Chapter 15

CCS in the International Context

Is CCS a necessity if an ambitious climate protection goal is to be achieved, for example the European Union's 2°C target? And what requirements must then be met for international implementation? This chapter examines those two questions in the light of economic scenarios and thoughts about a possible institutional framework for CCS. The focus is on a global perspective for CCS.

15.1 The Significance of CCS as a Climate Protection Option

The importance of CCS in the context of climate protection lies primarily in the possibility of stabilising the level of CO_2 in the atmosphere at a lower level. If the increase in global average temperature is to be restricted to 2°C above the pre-industrial level it will very probably be necessary to stabilise the CO_2 concentration in the atmosphere at below 450 ppm (Meinshausen 2006). This is the climate protection goal of both the European Union and the German government.[1] There is good reason to believe that it will only be possible to achieve this low stabilisation level at low overall economic cost if CCS can be used as an additional option for reducing CO_2 (alongside renewables and enhanced energy efficiency).

In fact, the lower the stabilisation level of CO_2 concentration is to be, the greater the importance of CCS. Fig. 15–1 shows that the contribution of CCS is evaluated differently in different models. The reason for this is that the models make different assumptions about the growth in emissions and the technical and economic potential of renewables.

The discussion about the relevance of CCS for global climate protection has gained in importance in recent years as doubts have grown that today's strategies will suffice to achieve a global climate protection goal. In particular, international controversy has blown up about whether the European Commission's 2°C target (Tol, in press) is achievable or sensible. Here interest focuses on the costs and strategies of climate protection.

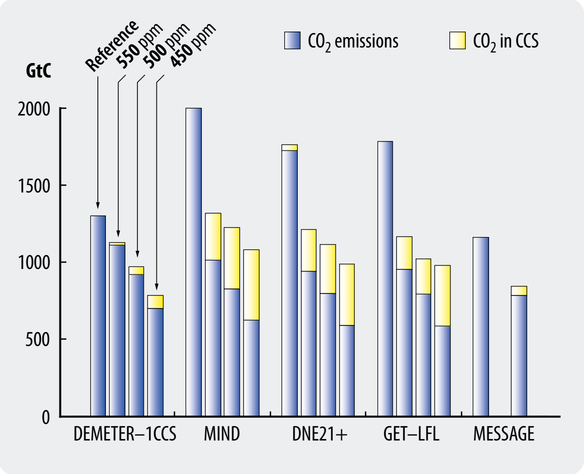

Fig. 15-1: Cumulative quantity of anthropogenic CO_2 emissions and CO_2 captured through CCS in relation to the stabilisation level of atmospheric CO_2 concentration (reference case = no stabilisation target) in various models (Edenhofer et al. 2006)

However, until recently assessments of climate protection costs have largely neglected the potential of technological progress for achieving reductions. Only recently have economists attempted to clarify the question of whether and to what extent technical progress can be fostered to reduce climate protection costs. The Innovation Modelling Comparison Project (IMCP) shows that technical progress really can reduce climate protection costs. The results of modelling presented in Fig 15–2 show that discounted economic costs increase clearly if a concentration target of 450 ppm or less is to be achieved, but in the overwhelming majority of the models they could be kept to figures below 1 % of global GDP.

In the case of climate protection, the economic costs quantify how many units of GDP would have to be sacrificed for the sake of climate protection.[2] Because these losses occur at different times they have to be normed to one particular point in time. This is done by discounting the GDP losses to a base year using a discount rate. Here the GDP growth in the case with climate protection is compared with growth without climate

---

[1] Cf. Sixth Community Environment Action Programme (2002), http://eur-lex.europa.eu/LexUriServ/site/en/oj/2002/l_242/l_24220020910en00010015.pdf.

[2] This approach relates exclusively to the costs of *reducing* climate change (mitigation). The costs of *adapting* to climate change (adaptation) are not included.

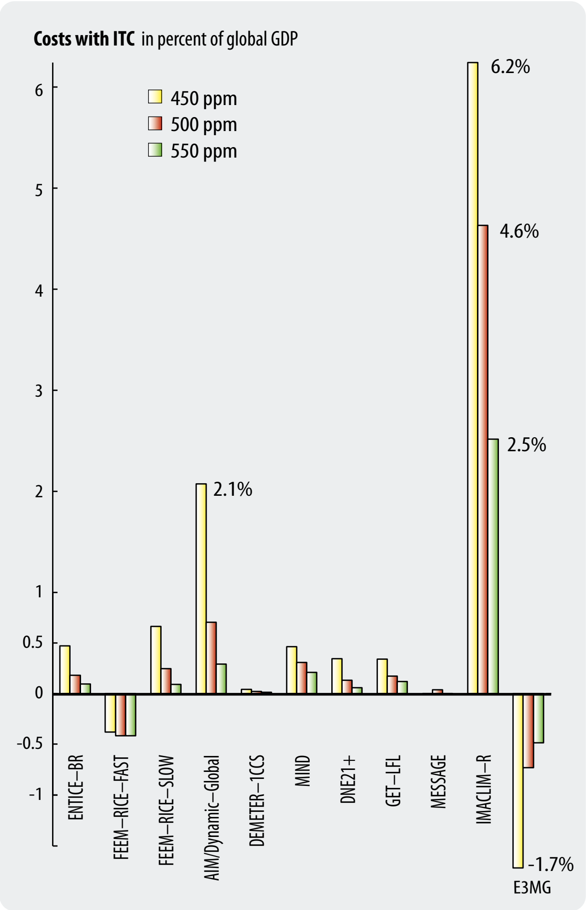

Fig. 15-2: Discounted economic costs in percent of global GDP, taking technological progress into account, in various models that account endogenously for technological learning effects. ITC: Induced Technological Change (Edenhofer et al. 2006)

protection. Discounted losses of one percent for the next hundred years mean that growth in the case with climate protection will be delayed by three months.[3]

In this context there is reason to hope that CCS can – especially at the global level – reduce the economic costs of climate protection, possibly by more than 30 % (IPCC 2005), if technical progress allows further refinement of the technologies.

The following main uncertainty factors affect the influence of CCS on the economic costs of climate protection, and are analysed in greater detail in section 15.2:

- Learning rates in using CCS,
- Learning rates for renewables,
- Leakage rates of geological formations,
- Discount rates,
- Costs of exploitation and extraction of fossil resources,
- Time of availability of CCS,
- Costs and speed of implementation of increased energy efficiency (supply and demand sides).

The term “uncertainty factors” should be understood as meaning that the listed factors have a decisive influence on the results of models of the use of CCS. At the same time the factors can be understood as risks that have to be discussed in connection with CCS.

The importance of CCS and the relevance of these uncertainty factors is reflected in a series of scientific studies where the outcomes of several different models of the application of CCS are compared (e.g. IPCC 2005, Edenhofer et al. 2006).[4]

In the public discussion about the implementation of CCS the debate about acceptable leakage rates takes a prominent place. If the part of the stored CO_2 quantified by the leakage rate escapes from the sink over a given period then the climate protection effect is reduced accordingly. The lower the rate the more effectively can CCS be implemented; therefore leakage is an important uncertainty factor in the economic analysis too. How these aspects could be dealt with institutionally and technically is discussed in section 15.3.

Alongside the question of the conditions under which CCS can make a contribution to climate protection, the possible impact of this technology on ecosystems and human health must also be discussed if we are to reach a comprehensive assessment. That approach of embedding climate protection in a more general understanding of sustainable development is ultimately also prescribed by the United Nations Framework Convention on Climate Change of 1997. In this context it must also be assumed that the perception of the risks associated with CCS could influence public acceptance of specific CCS projects at the local level (cf. e.g. Huijts 2003; overview in Flachsland 2005, 94 ff.). This question has already been discussed extensively earlier in this study.

---

[3] The following example explains where this estimate comes from: If we assume that global GDP grows by 2 % per annum in the business-as-usual case (i.e. without climate protection) and by 1.97 % per annum if climate protection measures are introduced, the losses over the century as a whole (measured as a reduction in global GDP discounted at 5 % per annum) would add up to 1 %. Thus global GDP would reach the absolute value in 2101 that it would otherwise (in the business-as-usual case) have reached in 2100 (cf. Azar and Schneider 2002 for a similar argumentation).

