

Mitigation of greenhouse gas emissions from land use: creating incentives within greenhouse gas emissions trading systems

John M. Reilly · Malcolm O. Asadoorian

Received: 27 July 2005 / Accepted: 2 May 2006 / Published online: 21 December 2006
© Springer Science + Business Media B.V. 2006

Abstract Terrestrial carbon sinks and sources were introduced into climate change mitigation related policy relatively late in the design of the architecture of those policies. Much literature addresses how terrestrial sources and sinks differ from emissions from fossil fuel combustion and, hence, is a possible justification for differential treatment of them in policy design. Late introduction in climate policy discussions and perceived differences appear to have resulted in very different policy approaches for sinks versus fossil emission sources. The attempt to differentiate has generated complexity in policy design and likely inefficiency in the operation of these policies. We review these issues and find that the characteristics claimed to apply to sinks apply as well to fossil sources, and differences that do exist are often more a matter of degree than of kind. Because cap-and-trade has gained momentum as the instrument of choice to control fossil emissions, we use as a starting point, how such a cap-and-trade system could be altered to include terrestrial carbon sinks and sources.

1 Introduction

The role of land use and land use change as either a source or sink for carbon and other greenhouse gases (GHGs) is a topic on which many volumes have been written. The Intergovernmental Panel on Climate Change (IPCC) completed a special report in 2000 that alone approached 400 pages and included citations to nearly 1200 related articles and papers (Watson et al. 2000). Furthermore each of the three IPCC working groups in the third assessment report addressed sink related aspects of land use and land use change. Working group I addressed the role of terrestrial systems in the carbon cycle (Houghton et al. 2001). Working group II addressed the impacts of climate change on forests and ecosystems, one consequence of which is changing levels of terrestrial carbon storage (McCarthy et al. 2001). Working group III addressed the potential for enhancing sinks, and the technologies and policies that might bring about such enhancement (Metz et al. 2001). The fourth assessment

J. M. Reilly · M. O. Asadoorian
Massachusetts Institute of Technology, Joint Program on the Science and Policy of Global Change,
Cambridge MA, USA
e-mail: jreilly@mit.edu; malcolma@mit.edu

report of the IPCC is in draft, and is not yet citable, but will contain updated reviews of land use, land use change, and terrestrial sinks.

In the Kyoto Protocol (KP), sinks were added relatively late in the negotiation process. Moreover, there was a relative vacuum of information as to how large these sinks were, and how they might change over time for the Parties involved. The sinks issue was relatively new and not afforded adequate time and consideration on how to include them. Despite this, the Kyoto model for sinks has been borrowed in other proposals such as the McCain-Lieberman Bill in the United States.¹

Unfortunately, this policy architecture for including sinks has generated complexity and potential inefficiency. More specifically, current carbon sink policy has focused on identifying what specific types of sink-enhancement actions can and cannot be included along with unwillingness to bring the entire terrestrial biosphere carbon stock within a policy target. In doing so, it raises the following issues: the definition of a ‘forest’, the difference between afforestation and reforestation, what constitutes ‘management’, the need to identify changes in carbon stocks due to human activities from those due to natural causes, and consideration of spatial and temporal leakage. Given this, a reevaluation of how land use activities could be included within climate mitigation efforts seems worthwhile. This paper seeks to review the policy history and the arguments for differentially treating carbon sinks with an approach guided by the key questions:

- Why was the current sinks policy architecture chosen?
- Why does it differ from the proposed cap-and-trade architecture for fossil fuel carbon which many environmental economists see as a more cost-effective approach?
- Are issues that arise with sinks so different in degree that they cannot be effectively incorporated into a cap and trade system?

While a review of these issues, the paper is not intended as a review of the vast literature on sinks.

2 Current climate policies, emissions trading, and the role of sinks

After advocating for sinks and emissions trading in the KP, the United States and Australia are among the few countries that signed the KP initially and have now expressed their intention of not ratifying it. Therefore, key Conference of the Party (COP) members who were most influential in the decision to include sinks are no longer part of the KP. Canada, also a strong advocate, has ratified and appears most active among the ratifying Parties in developing sinks related measuring and monitoring techniques. The ratification by Russia moved the KP across the threshold of 55 percent of Annex B Parties required for it to enter into force (UNFCCC 1997; UNFCCC 2005).

