconsistencies with the UNFCCC sink definition and the IPCC inventory guidelines.
[35] This is to say that the emissions have been physically formed, though they have not been released into the atmosphere.

Annex I countries, we introduce a new credit type called “Storage Unit (STU)” for carbon dioxide storage in Annex-I countries.

As pointed out before, CCS will encompass the possibility of cross-border projects, meaning that the capture takes place in a different country than the storage. This makes it necessary to examine different combinations of capture and storage locations, and their consequences in terms of accounting under the climate regime. The theoretically possible combinations are illustrated in Table 6.

Table 6: Possible combinations of capture and storage locations

Number of countries involved					
One		two (cross-border)			
Case		Case	Capture	Storage	„Mechanism“
1	Annex-I (domestic mitigation)	3	Annex-I	Annex-I	JI
2	non-Annex-I (unilateral CDM)	4	Annex-I	non-Annex-I	CDM
		5	non-Annex-I	non-Annex-I	“South-South” CDM
		6	non-Annex-I	Annex-I	No mechanism but similar to domestic mitigation

The inventory approach recommended above is explained for the one country case first. CCS projects involving two countries fall into the category of the flexible mechanisms and are dealt with in the next section.

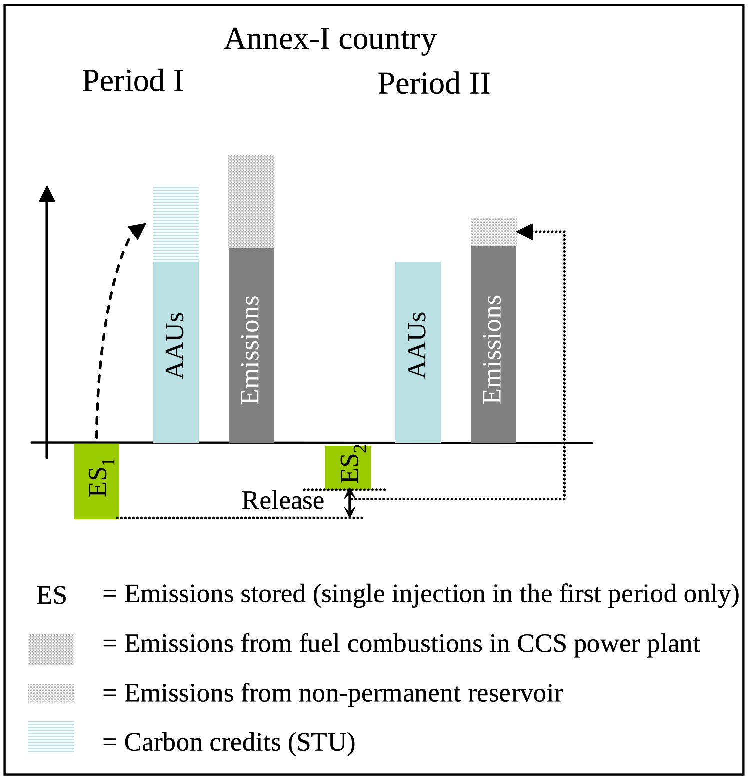

Figure 6: Proposed approach for considering CCS in the inventories of Annex-I countries

Assume a CCS project (capture and storage) to take place in one Annex-I country only. A certain quantity of CO_2 is captured and stored in the first period (see Figure 6). The carbon dioxide emissions formed during the capture process are considered in the emission inventory of that country. This implies that, whatever may happen during transportation and injection, the CO_2 would have already been accounted for. Only those tonnes of CO_2 which arrive at the reservoir and which are stored would result in a STU.

This seems important as, although not discussed yet, there might be an incentive to ship CO_2 to the high seas for release into the atmosphere outside the national territory. As discussed above, so far there is no legislation dealing with this issue. This aspect may also be important in the context of cross-border projects.