[4] The discussion about CCS and the associated uncertainty factors has also been conducted by pressure groups (especially environmental groups) and by the German government’s Advisory Council on Global Change (WBGU) (cf. WBGU 2003, WBGU 2006).

15.2 CCS in a Portfolio of Climate Protection Strategies: Analysis of Uncertainty Factors

Here we explore the role of CCS for climate protection using the tools of social cost-benefit analysis. The **MIND model** employs CCS as a technological option – alongside the use of renewables and measures to improve energy efficiency – with the goal of maximising social welfare and setting a limit to emissions or temperature rise.[5]

Here we discuss outcomes from the models in order to assess the global risks described above. In various scenarios we identify the critical variables for the introduction of CCS in the electricity sector by evaluating the effects of parameter modifications on the model results (total amount of CO_2 sequestrated or costs incurred). In the graphics showing the results of the simulations (Figs. 15–3 ff.) each tile represents the result of the particular combination of parameters. The gradient represents the sensitivity: in areas of high sensitivity (steep gradient) small changes in the parameters cause large changes in the amount of sequestrated CO_2 or the costs.[6]

Altogether, the application of CCS demonstrates a broad range of outcomes. Depending on the assumptions used in the models, between 0 and 700 Gt carbon are sent for storage between 2000 and 2100. Using Monte Carlo simulations it was possible to show that under plausible assumptions the median and mean would amount to about 100 GtC by 2050 (Bauer 2005). That order of magnitude also corresponds with other estimates for the technical potential of CCS.[7]

15.2.1 The Cost Reduction Potentials of CCS and Renewables and the Discount Rate

The results of the simulation are conspicuously dependent on learning rates and leakage rates. **Learning rates** designate the cost reduction per unit that results when the cumulative capacity is expanded. Here the learning rates for CCS and for alternative technologies play the decisive role. CCS plant can come into play as an option above all where it becomes profitable more quickly than renewables. This assumes that the current learning rates and market developments for renewables will not continue over the next 20 years, in particular that there are no so-called technology leaps where as yet unforeseeable developments become usable for renewables. The more slowly the cost-cutting potential of renewables is realised and the more robust the technical possibilities and cost-cutting potential of CCS technologies become, the greater the cumulative amount of captured and stored CO_2 will be and the longer the timeframe for using CCS as a climate protection option. The less energy is saved and the higher the global primary energy consumption, the greater will be the importance of developing climate-friendly energy sources.

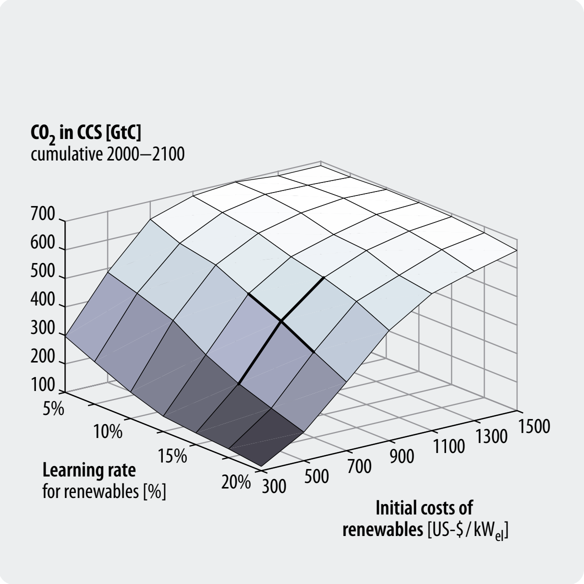

Fig. 15-3: Optimum cumulative amount of sequestrated carbon between 2000 and 2100 in relation to learning rate and the initial investment costs of renewables

The MIND model investigates a direct connection between the development of the two learning rates in relation to implementation of the CCS option. Fig. 15–3 shows the amount of stored carbon in gigatonnes calculated by MIND in relation to the learning rate for renewable electricity generation options and the initial costs for new generation capacity for renewables.[8] A low learning rate and/or high initial costs characterise a development trajectory for renewables that takes effect relatively late compared with CCS. Therefore in this case the amount of sequestrated CO_2 increases significantly. An area of particularly high sensitivity is found for comparatively low initial costs for renewables with simultaneously high learning rates.

Alongside learning rates and initial investment costs, the level of **floor costs** also determines the rate of techno-

---

[5] The MIND model is an integrated assessment model that couples a model of the global economy based on the concept of endogenous growth (and focused on the energy sector) with a climate model. It calculates timelines of investment and consumption decisions which combine a prescribed limitation of the rise in global mean temperature with maximising the social good on the basis of per capita consumption over the whole period (Bauer 2005, Edenhofer et al. 2005).

[6] The figures for the sequestrated amount are given in the graphics in gigatonnes of carbon (GtC). The corresponding amount of CO_2 is greater by a factor of $44/12 \approx 3.67$.

[7] On the basis of technological solutions whose fundamental applicability has already been demonstrated, the IPCC concludes that it is almost certain that up to 200 Gt CO_2 could be sequestrated (at least 99 % probability) and probable that up to 2,000 Gt CO_2 could be sequestrated (66–90 % probability) (IPCC 2005). For a detailed discussion of storage potential see chapter 7.

[8] In this model costs are given as specific investment costs (€/kWel), but this value allows no direct conclusions to be made about the level of electricity generating costs (Ct/kWh).

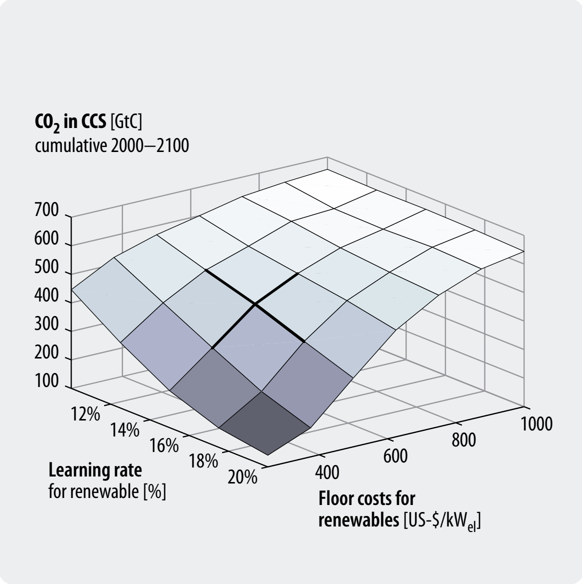

Fig. 15-4: Optimum cumulative amount of sequestrated carbon between 2000 and 2100 in relation to learning rate and floor costs

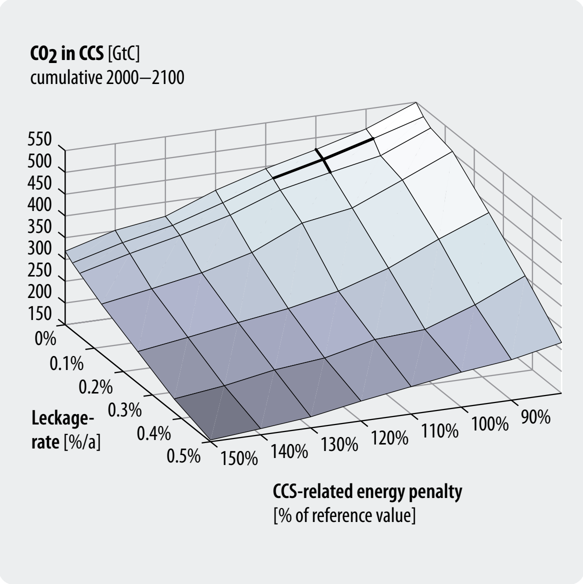

Fig. 15-5: Optimum cumulative amount of sequestrated carbon between 2000 and 2100 in relation to leakage rate and the energy penalty on the optimum amount of sequestrated CO$_2$

logical progress.[9] The higher the floor costs for renewables, the more slowly the capacity of the renewables can be expanded, assuming a given volume of investment, and consequentially the greater the amount of sequestrated CO$_2$ for a given climate protection goal (see Fig. 15-4). With very high floor costs the potential for technological progress also falls. The contribution from CCS then ceases to be sensitive to the learning rate.