Australia has indicated that it, while not ratifying the KP, would meet its KP obligation. What this means is unclear, but it may affect the sinks issue. If not formally, Australia could possibly pursue a strategy of meeting the numerical target while defining credits for land use change beyond the limits of the KP. The prospect of crediting reduced rates of deforestation against Australia’s target was identified in at least one study of the pros-and-cons of Australian ratification (Kyoto Protocol Ratification Advisory Group 2003).

¹ See Lewandrowski et al. (2004) for a detailed examination of sinks policy in the United States and a review of lessons learned from modeling sinks in McCarl et al. (2005).

At this point, the possibility that the United States will meet its KP numerical target seems highly unlikely. Instead, the Bush Administration announced an emissions-intensity target that would allow emissions to rise above the 2000 levels, contradicting the KP requirement that the United States return to 93 percent of 1990 levels (White House 2002). For the time being, the current Administration believes its intensity target will be met through voluntary measures. Consequently, it is relatively difficult to rigorously determine whether the actions proposed are sufficient to meet the intensity goal given the following: the nature of the target and the promised actions, the varying changes in emissions intensity in different industries, and changing industry composition over time. The other continuing effort in the United States is a program whereby entities can receive recognition for reducing emissions or enhancing sinks by being awarded “registered reductions” (US DOE 2002). The ‘incentive’ to do so is either good-will or, more likely, expectations that at some point, there will be a mandatory cap on at least some entities and that registered reductions could be applied to them.

Despite the absence of the United States and Australia, the push for emissions trading appears to have taken-hold to some extent under the KP. The European Union (EU) has been developing an emissions trading system, and introduced a test phase to run between 2005 and 2007 prior to the first KP commitment period (EC 2003, 2005; Betz et al. 2004). Although the EU was initially hesitant on emissions trading, it now appears to be a major force in designing a domestic system that could be a model for other Parties, thereby making the vision of an international market for permits a reality (Ellerman 2001). There is, however, still a long way to go to extend such a trading system among all ratifying Parties. The EU’s test program is limited to large emitting point sources (>10,000 tons of CO₂ per year), representing less than one half of the EU’s total CO₂ emissions. Other key Parties including Canada, Japan, and Russia have not yet moved to establish emissions trading systems. Performance to date in the EU’s trading system (2005–early 2006) has resulted in prices on the order of 20 to 28 €/tCO₂, surprisingly high to many analysts because the required reduction was estimated to be only about 1 percent (Pew 2005; Point Carbon 2005a,b).

While emissions’ trading remains alive under the KP, the push for sinks was not nearly as successful. Part of the reason that the agreement was not reached at the 6th meeting of the COP in The Hague in November 2001 was that the EU desired limits on the total quantities of sinks credits that could be applied against each countries emissions cap. However, this was unacceptable to the United States, and probably made it impossible to obtain sufficient votes in the Senate to ratify the agreement regardless of the outcome of the 2000 election (Reiner 2001; Reilly 2003).

The different willingness to embrace sinks appears to derive from different views of the climate change issue as a societal problem, and different implications for countries of the negotiated targets. Many in Europe view the climate change problem as one of reducing emissions typically stemming from the broader agenda of switching from fossil fuels to ‘renewable’ energy. Others view the use of sinks as denial/avoidance of these necessary steps to move the economy away from fossil fuels. In the language of economics, this view can be described as a situation whereby markets failed to price fossil fuels to include all of the external social costs associated with them (e.g., security, air pollution, other health and safety issues, their nature as exhaustible resource, etc.). Rather than try to correct each of the problems, renewable energy proponents appear to regard the answer as simply switching away from fossil fuels. Thus, sinks credits are considered a loophole to allow for continued fossil fuel use. The targets of the EU were also seen as easier to meet because of German reunification as well as the large-scale shift to gas for electricity production in the UK that reduced emissions in these countries below 1990 levels. Forest sinks potential was also seen as much more limited in Europe compared to the potential in most other countries. These

various factors appear to have contributed to the EU's climate negotiating positions and in the formulation of EU domestic policies.