At the end of a commitment period the country could surrender the STUs in order to compensate (parts of) the captured emissions already added to the national emissions. As the number of STUs received increases with the efficiency of the capture, transportation and storage processes, the approach is incentive compatible. In the second (commitment) period, the releases from the reservoir are important. As long as no releases take place (permanent storage) nothing changes compared to the first period. If, however, parts of the stored carbon dioxide re-enter the atmosphere, they are considered as emissions in the national inventory of that country. Appropriate monitoring would be, thus, of crucial importance.

This approach is equal to the creation of RMUs as used for removals in the LULUCF area. The second case without cross-border projects is the one with a non-Annex-I country investing in a CCS project. This would fall under the category of a unilateral CDM project. But as long as the STUs are not used for compliance by any Annex I country this case is not interesting. In the following, we discuss accounting options for cross-border projects.

Cross border projects

According to Art. 6 and Art. 12 of the Kyoto-Protocol, the project-based mechanisms involve two Parties. Recalling the geographical distribution of storage sites (see Table 4) and CO_2 point sources (see Hendriks et al. 2004, p. 45) CCS cross-border projects seem quite likely, if CCS would enter the climate policy regime. Torvanger et al. (2004, p. 2), for example, explicitly refer to the huge storage capacity in Norway and point out that it would be possible to store a sizeable share of the European emissions in the future.

Torvanger et al. (2004, p. 8) also discuss three different ways of dealing with cross border projects:

1. Handling under the existing flexible mechanisms
2. Consideration of CCS as end of pipe technology; country where CO_2 is captured receives the credits
3. Consideration of CCS as sink category. Credits are given to the country where the carbon dioxide is stored.

The first option proposed, however, is no real option, at least for the case with two Annex-I countries (JI) involved. In this case, for each ERU transferred to the investing country an AAU would have to be deducted from the host country’s Assigned Amount. However, in contrast to a traditional JI project (e.g. improvement of efficiency of power plant) no emissions from national sources in the host country are avoided – nevertheless AAUs are deducted from its budget. Thus, the host country would fall short of emission rights and would have to take additional actions in order to be compliant. Options 3 is equivalent to case 1 presented above (see section *Inventories*). Option 2, however, seems to be incomplete as it suggests the generation of credits for capturing CO_2 without stating how emissions are to be taken into account in whatever inventory. This could endanger environmental integrity if, for example, the emission reduction approach is chosen. It may also be a problem in non-Annex B Parties, since these do not have an emission target at all.