CCS can be applied economically efficiently only on condition that the forecast leakage rates of well under 1 % per annum are actually adhered to.[10] According to current estimates this condition is fulfillable. The IPCC's hypothesis is that for the global proven potential of 2,000 Gt CO$_2$ more than 99 % of the sequestrated CO$_2$ would "probably" remain in the sink after a storage period of 1,000 years (IPCC 2005).[11] Where CO$_2$ is stored in closed geological formations it should take several thousand years for significant amounts of CO$_2$ to come to the surface through diffusion processes, but measurable leaks could occur sooner too, for example through unexpected faults.[12] The sensitivity study presented here makes no claims as to the probability of leakage rates, but merely shows how the assumed leakage rates influence the overall result.

Fig. 15-5 documents how the overall amount of injected CO$_2$ depends on the leakage rate and the energy penalty.[13] It describes the effect whereby, because of the energy required for the CCS technology itself, the technical efficiency of the power station falls when additional components for capturing (and sequestrating) CO$_2$ are added. The smaller the amount of CO$_2$ escaping from the geological formations and the more favourable the energy penalty, the more cost-effective and efficient is the application of CCS. The figure also shows that the leakage rate definitely has a noticeable influence on the use of CCS, especially in connection with a low energy penalty.

For the cost-cutting potential the result is the following. If we assume an average learning rate of 15 % for renewables and an annual leakage rate of 0.05 % of the stored CO$_2$, it turns out that limiting atmospheric CO$_2$ to below 450 ppm would involve a relative loss of only 0.6 % of global GDP compared with the business-as-usual option, and the capture and sequestration of approx. 456 GtC.

With increasing use the relative costs of CCS sink. In comparison to versions with lower learning rates considerably more CO$_2$ is stored. Increasing efficiency of the investments in CCS (caused by learning curve effects and a decreasing energy penalty) allows the cumulative amount of CCS to increase until the technical progress is exhausted and no significant further reductions in the economic costs of climate protection can be achieved.

---

[9] Floor costs are those costs that cannot be reduced through learning processes, for example specific material consumption.

[10] With an annual leakage rate of 1 % only about 60 % of the stored quantity would remain in the sink after 50 years, while after 100 years about two thirds of the original stored quantity would have escaped.

[11] According to the IPCC "probably" means a probability in the range 66–90 %.

[12] As well as geological strata other sinks, such as the oceans, are also under discussion. But in the general discussion geological formations play the dominating role.

[13] The energy penalty is the additional energy required for the CCS technology. One hundred percent represents a default value, values < 100 represent a lower energy penalty, in other words a smaller loss of efficiency.

The **discount rate** also plays an important role in models for calculating climate protection strategies because it is decisive in determining the emission reduction goals. The higher the discount rate, the more is consumed in the present and the less invested, which means that more of the costs of climate protection are displaced into the future – and with them the emission reductions.

The level of the discount rate has considerable influence on the selection of avoidance options. With a high discount rate CCS plays a bigger role and at the same time greater use of renewables is delayed. The reason is that in this case the investment that must be made in renewables today – and thus the costs of restructuring the energy system – is postponed, because a high discount rate makes it more profitable in the future. The extended use of fossil fuels implied by this constellation can only be reconciled with climate protection targets if the use of CCS is expanded.

The introduction and promotion of renewables (and an increase in energy efficiency, which is not explicitly addressed in this study) remain unavoidable, especially if we assume that geological storage potential is limited and relevant leakage rates will occur. Investment in CCS could ease the transition to an emissions-free energy supply if the current speed of market development and cost reduction for renewables were to slow considerably and at the same time CCS technologies were to realise their cost-cutting potential very quickly. If both options are roughly equally successful economically, the relative demand will depend largely on the level of successful efficiency increases.

15.2.2 The Costs of Exploration and Extraction of Fossil Fuels

The role of the availability of fossil resources has to date played little part in calculations of the opportunity costs of climate protection in general and CCS in particular. The more fossil resources (coal, oil, natural gas) are available when an effective climate protection policy is introduced, the greater the opportunity costs of climate protection. This is because climate protection devalues the reserves of fossil resources and the whole stock of capital that is tied up in the fossil resource sector. With climate protection a large part of the reserves that were economically usable in the business-as-usual scenario would no longer be viable.

The faster technical progress in the exploration and extraction sector opens up new fossil resources, the stronger this effect becomes. If technical progress in the exploration and extraction sector is very dynamic CCS will find relatively broad application in order to allow the fossil resources to be used even under the conditions of relatively ambitious climate protection. The following scenario analyses investigate the effects of uncertainties about the current status of progress in exploration and extraction and the associated costs – the detail of which is currently controversial.

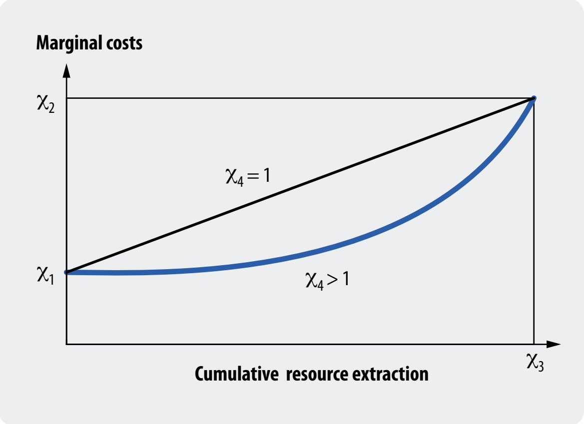

Fig. 15-6: Rogner curve, showing in a simplified form the marginal costs of resource extraction in relation to cumulative resource extraction (based on Nordhaus and Boyer 2000)

But first we have to clarify what we mean by resources: “resources” are the physical totality of existing raw materials, while “reserves” are the deposits that can be exploited with today’s technology at today’s prices (Rogner 1997). If the technical possibilities and associated costs change, resources become reserves. Rising prices lead to increasing efforts to open up new resources and turn them into exploitable reserves.

The Rogner curve abandons the distinction between resources and reserves. It describes the extraction costs in relation to the quantity extracted to date. The trajectory of the cost increase depends on three aspects. Firstly, the extraction costs themselves, secondly the possibilities of substitution between the different fossil fuels and thirdly technical progress (Rogner 1997, Leggett 2005).

The Rogner curve can be understood as follows: opening up new resources counteracts the exhaustion of the existing ones, and the more units of a resource have already been extracted the more exhaustion leads to increasing extraction costs. In the ideal case the cost increase is constant (see Fig. 15-6, Rogner 1997). Uncertainties about the shape of the curve are described by parameters: χ_3 represents the resource base; χ_4 describes whether the cost increase takes effect early (small value) or only begins later (high value).[14]

Fig. 15-7 shows that the costs of climate protection increase, if more fossil resources become available, for example through intensified exploration efforts. Fig. 15-7 shows the costs of climate protection in relation to the available resource base χ_3 and the parameter

---

[14] For example if $\chi_4=1$ is selected the Rogner curve is a linear function, i.e. a straight line, while $\chi_4=2$ produces a quadratic Rogner curve. In the quadratic case the costs remain lower than in the linear case until quantity χ_3 has been extracted. Beyond that point the quadratic function describes higher costs. This effect is amplified further by selecting larger values for χ_4 (e.g. $\chi_4= 3$, cubic).