In contrast, the perspective of the United States and the Umbrella Group² focused directly on the climate-GHG problem, and key Parties among this group faced relatively larger reductions in emissions from projected reference levels. The direct focus on climate, as opposed to the broader concern about fossil energy, meant that it did not matter whether fossil fuel emissions were reduced, carbon uptake by vegetation and soils were increased, or carbon was otherwise sequestered. One ton removed from the atmosphere was considered equivalent to reducing emissions by a ton. This focus, along with a desire for cost-effectiveness, led to a desire for maximum flexibility in choosing the least-costly way to meet the emission reduction. Separate quantity limits on the use of sinks, if binding, would result in a two-tier permit market – a higher price for emissions reduction and lower price for sinks reflecting the fact that there were more relatively inexpensive sinks options available than allowed by the restriction on their use. Among most analysts, the sinks quantities allowed in the KP, as finally negotiated at COP 7 in Marrakesh in 2001, are seen as limiting in this way. Moreover, the definition of what can be counted is flexible enough such that the agreement has been widely modeled as simply a relaxation of the constraint on emissions (Babiker et al. 2002). Underlying this view is the calculation that most countries are likely to have sufficient carbon uptake in forests without any additional actions beyond filling their sinks limit. In particular, the KP allows consideration of forest uptake within the period 2008 to 2012 to be credited against emissions during the same period. This sequestration is associated with reforestation and afforestation of pre-identified forests beginning in year 1990.

The KP language requires active management to receive credit for carbon uptake. For some countries, the implicit definition of 'management' was very narrow involving: identified tracts of land that were planted/replanted, and managed with the express intent of storing carbon. Analysts began referring to 'Kyoto forests' to represent the idea that areas receiving credits for forest activities would be expressly identified. However, the United States, leading up to the COP meeting at The Hague in 2000, proposed that "forest management is an activity involving the regeneration, tending, protection, harvest, access and utilization of forest resources to meet goals defined by the forest landowner" (UNFCCC 2000). Under this relatively broad definition, it would include essentially all forestland in the United States as well as most developed countries, given the fact that property laws limiting access appear to qualify the land as 'managed' under this definition.

While the logical basis for including sinks in climate policy is relatively strong, the "weak link" in the argument is the lack of proven methods for measuring and monitoring them. Even at the present time, a complete inventory of carbon sinks for all the major Parties is not available, and there are legitimate questions concerning the accuracy of them. Negotiating the KP caps, with sinks broadly included, implies that the negotiating countries were not aware of their own 1990 net emissions baselines or what their magnitudes would be in 2010. Lacking resolution on how to interpret key terms in the KP, the quantified limits on sinks were finally agreed upon, giving up a portion of the 5 percent reduction that would have been achieved.

The specific numerical limits insisted on by the EU at The Hague, and those finally agreed at Marrakesh, ended, or at least tabled, a very confusing and complex discussion of just how to include sinks. With these numerical limits, the other language that would limit sinks is

²The Umbrella Group included the United States, Canada, Australia, Japan, and Russia and constituted an informal group of Parties negotiating the KP.

relatively unimportant. The ‘success’ of the negotiated limits is that countries can choose to expand the plausibility of sinks accounting; the ‘failure’ is that, if it is possible to easily fill up the sinks limit with sinks that would have otherwise occurred, the strict limits remove any incentive to actually enhance biological sinks. With a cap-and-trade system, regardless of the allowance price, the price for sinks credits would be limited, and could possibly approach zero, because the use of credits is limited far below the amount that could be forthcoming. For example, the EIA (2003) analysis of a cap-and-trade system in the United States, with a limit on credits, projected a two-tier pricing result with a lower price for credits than for allowances.