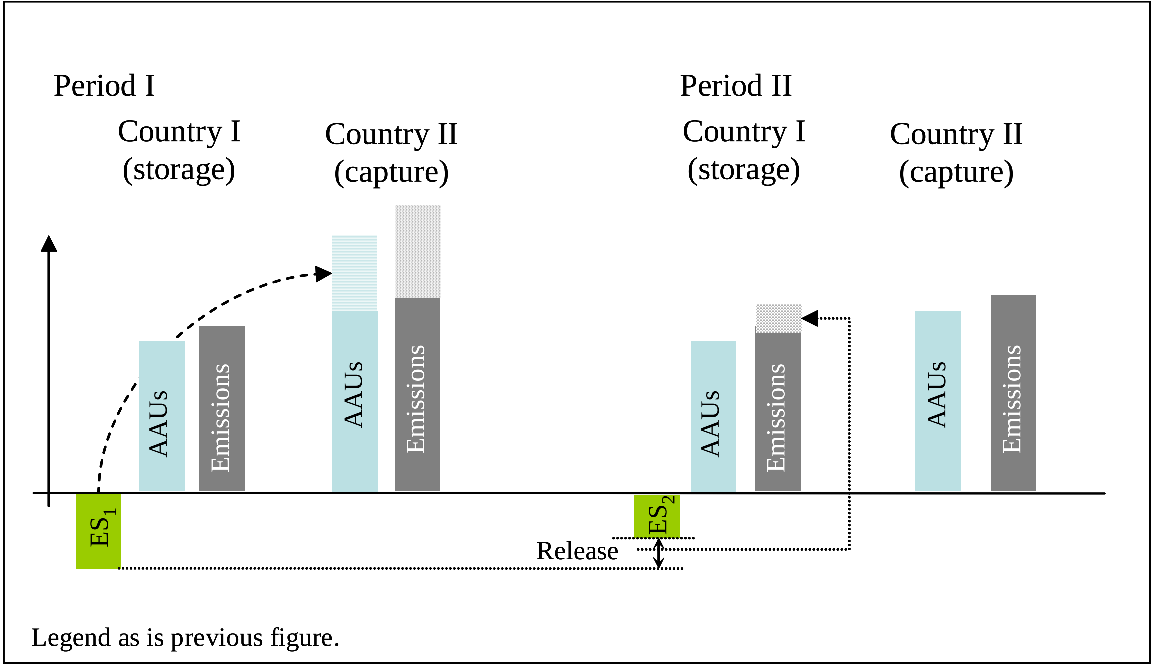

Figure 7: Cross border CCS project with two Annex-I countries involved (JI)

If using the removal approach, as done in this paper, there is no major change for JI-projects[36] compared to the one country case (see Figure 7). The credits generated after storage would most probably be transferred to the country where the carbon was captured.[37]

The STUs generated after storage would most probably be transferred to the country where the carbon was captured. Therefore, STUs would have the same characteristic as RMUs: they would be transformed to (permanent) ERUs, transferred to the buying country and imply seller liability.

The situation is slightly different when a non-Annex I country is involved (cases 4-6). Then it is important to distinguish whether capture or storage takes place in the non-Annex I country. In the case with capture in a non-Annex I and storage taking place in an Annex I country (case 6)[38], there is no risk of weakening environmental integrity. If emissions are released from the reservoir, they would later be considered in the inventory of that Annex I country.

If, on the other hand, emissions are stored in the non-Annex I country (case 4, CDM), environmental integrity is endangered. As non-Annex I countries do not have an emission target, emissions released after storage would not be counted towards a reduction target of the respective country. This is why we, again in analogy to the LULUCF rules under the CDM, apply the concept of temporary credits (tCERs) as illustrated in Figure 9 in order to account for non-permanence.

[36] i.e. two Annex-countries involved

[37] As the emissions are already added to its inventory, the latter has a strong interest in receiving the permits or an appropriate amount of money in the case the credits are sold to someone else.

[38] Imagine CO_2 emissions are captured in China and stored in empty Russian gas fields.

Figure 8 and 9 show the tCER approach (for case 4, CDM) with the capture taking place in an Annex I and the storage in a non-Annex I country. The non-Annex I country generates tCERs which are sold to the Annex I country.[39]