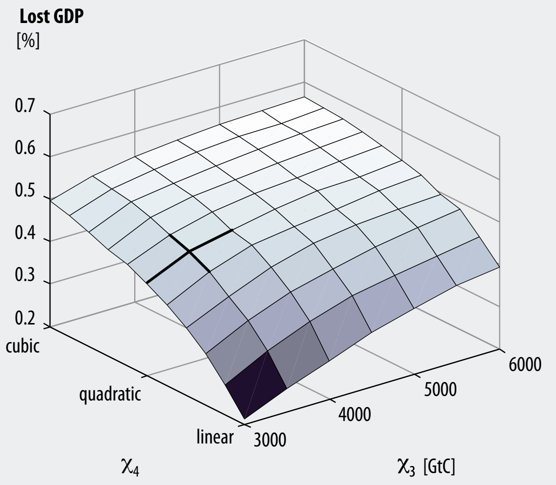

Fig. 15-7: Cost of climate protection as percentage loss of global GDP in relation to the resource base (χ_3) and the parameter characterising the development of extraction costs (χ_4)

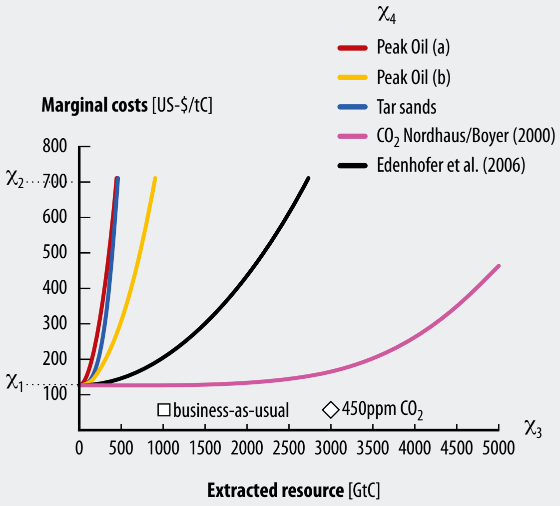

Fig. 15-8: Marginal costs of resource extraction in relation to cumulative resource extraction for the scenarios described in the text

for χ_4. Even if the costs of extraction only increase relatively late, the economic costs of CCS also increase for the whole period. The reason is that if extraction costs rise late (in the business-as-usual case) relatively large quantities of cheap fossil fuels would be available and would be used – which would then no longer be possible in the climate protection case. This would result in higher opportunity costs for climate protection. Assuming strong technical progress in the extraction sector the gap between the business-as-usual and climate protection cases in terms of the emissions to be reduced is relatively large due to the extensive use of fossil resources. Consequently CCS is used particularly intensively in order to achieve the climate target at all (Fig. 15-9).

The resource base for fossil fuels is currently estimated at 3,500 to 6,500 GtC (WEC 2000). If all of that were to be converted into CO_2 it would be impossible to limit climate change. The limiting factor for use of fossil energy would be the climate system rather than the fossil resources. Because the extraction costs for coal will rise more slowly than those for oil, a partial substitution of oil by coal is to be expected. For this reason too, the importance of CCS will probably increase.

In economic terms, the debate about peak oil scenarios is primarily about the costs of replacing oil by coal and gas rather than the question of when extraction peaks. Because the uncertainties are enormous here, four additional scenarios were calculated using different assumptions about the shape of the Rogner curve (see Figs. 15-8 and 15-9).[15] The three peak oil scenarios (Peak Oil (a) and (b), Tar Sands) assume that coal and gas can replace oil only at enormous cost. In the fourth scenario, which also enjoys a claim to plausibility and is used by Nordhaus as the basis of his forecasts (Nordhaus and Boyer 2000), the long-term costs of substitution are relatively low. The process of analysing the different Rogner curves described here – especially using bottom-up models – can be regarded as an important research task because it is on this that the economic benefit of CCS in the climate protection context will decisively depend.

If the costs of fossil extraction now fall through learning curve effects, the share of available reserves in the resource base expands. The lower the costs of exploration and extraction, the more CO_2 will be sequestrated over the course of the next century (Fig. 15-9). However, these learning curve effects and falling costs do not mean falling prices for fossil fuels, but rather a flattening out of the general price rise (in Fig. 15-8 this can be pictured as a transition to a curve with a less steep gradient).

The results of the simulations show that technical progress in exploration and extraction of fossil resources makes climate protection more expensive (cf. Fig. 15-7). Paradoxically, rising prices for fossil fuels do not lead the energy markets to invest exclusively in renewables. Instead, rising prices offer an incentive to invest in the exploration and extraction of high-emis-

---

[15] Nordhaus and Boyer (2000): χ_3 = 6,000 GtC, χ_4 = 4. Edenhofer et al. (2006): χ_3 = 3,000 GtC, χ_4 = 2. Peak Oil (a) :χ_3 = 500 GtC, χ_4 = 2. Peak Oil (b): χ_3 = 1,000 GtC, χ_4 = 2. Tar Sands: χ_3 = 500 GtC, χ_4 = 3. In all scenarios: χ_1 = 113 US$/tC and χ_2 = 700 US$/tC.

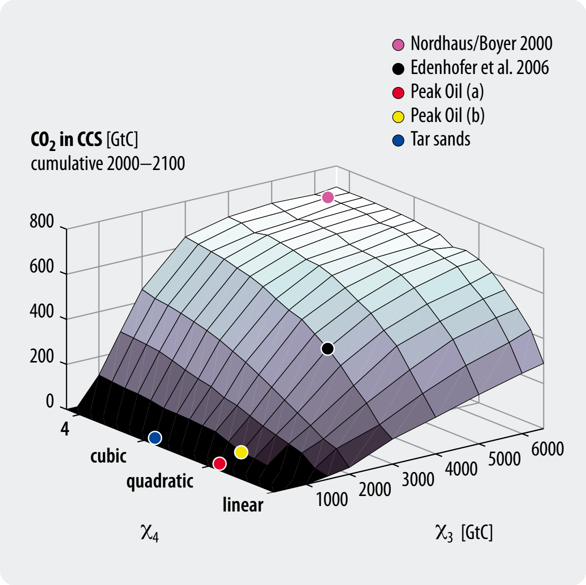

Fig. 15–9: Optimum cumulative quantity of sequestered carbon between 2000 and 2100 in relation to the resource base (χ_3) and the parameter characterising the development of extraction costs (χ_4). Coloured dots indicate the scenarios discussed in the text. Peak Oil (a) and (b) and Tar Sands are peak oil scenarios with relatively small differences in their parameters. As the name suggests, the Tar Sands scenario assumes that tar sands will be mined (see below).

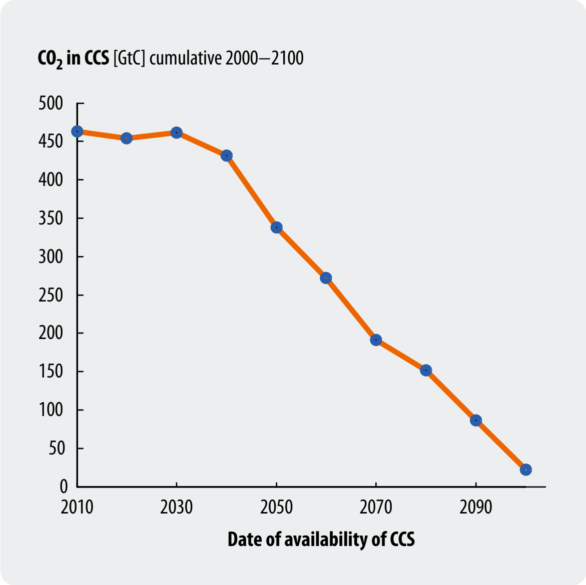

Fig. 15-10: Optimum cumulative quantity of sequestered carbon between 2000 and 2100 in relation to the time when the technology becomes available

sion fossil resources that had previously been largely ignored ("unconventional resources").[16] This effect can be observed at present: the high oil price has stimulated the extraction of tar sands and oil shales in Alberta, where they can be mined economically on a large scale at a price of approx. $80 per barrel (Economist 2006). So high oil and gas prices greatly increase the economic value of the fossil resources to the extent to which new deposits are discovered. The ensuing technical progress causes fossil fuels to continue to be competitive until their costs catch up with those of renewables.

Without climate protection policy, i.e. without internalising the social costs of a destabilised climate (and in particular with a resource-led increase in the focus on coal) the necessary restructuring of energy systems would come much too late to be able to meet relevant climate protection goals.