The combination of three (3) main factors have led some analysts (e.g. Bohringer 2001; Manne and Richels 2001; Babiker et al. 2002) to conclude that the cap on the remaining Parties may be non-binding in the first commitment period: (1) withdrawal of the United States and Australia where emissions are growing rapidly; (2) a target for Russia and the transition economies of Eastern Europe well above expected emissions (so-called ‘hot air’); and (3) the sinks quantities that were ultimately allowed. Thus, even without relatively generous sinks accounting, it is highly uncertain that the emissions target in the KP will generate real environmental gains. If it does, it likely depends on countries doing more than they pledged to do under the agreement, by implementing domestic policies and not fully availing themselves of the excess credits above reference emissions from Russia.

Although the current stated policy of the United States is to reduce GHG intensity by 18 percent over the decade, other unilateral policies have been proposed, most notably the Climate Stewardship Act of 2003 (S. 139), widely known as the McCain-Lieberman Bill. If history is any guide, Bills that fail to pass in the Senate are often reintroduced at a later date, or their language is borrowed for future attempts to draft a Bill with similar objectives. Thus, despite its failure, the McCain-Lieberman Bill provides some insight as to how the United States Congress may possibly approach the problem of mitigating climate change. It was a cap-and-trade with year 2000 emissions as the benchmark, and relatively broadly covered emissions of GHGs. The cap did not cover land use sources or sinks or small sources (<10,000 tons of CO₂ equivalent), although it did cover transport fuel by bringing it under control at the refinery. Small sources and terrestrial sinks of any size were covered under a crediting system, but the total number was limited to a percentage of the total allowances. Paltsev et al. (2003) and EIA (2003) provide a comprehensive discussion of the Bill’s provisions as well as an analysis of its economic implications. While numerically different than the Kyoto target for the United States, the mechanism for sinks (i.e. project credits produced outside the cap with a limit on how many could be applied under the cap) is essentially the mechanism of the KP.

Having described the complexity of sinks inclusion in the KP, a final requirement here is to briefly review the KP language involving sinks. In that language, there was an apparent compromise among those preferring to limit sinks and those preferring broad coverage. This resulted in an attempt to limit sinks by defining specific sinks projects on which all could agree, referred to as “Article 3.3 sinks”. It allows “. . . removals by sinks resulting from direct human-induced land-use change and forestry activities, limited to afforestation, reforestation and deforestation since 1990, measured as verifiable changes in carbon stocks in each commitment period . . .” to be used to meet commitments under the Article.

In lay terms, the definition of reforestation, as opposed to afforestation, has required people to imagine how far back in history or pre-history one might go to determine whether a forest was there or not. Moreover, defining a forest has required consideration of the minimum density and height of the woody vegetation (Birdsey et al. 2000). The debate is highly philosophical as analysts struggle with attributing some part of sink increase to “direct

human-induced” change apart from that which is due to natural causes or indirect actions by humans. Those pushing for broader inclusion of sinks remain hopeful for the “Article 3.4 sinks.”

Upon its entry into force, the KP allows consideration at the Meetings of the Parties (MOP) to determine the “modalities, rules and guidelines as to how, and which, additional human-induced activities related to changes in greenhouse gas emissions by source and removals by sinks in the agricultural soils and the land-use change and forestry categories shall be added to, or subtracted from, the assigned amounts for Parties . . .”.

3 An idealized CO₂ cap-and-trade system with land use sinks

Now suppose we turn attention to how sinks might be included in a modified approach.

3.1 Simple scenario of two hypothetical countries

Consider the following hypothetical example illustrated in Table 1, parts A and B. Let there be two countries: Country A and Country B. Assume both countries have the same 1990 fossil fuel CO₂ emissions and the same 2010 projected emissions. Further in Table 1A, Country A has a large net land use sink, and Country B a moderate land use source. In the absence of policy, increases are predicted in both Country A’s land use sink and Country B’s land use source.

In Table 1B, we use a KP-type target of returning to 90 percent of 1990 emissions levels and we see that reaching the target differs when we apply it to only fossil emissions versus total net fossil and land use emissions (Policy 1). In such a case, Country B appears to gain by including land use emissions because its allowance level based on total net emissions is 99, increased from 90 if only fossil emissions were included. In contrast, Country A receives only 72 allowances compared with 90 and, hence, initially appears to be worse-off with the total CO₂ accounting. However, when achieving the reduction for 2010 (Policy 2), Country A benefits from the more inclusive accounting because its sink requires reduction to 23 below the projected reference, as compared to 30 percent if applied only to fossil fuels; Country B is worse-off requiring a reduction of 41% with the total accounting compared to 30%. This occurs because, in the absence of policy, sinks are projected to increase in Country A, thereby reducing the need to lower emissions or further enhance sinks. In Country B, however, the land use source is growing, generating more pressure over time to reduce emissions or increase uptake to offset the land use source.