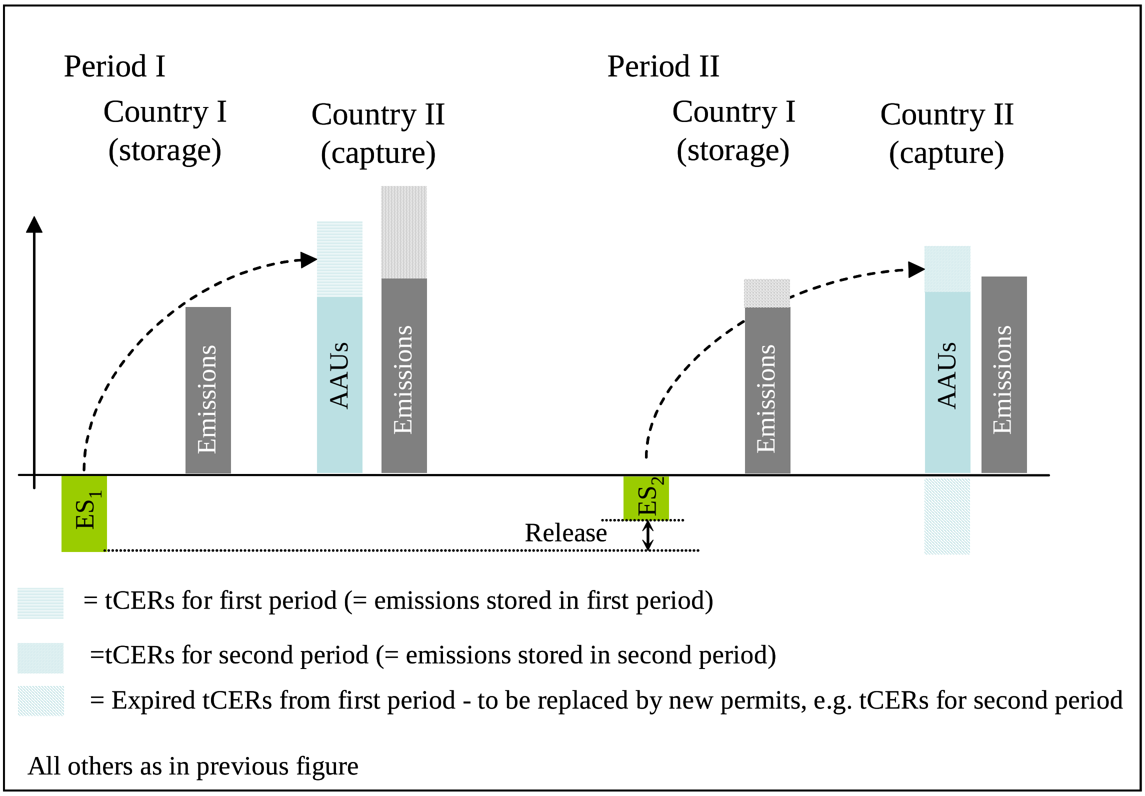

Figure 8: Cross border CCS project (case 4) with capture in Annex-I and storage in non Annex I countries (CDM), using the tCER approach

As tCERs expire after five years[40] the Annex I country has an additional debt equal to the number of tCERs used for compliance in the previous commitment period. This debt may either be settled by buying permanent permits such as AAUs or CERs or new tCERs (or lCERs). With high reservoir quality, only a small amount of the stored CO_2 will be released during the last commitment period. Thus new tCERs will be issued for the amount remaining in the reservoir. In case no CO_2 has been released at all, the quantity would be equal to the one in the first period, and no purchase of new permits would be required. In case all emissions stored in the first period have re-entered the atmosphere, no new temporary credits would be issued and all expired tCERs from the previous period would have to be replaced. This approach would guarantee that non-permanence of storage will be accounted for.

[39] Theoretically, the non-Annex I country could also sell the tCERs to any other country. However, as in the previously discussed cases, the capture country has an incentive to buy the credits, since the captured CO_2 already appeared in its emission inventory.
[40] One may, of course, consider longer periods for CCS CDM projects.