However, in recent years a partial rethinking on the part of the energy business has been observed. As well as stimulating increased efforts to exploit unconventional resources, higher oil and gas prices have also given a clear boost to technologies for using renewables (Leggett 2005). The rising costs of climate protection caused by technical progress in exploration and extraction of fossil resources can be moderated if CCS is introduced on a relatively large scale. Time is working for CCS: the longer it takes to agree a treaty regime for international climate protection, and the longer fossil fuels are used on a massive scale and can in some way benefit from learning effects, the more probable it becomes that CCS will be introduced on a large scale.

If a structural restriction on the extractability of conventional fossil fuels – and thus a lasting price rise – occurs within the coming years or decades different substitution effects will occur. But these types of substitution over time and their overall outcome have not yet been sufficiently investigated. Overall the analysis shows clearly that the development over time of the use of different fuels is still subject to uncertainties. In the following section the effects of CCS becoming available at different times are examined.

15.2.3 Timeframes of CCS Availability

In the discussion about the benefits of CCS the time when it becomes available plays a central role. Some critics claim that if the CCS option does not become available on a large scale within the coming decade then it will not be an economic proposition. This argument deserves closer examination.

The simulations show that CCS can still be worth using even if its introduction is delayed by decades – although the cumulative quantity of CCS for the twenty-first century decreases considerable if it turns out that the technology will only become available after 2050 (Fig. 15-10). The discounted consumption losses caused by the costs of climate protection rise accordingly (Fig.

---

[16] There are, however, limiting factors for the use of unconventional resources. For example social acceptance, which in the case of tar sands in Canada and oil shales in the United States could be a decisive factor, because of the severe environmental impact. Other limits are set by the scale that can be achieved over time. Large-scale provision of fuels gained from unconventional sources takes years and cannot be increased in any order (Economist 2006).

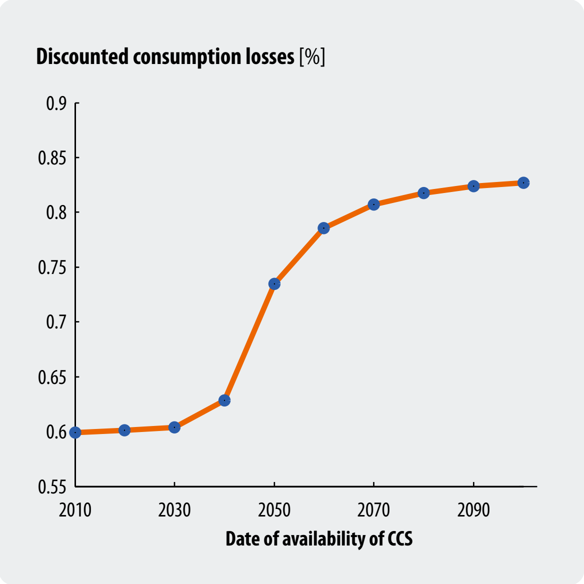

Fig. 15-11: Discounted consumption losses in percent caused by cost of climate protection, in relation to the time when the technology becomes available

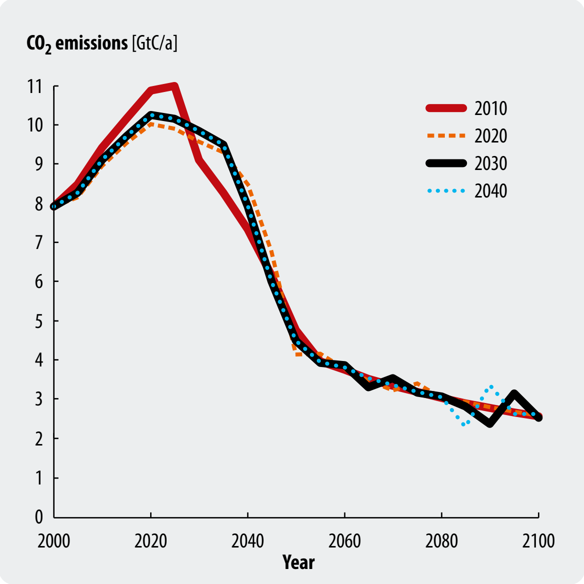

Fig. 15-12: CO_2 emissions paths with different availability dates of CCS

15-11), because the cost reduction potential of CCS for climate protection is greatest in the next four decades. However, if the CCS option becomes available later this does not decisively alter either the cumulative amount of reduced emissions or the timeline of reductions (Fig. 15-12).

Fig. 15-11: Discounted consumption losses in percent The results can be explained as follows. If there is a delay in the introduction of CCS it is more worthwhile from today's perspective to force the promotion of renewables from the outset, because after 2050 the costs of extraction of fossil fuels will increase steeply, which makes large-scale use of CCS after 2050 less attractive. With the assumption that learning curves for renewables remain constant, the rising costs of fossil fuels cause the opportunity costs of climate protection to rise most strongly in the first four decades when the CCS option is not available.

Overall the contribution of CCS to the implementation of an ambitious climate policy consists in reducing the costs regardless of when it is introduced on a large scale. These cost reductions turn out differently depending on whether CCS is implemented sooner or later.

15.3 Requirements for an Institutional Framework for CCS

The introduction of a climate protection option is associated with far-reaching consequences of an institutional nature. The specific costs and risks for CCS must be noted, but also the possibility of integrating CCS as an additional climate protection option in a portfolio of existing policy instruments.

In the following, various aspects are identified that will have to be taken into consideration when drawing up a regulatory framework for CCS. The starting point here is the question of what consequences can be drawn from the results of the modelling in the previous section for the debate about whether the "cap and trade" system or a technology protocol should be the governing approach in climate protection agreements. Then we move on to examine crucial legal aspects of a regulatory framework for CCS, supplemented by an overview of examples of existing arrangements in the United States, Japan, the EU and Germany. Lastly, the international challenges are outlined for an institutional framework that would accommodate the economic analysis from section 15.2 and aim to integrate it appropriately in the international climate regime.

The work of developing a suitable institutional framework involves challenges on several levels:

- Time: The long timeframe for CCS demands particular attention; the consequences of leakages must be dealt with over much more than a few decades.
- Space: Local risks (for example for ecosystems near a sink) and global impacts (i.e. the possible risk to climate protection goals through leakages from sinks).
- Content: New concepts are required if CCS is to be integrated in the global climate protection regime. Local risks have to be covered by existing legal frameworks as well.

The implementation of an institutional framework depends on the approval of democratic sovereign bodies, so the public perception of CCS must not be neglected. Currently CCS is regarded with scepticism by the public, especially in direct comparison with other climate protection options, but there is also a great information deficit (IPCC 2005), so it would seem advisable to improve the supply of information to the public and intensify public discussion of the CCS option.

15.3.1 The Basis for an Institutional Framework: "Cap and Trade" versus Technology Protocol

The modelling results point to a central dilemma of current climate protection policy. Renewables are the central option for creating a sustainable low-emission energy supply, while CCS is seen as an option for reducing the costs of the transition (see also Bauer 2005). In both cases, the cost-cutting potential is only realised if sufficient investment occurs. But this investment will not be made unless the prices for emission certificates rise and the certificate prices cannot rise unless further emissions agreements are achieved. Such agreements are being held up because the treaty states regard climate protection as being expensive, but costs cannot be reduced unless there is investment.

If the oil price also rises – even if only temporarily – this will divert investment to the resource extraction sector where it can increase the size of available reserves which in turn further increases the economic cost of climate protection.

These are the arguments that are behind the debate between the technology protocol idea and a "cap and trade" system. On the one side the proponents of technology protocols do not expect that multilateral agreements will come soon enough to allow low-emission energy technologies to be developed sufficiently quickly. But the development of these technologies is necessary if the costs of climate protection are to be kept within acceptable limits. On the other side the supporters of "cap and trade" approaches argue that unless emissions reductions are specified there is no incentive to introduce CCS and renewables on a large scale. So in the long term a technology protocol alone cannot guarantee effective climate protection.

A combination of technology protocol and "cap and trade" certainly could offer an opportunity to bring movement into the international climate negotiations. And through its cost-cutting potential CCS could contribute to the success of this approach. At the same time, targeted support for CCS technologies makes sense then because the greatest economic benefit will be gained if CCS is introduced in the coming decades. Therefore political support for pilot projects is of great importance – not only for CCS but also for renewables and efficiency increases. Section 15.3.6 takes a closer look at the importance of pilot projects.