There are several lessons we gain from this simple exercise.

- Moving from a fossil-only accounting to a total accounting, including both land use and fossil emissions, does not necessarily benefit the country that receives more allowances or the country with the larger net sink in the base year. Most importantly it is whether, in the absence of policy, the land use sink or source is projected to grow or be reduced.
- Including sinks in an accounting framework does not necessarily lower the real reduction. From Table 1, including sinks results in a reduction below reference totaling 64 across both countries, as compared to 60 if sinks were excluded. Note in other situations, which readers can invent if they are so inclined, total accounting could lead to an increase in net emissions.
- Declines in net emissions to the atmosphere due to the inclusion of land use sinks can be eliminated by adjusting the target reduction. If one has a projection of land use emissions

Table 1 Two hypothetical countries fossil and land use carbon

Years	Country A				Country B		
	Fossil Emissions	Net Land Use Emissions (+) or uptake (-)	Total net emissions	Fossil Emissions	Net Land Use Emissions (+) or uptake (-)	Total net emissions	
	1990	100	-20	80	100	10	110
2010 Reference	120	-25	95	120	20	140	

B. Allowance allocations and real reductions – fossil only compared with total net accounting

Policies:	Country A		Country B	
	Fossil-Only	Total Net	Fossil-Only	Total Net
1. Hypothetical target of 0.90 of 1990	90	72	90	99
2. Reduction from 2010 projected emissions	30	23	30	41

for 2010, it is easy to calculate an adjusted percentage reduction from 1990 that will lead to exactly the same reduction from the reference in 2010 for each country.³

- Differentiation concerns arise with respect to fossil emissions where there are recognized differences in projected growth among countries, and those projections were also highly uncertain at the time the targets were set.

3.2 Additional implications for landowners

To implement a trading system that operates among private parties, the country-wide allocation must be distributed to private parties. This raises some additional issues about the implications for landowner participation in a cap-and-trade system. For illustration, consider another hypothetical scenario in parts A and B of Table 2, focusing on the domestic situation in Country C. Let us assume there exist two fossil fuel users with identical emissions in 1990 (Fossil Source 1 and Fossil Source 2). In addition, let there be two landowners, one with net sequestration (Landowner 1), and one that is a net source (Landowner 2). Fossil Source 1 has a projected decline in emissions in the reference for 2010 and the reference path for Fossil Source 2 is to increase substantially, relatively speaking. Landowner 1 remains a sink in 2010, though its sink declines; Landowner 2, while a source in 1990, becomes a small net sink in 2010.

It is important to note that it is almost inevitable that the gross sink amount in the country (summing the sink for only those landowners or parcels that are net sinks) is much greater than the country's net sink. Much of the discussion of sinks credits, at least in the United States and Canada, focuses exclusively on credits for carbon uptake. This focus eliminates those landowners who are net sources from the program. If that is the case, then it is the gross sink amount (not the net sink amount) that limits the amount of sink credit, and the gross amount is almost inevitably a much larger number. The gross sink amount is not even well defined unless the parcels of land are well defined and unchanging over time.

In the example of Table 2A, consider the possibility that Landowner 1 has some land that is a net source, emitting 20 annually in 1990. To have a net sink of 40 in 1990, the remaining areas are a sink of 60. If there is an incentive to only count net sinks, Landowner 1 might sell the parcel that was a net source and, hence, get credit for 60 instead of 40.