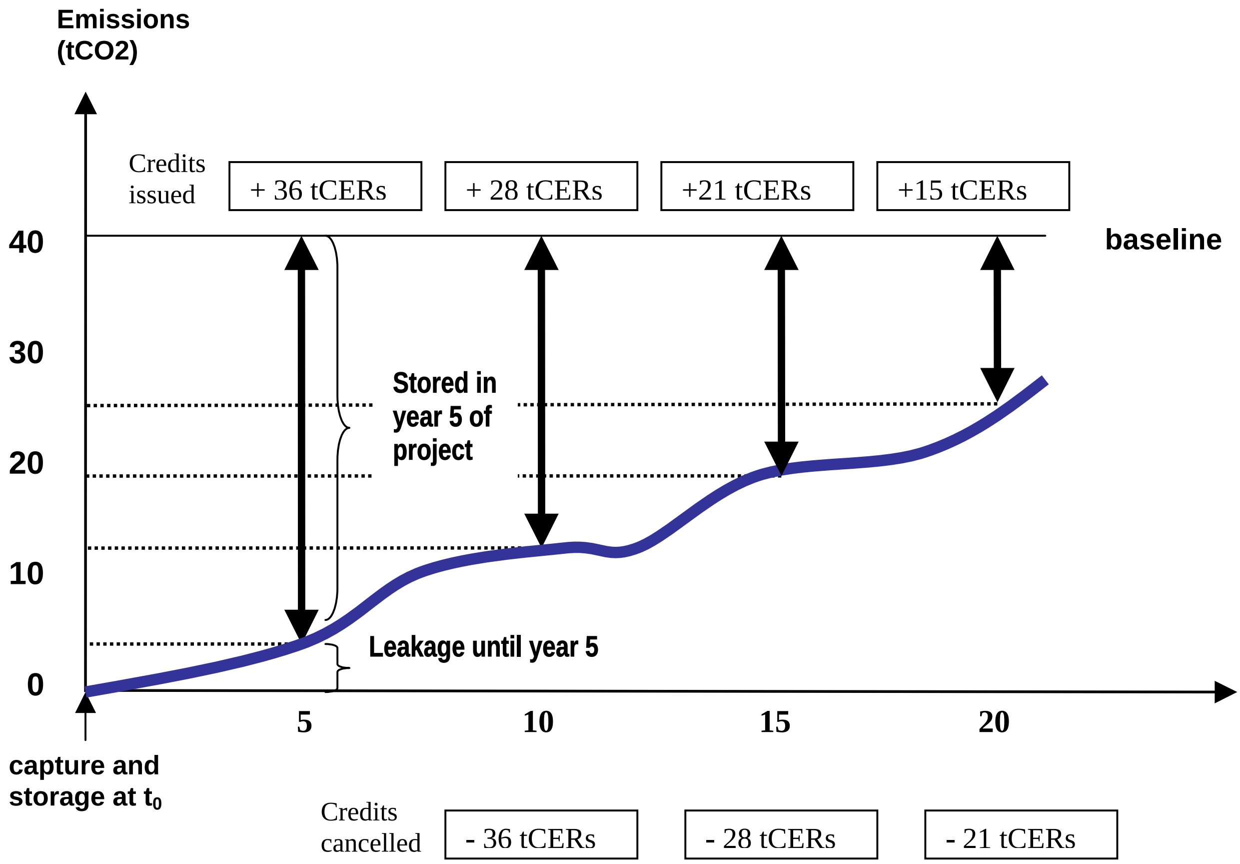

Figure 9: The tCER approach applied to CCS

However, accounting might become much more complicated than discussed so far if different exporting (capture) countries use the same storage reservoir and if release rates are a function of the quantity stored. Transboundary reservoir, too, may be difficult to deal with due to the territory principle underlying the Kyoto Protocol

Economic implications of non-permanence of CCS

CCS, with the exception of EOR and maybe ECBM, does not render any additional income except the one generated by the credits for the CO_2 storage. Kallbekken and Torvanger (2004) compare the net economic benefit of geological storage with different levels of permit prices, and come to the conclusion that geosequestration is likely to be economically viable only in those case where costs are low and permit prices are high. However, when comparing costs with the benefits of geosequestration, the cost term must also include the costs of non-permanence of carbon dioxide storage.

We call the cost incurred to compensate for future releases of CO_2 replacement costs (RC). Here we assume buyer liability, thus, using the example of expiring credits (tCERs) which have to be replaced by the country holding the credits in case of CO_2 releases. The replacement costs are equal to the discounted cost incurred for buying (permanent) credits on the market to compensate for future CO_2 releases.[41] Therefore, the benefit of temporary storage (in economic terms) lies in the postponement of the purchase of a permanent permit.

[41] See also Ha-Duong (2003).