15.3.2 Critical Legal Aspects

Consequences of the precautionary and polluter pays principles in environmental law

Environmental law is based on fundamental principles that can serve as a normative guide for regulating CCS. They are applied at the German, European and international levels – sometimes with differing formulations and emphases (Kloepfer 2004).[17] Among these, the precautionary principle, the polluter pays principle and the principle of public responsibility are the most relevant for CCS.

The precautionary principle requires legislators to take preventive action even against possible future dangers. In view of the long-term nature of CO_2 storage and the ensuing consequences any institutional framework will have to define suitable arrangements for dealing with future risks. Specifically, the legal framework for CCS must therefore be in a position to ensure responsibility and liability for future risks – especially leakage of CO_2 – over very long periods of time. By the time a problem is discovered in the storage formation the company responsible for sequestration there may no longer even exist. Incentives to shift legal and financial responsibility to future generations must be avoided, but suitable global frameworks for that do not yet exist (IPCC 2005).

In this connection the polluter pays principle is also relevant: the cost of environmental harm is always borne by the polluter. But if the polluter cannot be identified or if application of the principle would lead to serious economic disruption, the principle of public responsibility dictates that the public has to bear the costs. For possible harm resulting from sequestration, that means arrangements have to be avoided that shift responsibility for risks from CCS from the responsible companies to the state. But the state will bear an ultimate responsibility, especially in the event that the company no longer exists when harm occurs (see also WBGU 2006).

Defining an acceptable leakage rate

As well as the unavoidable slow leakage from CO_2 sinks, accidents while capturing, transporting and storing CO_2 can also cause the sudden release of larger quantities of CO_2. Because of the risk of grave local damage to ecosystems and human health, safety thresholds must not be exceeded. However, arrangements for this can be based on existing regulations for plant failure (IPCC 2005). Low leakage rates have a great effect in the long term and are acceptable only up to a particular maximum level because they counteract the global climate protection effect and possible emission reduction obligations. The associated problems and proposals for solutions are discussed in more detail in section 15.3.5.

---

[17] For European Union law see Art. 174, para. 2, item 2 of the EC Treaty, introduced by the Single European Act of 1986. This provision was explicitly included in German law by Art. 34 of the Unification Treaty of 1990.

Selection and approval of sinks

The selected sinks must simultaneously satisfy the criteria of safety against accidents, low long-term leakage and good cost efficiency. Companies will attempt to externalise the costs of selecting safe sinks while also passing the risk of leakage to third parties, such as the state. Following the polluter pays principle, the crucial point will be to create incentives for companies to find safe sinks and accept liability for possible leakage. Here the liability rules should at the same time promote technical progress in the direction of enhancing safety (see for example Perrings 1989). On the other hand, the principle of public responsibility requires suitable arrangements to be found for the eventuality that the operating company ceases to exist.

Supervision and monitoring of sinks

Sinks have to be supervised in order to monitor the amount of CO_2 stored and the rate of leakage and to impose penalties if necessary. Apart from the issue of whether it is even technically possible to measure leakage rates in ranges under 0.1 percent per year, for example, it is also necessary to define the period of time over which sinks are to be supervised.

There are proposals to give this task to private-sector companies for a period of about 30 years (Wilson 2004). Given that reliable CO_2 storage must in principle be guaranteed over millennia, the precautionary and polluter pays principles throw up the question of how long-term supervision of storage can be guaranteed, and by whom. The argument against the idea of giving sole responsibility to the public sector would be that this might distort competition to the disadvantage of other climate protection options (Dietrich and Bode 2005).

Attributing responsibility and liability

The issues of responsibility and liability that arise in connection with CCS can be divided into three areas:[18]

- Operational responsibility and liability in connection with the processes involved,
- In-situ liability for harm to human health or to local ecosystems caused by an accident,
- Responsibility for leakages in terms of the consequences for climate protection, also in order to generate incentives even at the planning and sequestration stages for ensuring the best possible storage conditions.

Ways of dealing with the first two areas can be derived from existing arrangements (for example safety in manufacturing, transporting and storing chemical products), although it is difficult to achieve agreement with respect to balancing the polluter pays and public responsibility principles and thus the distribution of risks between operating companies and the state. But responsibility for consequences for the climate cannot easily be dealt with within the scope of existing arrangements. The potentially long interval between sequestration and the harm it could cause makes it more difficult to apply existing liability rules. Additionally, the violation of individual legal interests as a result of the negative effect on climate caused by the leakage is difficult to prove (Dietrich and Bode 2005).

A further challenge for regulations dealing with responsibility is the issue of sinks that extend across national borders. Sequestered CO_2 can cross borders intentionally or – via leakage between geological formations – unintentionally (IPCC 2005). This is another reason why CCS must be subject to an international regulatory system. The controversial proposal to inject CO_2 into international waters complicates the problem even further. International conventions, in particular the London Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter of 1972, must be taken into account here as considerable legal obstacles (IPCC 2005).

15.3.3 Statutory Regulations in Selected States and the EU

Here we briefly summarise the existing legal situation in the European Union and Germany, in Japan and the United States to the extent that is relevant for CCS (cf. description in Flachsland 2005, 165 ff. and references there).[19] For the legal position it is relevant that sequestration of CO_2 – apart from the first CCS pilot projects – has to date always been conducted as part of an industrial process rather than for reasons of climate protection. For example in the oil industry CO_2 can be injected into a deposit to improve the recovery rate (enhanced oil recovery). For this reason – and because the quantities and storage periods involved with CCS are many times greater and longer than for operations to date – the current legal situation cannot be applied to future CCS projects.[20] So the legal position is still rather unclear and requires further investigation.

European Union and Germany

CCS would probably be regulated at the level of European law, because the EU holds partial responsibility for the community's environmental policy (according to Art. 174 of the EC Treaty), and also because of the possibility of transfrontier storage. Directive 96/61/EC

---

[18] For a more detailed discussion see de Figueiredo et al. (2006).

[19] As well as the legal situation, the treatment of CCS in the scope of EU emissions trading must also be considered. For more detail, please refer to the literature (Dietrich and Bode 2005).

[20] The amounts of CO_2 sequestrated in current CCS pilot projects (e.g. Weyburn, Sleipner, Ketzin) are many times smaller than would be the case with large-scale CCS projects pursuing ambitious climate protection goals.

lists industrial facilities – principally large-scale point sources of emissions – that require official permits. Although the facilities required for CCS are not to be found in this list – and there would be certain problems involved in including them – it at least becomes clear that facilities of this kind do in principle require official approval under EU law.

With respect to possible contamination or pollution of drinking water, the European Water Framework Directive specifies that freshwater reservoirs must not be contaminated in any way. Here too the question arises how risks associated with CCS can be integrated in this framework.

In current EU law captured CO_2 is defined as waste (as of December 2007). Currently underground storage of substances that are subject to physical, chemical or biological change after disposal is explicitly forbidden in the EU.21 However, the European Commission has announced that it intends to exclude CO_2 captured forCCS purposes from waste law. In January 2008 it published a proposal for a "directive of the european parliament and of the council on the geological storage of carbon dioxide". Its main scope is the regulation of CO_2 storage and the removal of barriers in existing legislation to CO_2 storage.

In addition to EU environmental law, national legislation must also be considered. In Germany this includes the Federal Mining Act (Bundesberggesetz) on underground storage of natural gases, the Closed Substance Cycle and Waste Management Act (Kreislaufwirtschafts- und Abfallgesetz), the Federal Water Act (Wasserhaushaltsgesetz) and the Federal Immission Control Act (Bundesimmissionsschutzgesetz).

All the listed laws include points where official permits would be required for CCS, so integrating CCS in existing regulatory frameworks would bring with it a number of difficulties. Consequently, CCS would probably be regulated in a specially designed framework of its own.