This issue of deforestation is not ignored in the KP. Rather, reducing deforestation is considered a potentially creditable action, but the failure to include the entire terrestrial biosphere in tracking compliance with the policy targets creates problems. In particular, the incentive to voluntarily produce credits depends on how the baselines are established for each activity. Those emissions sources that do not voluntarily enter a crediting system are not covered at all and thus existing sinks may become sources, or existing sources may grow larger. Lack of full coverage creates the problem of leakage – reductions among credited sinks being offset by increases in non-covered land areas. However, allowing landowners to voluntarily register credits when it is in his/her interest exacerbates the problem. This is because it is almost certain to enlist those who intend to increase sinks anyway, while producing no incentive to control for those who intend to become a large source.

In Table 2B, we identify some hypothetical allowance allocation policies, assuming that a cap would cover terrestrial biosphere sources and sinks as well as fossil emissions. The common implicit assumption in most discussions of sinks allowances is that one can only

³ Depending on the merit criteria, the inclusion of sinks could lead to a different optimal level of reduction or split among countries. This example is meant to indicate only that through adjusting the allowance level any reduction amount can be achieved, including the exact level one would have achieved without sinks.

Table 2 Hypothetical scenarios for emissions sources and sinks in country c with a target of 0.90 reduction from 1990 below total net emissions

A. Emissions in 1990 and reference emissions projections for 2010					
Years	Fossil Source 1	Fossil Source 2	Landowner 1	Landowner 2	
1990	50	50	-40	20	
2010 Reference	40	80	-20	-5	
B. Possible Allowance Allocation Policies, in parentheses required reduction (\pm) or excess allowances (-) that could be sold					
Policies	Fossil Source 1	Fossil Source 2	Landowner 1	Landowner 2	
1. Grandfather to 1990 with Proportional Reductions	45 (-5)	45 (35)	-36 (16)	18 (-23)	
2. Estimate 2010 Reference with Proportional Reductions	30.3 (4)	60.7 (4.5)	15.2 (-4.8)	-3.8 (-1.2)	
3. Proportional Responsibility from 2010 Reference	33.6 (6.4)	67.4 (12.6)	-23.2 (3.2)	-5.8 (8)	
4. Credit for 1990 baseline sink, proportional reduction for all sources from 1990	30 (10)	30 (50)	0 (-20)	12 (-17)	
5. Credit for any sink in 1990, allowance to match any land use source, proportional reductions for fossil sources from 1990	26 (14)	26 (54)	0 (-20)	20 (-25)	

cap sources, not sinks. Of the five (5) allowance allocation policies in Table 2B, the first two we propose do not distinguish between sources or sink in determining allowances.

Policy 1 is essentially the Kyoto allocation rule as applied to a country's emissions, used to allocate the allowances among entities within a country and including both fossil sources and landowners. Like the Kyoto national allocations, it uses 1990 as a benchmark and allocates the reduction to individual entities proportionally. As a result, Country C's target is 90 percent of 1990 net emissions such that each entity receives an allocation proportional to its 1990 emissions/sinks. For the land use source (Landowner 2), this is a reduction of its emissions to 18 from the 20 emitted in 1990. For the land use sink (Landowner 1), the allocation is -36 compared with emissions of -40 (i.e. a sink of 40 in 1990). Rather than receiving an allowance of 0 (i.e. 40 more than its "needs" as of 1990), Landowner 1 starts in a debit position. However, it has sufficient sink to cover this debit and beyond, at least as of 1990. The varying rates of growth of emissions and changes in sinks for the 2010 reference conditions reveals the same issue that has plagued the Kyoto national allocations. If the targets are undifferentiated, then these different expected growth rates lead to very different burdens. Although the Kyoto allocations refer to 1990, differentiated reductions for individual countries took into account, to some degree, expected differential growth in emissions. Here we see that Policy 1 results in very different required reductions for individual entities; Fossil Source 1 and Land Owner 2 have allocations well above the projection of reference emissions. They could sell these allowances and possibly reduce further at a relatively low cost and sell even more. The burden of buying permits would fall on Fossil Source 2 and Landowner 1, even though Landowner 1 is a large sink. How large this differential growth effect can be, obviously depends on how differently emissions and sinks are expected to change for different entities.

Policy 2 corrects this differential growth problem by making the allocations proportional to the projected reference for 2010. This reveals a different issue that arises with simply multiplying the base by 0.90. The mathematics produces the correct national cap of 72, but the Policy means that any entity that is a sink will necessarily have excess credits to sell; this occurs for both landowners in this example.