Consequently, the value of temporary storage (V^{temp}) is equal to the value of a permanent emission reduction (V^{perm}) minus the replacement costs[42]:

$V^{temp} = V^{perm} - RC$

The smaller the release rate and the higher the discount rate, the lower will the replacement costs be . With decreasing replacement costs[43], the value of the temporary credit will increase. Due to these additional costs related to future releases of CO_2, any (temporary) CCS activity must be cheaper than permanent mitigation options by an amount equivalent to the replacement costs.

Table 7 shows the value of temporary storage for different release and discount rates expressed in percent of the value of a permanent emission reduction. In the calculation we assumed a stable price for (permanent) emission reduction credits.

While at low release and high discount rates, the value of temporary storage is almost equal to the one of permanent emission reductions, high release rates and low discount rates lead to substantial decreases in the value of temporary storage. The assumption underlying such a calculation is that some form of climate regime exists for thousands of years in the future in order to guarantee the replacement of credits and the setting of emission reduction targets.

Table 7: Value of temporary storage in percent of the value of (permanent) emission reduction, stable carbon price path[44]

V^{temp}		Release rate (%)			
		0.01	**0.1**	**1**	**5**
	1	98.8	90.6	48.5	14.2
Discount Rate (%)	**5**	99.6	97.7	80.8	42.5
	10	99.7	98.7	88.0	56.5
	15	99.8	99.0	90.7	63.2

If the above assumption is not fulfilled, it has to be questioned, if CCS can be a sustainable mitigation option to combat climate change.

A solution to this problem, at least in the framework of the CDM, could be to adapt crediting periods to human time horizons. Such a limitation is already incorporated in the modalities of forestry sinks in the CDM, where maximum crediting periods are no longer than 60 years. All temporary credits of the respective LULUCF project expire after this period. This is equivalent to the assumption that after 60 years all the sequestered carbon is released to the atmosphere, even if it remains sequestered in the biomass thereafter. However, shortening crediting periods, as illustrated in Table 8, will make temporary carbon storage less attractive, since it reduces the value of temporary storage even further. The reason for such a pattern originates from the fact that crediting periods considerably shorter than retention times neglect a great part of the storage taking place beyond the crediting period (here 60 years). Therefore, the benefit from postponing the purchase of permanent credits cannot be realized, as illustrated by Figure 10.

[42] The value of temporary storage consists of the price obtained for the chain of temporary credits generated during the crediting period.
[43] Decreasing replacement costs could be linked e.g. to lax emission reduction targets in the future. In the case of a breakdown or discontinuation of the climate regime, replacement costs would be zero.
[44] With increasing prices in the future the general message does not change. Only the percentage figures change.

Furthermore, a limitation of the crediting period leads to the effect that the value of temporary storage decreases with lower release rate, just opposite to Table 7.

Table 8: Value of temporary carbon storage in percent of value of permanent emission reduction, stable carbon price (time horizon 60 years)

V^{temp}		Release rate (%)			
		0.01	**0.1**	**1**	**5**
Discount Rate (%)	**1**	0.1	1.3	9.3	11.8
	5	0.4	3.7	26.6	38.1
	10	0.5	4.5	33.3	51.9
	15	0.5	4.8	36.0	58.6

The effect discussed implies the question if very short crediting periods might provide an incentive towards storage reservoirs with rather high release rates, therefore shifting a great burden to future generations, as discussed above.