Japan

Japan plays a special role among the states leading the development of CCS, because the geographical and geological situation there means that storage would probably take place largely in the oceans rather than in geological formations.[22]

One special problem that arises here is the possibility of harming the "biological pump" of the oceans, where phytoplankton in surface waters bind atmospheric CO_2 and subsequently transport it to greater depths. If injected CO_2 returns to the surface it will reduce the pH value there, which would in turn reduce the performance of the pump. Furthermore, the ecological consequences of increased CO_2 concentrations in marine systems are largely unknown (see also section 11.3).

United States

In the United States geological formations have been used to sequester waste since the 1930s. After problems arose, especially with contamination of drinking water, the federal authority, the Environmental Protection Agency (EPA) in the 1980s instituted the UIC programme (Underground Injection Control). Thirty-four states have expanded the scope of this federal regulatory programme by adding regulations of their own.

The central element of UIC is its classification of boreholes used for sequestration into different categories. The first category covers the storage of household and hazardous waste in sealed geological formations that are separated from drinking water reservoirs by impermeable strata. They must satisfy the strictest safety standards and they cause the highest regulatory costs. The second category comprises the extraction and sequestration of substances during energy production (enhanced oil recovery). Comparable standards apply here too, although authorisation is handled less strictly. The other regulatory categories are unlikely to be relevant for regular CCS operations.

The regulations for pipeline construction basically stipulate that a right of way (ROW) is required. In deciding whether to grant a ROW, the Federal Energy Regulatory Commission (FERC) considers possible ecological impact and the existing public interest in the respective pipeline.

15.3.4 CCS in the Kyoto Protocol

Multilateral agreements represent the main thrust of global regulation efforts. The most relevant for CCS are the United Nations Framework Convention on Climate Change and its expression in the Kyoto Protocol, where flexible market mechanisms (certificate trading, joint implementation and clean development mechanism) play a key role for achieving the agreed emissions reductions cost-efficiently. CCS could be included in the flexible mechanisms as an emission-reducing measure.

CCS is not yet mentioned explicitly in the United Nations Framework Convention on Climate Change (UNFCCC). But the revised version of the "IPCC 2006 Guidelines on National Greenhouse Gas Emission Inventories" (corrected April 2007) for the first time provides guidelines for defining and measuring emissions sequestered through CCS (and their possible re-

---

[21] In the case of CO_2 that could mean chemical reactions with other substances or phase changes caused by expected underground migration processes.

[22] However, the London Convention (mentioned in section 15.3.2) presents legal obstacles to implementation. Furthermore, the lack of public acceptance could hamper or completely prevent the realisation of marine CO_2 storage (see also the analysis of actors in chapter 3).

emission).[23] CCS is categorised as a set of technologies that allows emissions savings that are to be included in the national greenhouse gas inventories (Eggleston 2006).

The possibility of stored CO_2 migrating across state frontiers is a challenge, especially when a flow of CO_2 occurs from an Annex B country to a non-Annex B country (IPCC 2005). In the aforementioned regulatory frameworks leakage from sinks is assigned to the emissions inventory of the state on whose territory sequestration was carried out (Eggleston 2006). Finally, technical uncertainties involved in the monitoring of sinks and the measurement of leakage rates still result in uncertainties in the calculation of emission reductions (IPCC 2005). The guidelines for this provide for a combination of measurement and modelling approaches to be specified on a case-by-case basis (Eggleston 2006).

In view of the uncertainties about leakage rates, the WGBU calls for sequestered CO_2 not to be counted in full as avoided emissions. Alongside regulatory agreements such as a fixed deduction from the emissions volume the WGBU proposes market-based liability mechanisms, in particular the instrument of Carbon Sequestration Bonds, which are described in the next section (WBGU 2006).

If CCS is included as an avoidance measure in the Kyoto Protocol, CCS projects could also be handled via flexible instruments such as the Clean Development Mechanism (CDM) and in principle also Joint Implementation (JI). The UNFCCC treaty states conference in November 2006 decided to instigate an SBSTA process with the aim of reaching a decision at the 2008 treaty states conference (CoP 14).[24] Beforehand there was also discussion in the responsible bodies about the economic incentive effect of the flexible instruments in connection with CCS and the question of how long-term liability could be shared by the participating states (Wuppertal Institut 2006).[25]

15.3.5 Carbon Sequestration Bonds: A Proposal for Regulating Responsibility for CO_2 Storage

The central question in regulating CCS is to systematically include critical uncertainty parameters in the institutional framework and to create incentives that would encourage the CCS and renewables options to develop in a complementary way (see section 15.2.1). In this context the specific case with CCS is that it is *not* a backstop option that can be applied as a permanent long-term solution to the climate problem, because the storage capacities and fossil resources are limited. Instead, this option is a set of technologies that could fulfil an important bridging function for the transition to an energy system characterised by renewables and energy efficiency. The later or more slowly the cost-cutting potential of renewables can be mobilised, the more important this function would potentially be.

The long-term stability of sinks (i.e. the leakage rate) represents an uncertainty factor that demands risk management of its own over and above the emissions trading of the Kyoto Protocol. The instrument of **Carbon Sequestration Bonds** (CSBs) is the only proposal to date for this (the following description follows Edenhofer et al. 2004, see also WBGU 2006). It presupposes a modified system of CO_2 emissions trading and is to that extent compatible with the market approach of the existing Kyoto Protocol. The CSB instrument attempts to solve the key problems of how the use of sinks with low leakage rates can be encouraged and how residual leakage and its climate impact can be dealt with.

In the following we describe the two versions and their respective impact on safety of storage. They are not mutually exclusive, and indeed could be combined. In both cases politically supported CCS pilot projects could improve the effectiveness of the CSB system and thus of global regulation. By improving the reliability of information about CCS, pilot projects would resolve market distortions that could otherwise reduce the chances of success of the CSB instrument.

Version 1: CSB as an instrument supplementing emission rights

The maximum level of harm caused by leakage of stored CO_2 is easy to calculate in financial terms. It is the amount of CO_2 that escapes from the geological formation multiplied by the certificate price of the emissions at the time leakage occurs. If CO_2 escapes from a geological formation, the atmosphere is used as the "sink" for the CO_2, but no price has been paid for this use. So in the event of leakage the company would have to purchase a certificate for this use of the atmosphere.

Because the volume of certificates doesn't rise, their price increases. This signals to investors, consumers and businesses that utilisation rights for the atmosphere are scarcer than they originally assumed.

However, with this solution alone it will not be possible to prevent companies from acting speculatively when they store CO_2 in geological formations. The management of a company could speculate that the CO_2 will not escape until the company has ceased to exist, that the certificate price will fall in the long term or simply that a different management team will have to cope with the problem. If the timeframe of investors and managers is shorter than the suspected timeframe of CO_2 leakage and the willingness to take risks is high, storage in geological formations with less long-term stability can represent a business opportunity for investors to pass the

---

[23] Here only CCS with geological storage is considered.

[24] SBSTA is the Subsidiary Body for Scientific and Technological Advice

[25] Certain energy corporations (e.g. Shell, BP) are currently already lobbying for CCS to be integrated in the CDM (Point-Carbon 2006). But because there is still great uncertainty concerning the risks of CCS, environmental groups such as Greenpeace criticise the idea of integrating CCS in the CDM system because this would export the risks to the developing countries (Greenpeace 2005).

risk on to future generations. So it is crucial to create an incentive in advance for companies to store CO_2 in the safest possible formations in their own interests.

The introduction of Carbon Sequestration Bonds opens up the possibility of rational risk management. Any business that wished to store CO_2 in geological formations would have to purchase a bond corresponding to the value of the stored quantity of CO_2. From the company's point of view, this bond is an asset that appears on the assets side on its balance sheet. The company guarantees for the term of the bond that the CO_2 will remain in the geological formation. If this actually happens the bond will be repaid to the company with interest (at the level of a long-term security). But the bond is also depreciated every three years by an as yet unspecified environmental agency, unless the company can demonstrate beyond doubt that the CO_2 has remained in the geological formation. If CO_2 escapes, the bond will be partially devalued and the company is forced to partially write off its claim against the environmental agency.