The algebra of this reduction is:

$$\text{National target} = \% \text{REDUCTION} * \text{EMISSIONS} + \% \text{REDUCTION} * \text{SINKS} \quad (1)$$

Policy 3 seeks to make the burden reduction proportional to the level of emission source or sink by altering Equation (1) slightly, indicating the percentage change ($\% \Delta$) as:

$$\text{National target} = (1 - \% \Delta) * \text{EMISSIONS} + (1 + \% \Delta) * \text{SINKS} \quad (2)$$

Knowing the national target, projected emissions, and projected sinks, we can then solve Equation (2) for the $\% \Delta$. This formulation simply generates an allowance allocation that, without trading, would require sources to proportionally reduce their emissions and sinks to proportionally increase their sink. For Policy 3, the $\% \Delta = 0.159$. This means that emissions sources receive an allowance that is 15.9 percent below projected reference emissions, and sinks receive an allowance debit of 15.9 percent more than their projected sink. This again leads to an allocation that meets the national cap. Here, however, no entity has allowances that would allow them to sell credits without taking some additional action beyond what is projected to occur in the reference. In other words, each entity bears a "proportional" burden.

This formulation is far from perfect. Note that Landowner 2 has a small net sink and, hence, the equi-proportional change results in a small absolute change. Consider the case of a landowner who inadvertently was at 0, neither a source nor a sink. He/she would have no

burden, even though he/she may be in a position to become a significant sink with relatively little effort. At first, this does not appear so very different than the problem for fossil emitters – reductions may be costly and difficult for one and easy for another and so equi-proportional reductions need not imply the same cost burden. However, for landowners, it is not unreasonable to imagine an owner of 100 acres versus 1,000,000 acres. If the 1,000,000 acre landowner has zero net emissions, it would have no burden under Policy 3. However, other things being equal, there would be greater scope for increasing sinks on the 1,000,000 acres than on the 100.

The allocation principles in Policies 4 and 5 are more consistent with the view of the majority of the land use community. The implicit equity principle is that, inadvertently being a sink implies that one should be able to sell all of the sink allowances. In Policies 1 through 3, Landowner 1 receives zero allowances as opposed to a debit. Even though this entity's sink is declining, he/she has allowances to sell even without reversing the decline. Policy 4 treats the landowner source symmetrically with the fossil emission source, requiring a proportional reduction in emissions. Again, however, the zero problem is likely to occur. Large landowners with a source approaching zero would have a very small required reduction, with potentially the ability to easily become a large sink. This could be considered an asymmetric treatment with that of fossil emitters, but it is a symmetric treatment with Landowner 1 (i.e. the net sink). In a way, being a net source is villainous, but crossing zero on the number line makes you virtuous with a generous allocation of allowances as your reward.

Policy 5 further distinguishes between land use emissions/sinks and fossil emission sources by granting landowner sources an allowance equal to their emissions. This is most similar to the implicit assumption that landowners would enter a program voluntarily and have no burden to reduce unless they chose to do so. Thus, Landowner 2 could do nothing to change its land use emissions, and still would not have to acquire additional allowances. Although it initially appears that this is close to current policy approaches to include sinks via a credit system, capping Landowner 2 is actually superior. While he/she receives allowances equal to expected emissions, and not required to do anything, emissions cannot increase without acquisition of permits to cover them. Thus, with this Policy, it prevents spatial leakage within countries. Of course, the more allowances granted to landowners, the more the burden shifts to fossil sources. Policies 4 and 5 use 1990 conditions as the basis for establishing allocations. The same principles could be applied to reference 2010 emissions as in Policy 2. We leave construction of these Policies to interested readers who are so inclined.

The current community that is typically discussing sinks, views them primarily from a profit standpoint, consistent with Policies 4 and 5 presented here. The moral premise for realizing this “windfall” gain appears to be that sequestering carbon is virtuous and it should be rewarded. However, the main reason the uptake is now occurring is that, in the past history of this land, carbon-releasing deforestation or tillage practices occurred. Thus, today's virtue is only erasing yesterdays vice. As such, Policies 4 and 5 may not be as compelling.