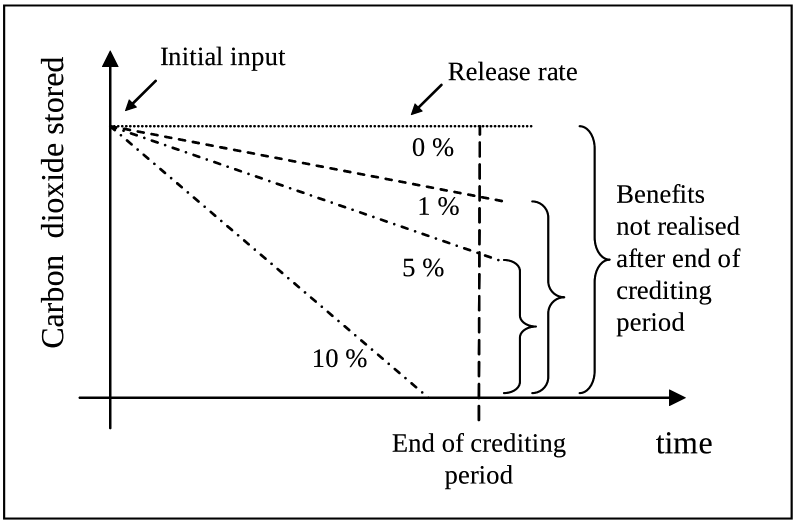

Figure 10: Effects of a limitation of the crediting period.

Furthermore, with such low values of temporary storage, it might make it impossible to cover the costs with the benefits generated from the created permits in most of the CCS options. Considering that current prices for one t of CO_2 are around 5-8 € per t of CO_2, and assuming rather modest increases in the near- and mid-term, most CCS activities are far off from compensating their costs by the income generated from carbon storage.[45] Those projects which are already profitable today (EOR) might play some role in the near-term future for climate policy strategies of Annex B countries. In the CDM, however, these projects will not be able to comply with the additionality criterion. However, future prices for CO_2, and therefore the benefits that can be expected for carbon dioxide storage, will depend on the development of the climate regime and the targets set for the second and consecutive commitment periods.

[45] It has to be mentioned, though, that CCS cost estimates range rather in the middle of mitigation costs of all mitigation options available.

Conclusions

Carbon capture and storage (CCS) in geological reservoirs is widely seen as a promising emission reduction option. In spite of the large literature on the issue, a comprehensive analysis of the integration of CCS into international climate policy regime is still lacking. Furthermore, no link between CCS and the existing experiences with the sinks options in the LULUCF area in the climate regime has been established. The present article fills this gap by applying the existing LULUCF rules for accounting of non-permanence to CCS and it discusses the economic and policy implications arising due to this consideration of non-permanence.

We come to the conclusion that a transparent and comprehensive accounting of non-permanence can only be achieved, if CCS is considered as a removal (sink) activity. Especially unexpected events like accidents or the expressive release of CO_2 during transportation on the high seas may endanger environmental integrity if an alternative accounting rule is applied. The approach supported in the study, however, is not compatible with the existing UNFCCC sink definition and the IPCC inventory guidelines. This may imply that the inclusion of CCS into the climate regime is generally not possible if environmental integrity is to be guaranteed. For cross-border projects, we discuss the special characteristics of CCS due to the potential geographical separation of capture and storage, and show consequences for the accounting of non-permanence. Following the LULUCF rules, we apply the tCER approach for those projects that would fall under the CDM. However, it has to be remarked that not all projects with non-Annex I participation are automatically CDM projects, if the removal approach is applied.

Based on the tCER approach, we show the economic implications of accounting for non-permanence of CCS. The value of temporary storage is almost equal to the one of permanent storage options if release rates are very small. However, with high release rates and low discount rates the value of temporary storage decreases.

In analogy to the LULUCF under the CDM, a limitation of the duration of the crediting period for CCS is considered. As a consequence of such a limitation, most of the economic benefits of the long retention cannot be realised.

Assuming no radical increase of carbon prices in the near- to mid-term, it is unlikely that CCS will be a competitive climate mitigation option unless technological breakthroughs reduce the energy penalty and thus the capture costs. Furthermore, public resistance and legal issues will probably be additional barriers to its implementation. Finally, we point out that massive CO_2 sequestration in the very near future may result in a vicious circle due to the resulting emissions released from the reservoirs in the distant future. These arguments suggest that CCS is probably not as an attractive climate mitigation option as widely supposed.

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