The sum that passes to the environmental agency can be used to subsidise renewables. This earmarking is designed to keep the transition to a climate-friendly energy system as short as possible. Subsidisation can also be understood as compensation for the competitive disadvantage suffered by renewables. But if stored CO_2 escapes from the geological formations in the intervening period, valuable time that would have been needed for a cost-effective restructuring of the energy system will have been wasted. As such, the bond represents a kind of insurance premium against risky and insecure CO_2 reduction activities.

Carbon Sequestration Bonds must be tradable on markets. Then a company can sell its bonds to obtain liquid funds. But companies will only be able to sell their bonds if they are able to offer buyers a better rate of interest than a security without risks. How high this risk premium is will depend on how great buyers perceive the risks to be that the bond will be devalued. So the company will only be able to achieve a high price for its bonds if it can convince buyers that the sink is safe.

The whole sector therefore has an incentive not to undermine confidence in the bonds. The threat of devaluation turns the safety standard of the geological formation into a tradable commodity, because companies then have an incentive to develop powerful monitoring techniques to demonstrate that the CO_2 has remained in the geological formation.[26] The better the proof the greater the value of the bonds. Because CSBs are tradable, investors can express their confidence in CCS by buying bonds. The greater public confidence is, the higher the price. Moreover, this would give the public the opportunity to participate via investment decisions in the general decision on whether or not to implement CCS.

Version 2: CSBs as special emission rights

In the second version CSBs are issued to ensure that a maximum emissions limit is observed. Here the CSB is no longer a separate instrument, but is fully integrated in the certificate trading system. So preconditions would be the implementation of such a trading system and the definition of a corresponding upper limit for emissions.

As in the first version, companies involved in CCS are required to purchase a certain number of bonds, again before sequestration. A bond represents an asset that can be traded immediately on the markets. But the purchaser of the bond then himself bears the risk that this bond will lose value if later emissions are subsequently charged to it. Only then would the bond have mutated into an emissions right. But the bond should not contain an emission right until it has been possible to demonstrate clearly what proportion of the CO_2 can be stored permanently.

After a certain latency period an independent environmental agency will verify how high the proportion of permanently stored CO_2 actually is. If a company can prove that the CO_2 is stored safely it is free to sell the bonds. This ensures that the emissions limit is not exceeded, and furthermore ensures that it is profitable for companies to store CO_2 as securely as possible.

In comparison with the first version, the security of storage is given a higher priority. A higher than expected level of leakage would not only cause a monetary devaluation of the bonds, but also the loss of real emission rights.

15.3.6 The Role of Pilot Projects: Levelling the Playing Field

Successful control of leakage risks through CSB is subject to two processes of market distortion: a) liquidity restrictions, b) social herd effects and time inconsistencies. Pilot projects initiated by the state and publicly funded could avoid these processes (Held et al. 2006).

Liquidity restrictions

Both versions implicitly presuppose smoothly functioning financial markets. But in reality liquidity problems can arise: Banks could overprice credit, and potential purchasers of CSBs could offer prices that were too low if they falsely overestimated the risks of different forms of storage because the financial markets lacked information about the future leakage rates of the alternatives. In other words there is an asymmetrical information structure. Pilot projects could provide the financial markets with the required information. Then the financial markets would be in a position to promote the further refinement of CCS efficiently and without further state control mechanisms.

---

[26] This proof would have to be verified by an independent body.

Social herd effects and time-inconsistency

When CSBs are transferred, expectations about risk are exchanged. Where there is great uncertainty about future leakage rates market participants might tend to copy the buying behaviour of other participants rather than making risk assessments of their own. At the beginning the risk might be underestimated (because leakage is more likely to be a problem in the distant future). If it turns out later that the confidence in CCS was too great, the prices for CSBs will sink. This forces other sectors to reduce their emissions more strongly or might even persuade the state to relax the upper limit for emissions. Conversely, in the long term overestimation of risk may discourage others from implementing potential emission reductions. The market horizon for CSB is consequently too short to allow a rational estimation of the risks. In this situation the state has to promote pilot projects to rectify the time-inconsistency by signalling to the market that it is pursuing a long-term interest in maintaining its emissions limit and having CCS with low leakage rates. At the international level this strengthens the confidence of other states that climate protection obligations will be observed.

The ultimate responsibility of the state arising from the principle of public responsibility that was underlined earlier as one of the crucial legal aspects (see section 15.3.2) also means that the state should emphasise its lasting responsibility for successful climate protection at an early stage by initiating lighthouse projects. In this sense ultimate responsibility would not be a matter only for the distant future.

Altogether Carbon Sequestration Bonds represent an innovative instrument to minimise the risk of leakage endangering climate protection goals while at the same time achieving a plausible distribution of responsibility between companies, investors and the state (WBGU 2006). With respect to the increasing involvement of re-insurers and "green funds" in climate protection, the introduction of a market instrument for regulating liability and safety could prove to be a sensible choice.

15.3.7 CCS in the Kyoto Architecture after 2012: A Possible Strategy for the EU

The challenge for a climate policy for the period after 2012 is to set the right price incentives for investment in emission-reducing technologies by means of effective international agreements (see sections 15.2.2 and 15.3.1). The European Union has set itself the climate protection goal of restricting the rise in global mean temperature by 2100 to a maximum of 2°C. This goal cannot be achieved by Europe acting alone, even though Europe's emissions goals are much more ambitious than the commitments made by other countries.[27] But the question is whether these goals signal credibly to the other main emitters that the EU is actually pursuing – and will implement – a policy that will both meet the agreed European reduction targets and also offer an international incentive for the other main emitters to aim for ambitious emissions targets themselves.

Convincing incentive systems are required to prevent countries from becoming successful "free riders" in climate protection. This will be all the more the case the quicker the involved parties learn that climate protection is associated with relatively modest costs and might even produce an additional dividend through growth potential (triggered for example by exports of innovative technology).

Currently one of the greatest challenges in international climate policy is persuading states that currently do not make such commitments – either because they are sceptical about the Kyoto regime (e.g. the United States) or because as newly industrialising or developing countries they are not covered by the firm obligations of Annex B (e.g. China) – to agree to adopt and observe emissions reductions. The introduction of CCS as an instrument could improve the chances of this. At the same time, from the EU's perspective the chances would improve of achieving its own ambitious climate protection goals. The idea that the CCS option would improve the willingness to adopt emission reductions can be backed up as follows for the cases of the United States and China.

The US Department of Energy (DoE) regards CCS as the central climate protection element for pursuing what the US-American administration regards as ambitious climate protection goals (e.g. stabilisation at today's level). And CCS is also an important issue in the Asia Pacific Partnership.

Over the coming decades China will undertake a great expansion of its power station capacity. The number of coal-fired power stations is expected to triple by 2030 (IEA 2002). So a potential market for CCS is already emerging today. The current Kyoto Protocol signatories could now grant countries like China and India generous emission rights that largely correspond with their business-as-usual emissions trend. At the same time an international fund could buy up these emission rights and take them out of circulation at least until the price of CO_2 rises to a point where CCS becomes profitable (von Weizsäcker 2004).

However it must be feared that the price of taking certificates out of circulation would be high. Europe would have to take on a disproportionate share of funding for climate protection. Europe can only reduce this funding burden if it succeeds at the same time in launching a credible technology policy that has the goal of bring-

---

[27] The EU aims to reduce CO_2 emissions by at least 20 % by 2020 (under certain conditions by 30 %) and by 60–80 % by 2050 (compared with 1990).

ing CCS technologies – and also renewable energy and efficiency technologies – quickly to the point where they are ready for large-scale commercial application. Europe could then hope to export CCS technologies. And the costs of buying up the certificates might possibly then be redeemed.[28]

The potential of the CCS option for globalising the market in emission certificates and thus enabling fast emission reductions should, however, not be overestimated. CCS can act as a bridge between today's energy system and a future energy system whose contours are only just becoming apparent. Most energy analyses show that renewables, alongside efficiency increases, will play a decisive role in the energy mix of the future. But they will be part of a portfolio of technologies where – especially from the global perspective – CCS could be able to make a decisive contribution to lowering costs and thus act as an incentive in international climate negotiations

---

[28] In terms of game theory, purchasing certificates and taking them out of circulation represents a side-payment.