In showing various policies through which a cap-and-trade system could be extended to sinks and sources related to land use, we hope we have demonstrated that there is a logical basis for treating sinks in a similar manner to a fossil source. It is possible to design a target to achieve the same net effect on the atmosphere with land use sinks and sources included and when they are not. To do so, requires an adjustment in the cap level to account for the net land use sink or source. Given different changes over time among countries or entities, their inclusion can have potentially large effects on burden-sharing. However, the burden-sharing effect can be overcome through differentiation or choice of allocation policy. Blindly excluding land use emissions and sinks, or giving landowners the choice to voluntarily sell

credits, does not eradicate these issues. It only limits/eliminates economic incentives to reduce emissions or increase sinks in the most cost effective manner.

With this idealized system developed, we turn to issues that have been the subject of considerable investigation with regard to inclusion of sinks, with the intent of identifying which of these remain relevant, and which of them largely vanish when the policy architecture is redesigned.

4 Sinks issues in policy discussions

As discussed previously, there are a host of issues that arise when including sinks in a climate mitigation policy. We identify eight (8) main issues that reappear in the literature on this subject: (1) How much to pay for an additional ton of sequestration as compared to an avoided ton of emissions?; (2) What should be done about the high variability of ecosystem uptake or large releases due to fire?; (3) How to resolve the problem of determining direct human responsibility for sequestration?; (4) To use a broad cap or to treat sinks as credits against a cap on fossil fuel emissions?; (5) Permanence and leakage, is it a special problem for carbon sequestration?; (6) Pre-existing distortions; (7) Measurement, monitoring, and enforcement; and (8) Carbon stored in products. Each of these are discussed in the following sub-sections, with the goal of determining if these are unique problems for land use emissions that prevent them from being included in broad cap and trade policy.

4.1 How much to pay for an additional ton of sequestration as compared to an avoided ton of emissions?

Many issues have been included in this question, and various solutions proposed. Some would like to pay landowners up-front for prospective storage once a forestation project has been established. Concerned that the carbon may not remain stored, the concept of ‘discounted’ tons has been created, whereby a fractional discount factor would be applied to account for possible return of carbon in the future (i.e. physical leakage). Others have proposed renting carbon storage. This involves paying a price per ton each year stored so that, if the landowner chose to do something differently in future, they could do so and would have received payment only for the time they actually stored the carbon. This is a solution to the problem of paying for a ‘permanent’ ton only to have the landowner abandon the activity that is keeping it sequestered. Many of these approaches are based on solid economic analysis, approaching carbon storage as an investment problem. McCarl et al. (2005) and Lewandrowski et al. (2004), for example, provide comprehensive review of different approaches.

Key to investment problems is the net present value (NPV) of the stream of returns. A landowner considering a sequestration project would compare the NPV of carbon storage against the investment cost plus the discounted stream of annual maintenance costs, just as he/she might compare the NPV of returns to installing irrigation to enhance crop production or establishing a forest for purposes of harvesting the wood. Herzog et al. (2003) offers one formulation of this NPV problem, formally expressed as follows:

$$NPV = p(0)a(0) + \sum_1^{\infty} p(t)a(t)(1+r)^{-t} \quad (3)$$

where: $p(t)$ is the price of carbon in year t , $a(t)$ is the net amount sequestered or leaked in year t , and r is the interest rate. They use the formulation to estimate a ‘discount’ factor for

ocean sequestration, assuming that the carbon would be sequestered in year 0 and would gradually return to the atmosphere over an extended period of time. Thus, in their problem $a(0)$ is positive and $a(t)$ is negative for $t = 1, \dots, \infty$. The same approach has been proposed for land use sinks. For conceptual purposes, the time periods could be of a length where sequestration all occurred in period 0. For example, each period could be 10, 20, or 40 years, and physical leakage then might occur in later periods.

Once a cap is established, the economically efficient approach for pricing carbon is to allow the market to determine it. A landowner who sequesters a ton of carbon in period t may choose to sell the ton at the market price in time t or hold it for future use or sales. At time $t + n$, should he/she emit a ton of carbon back into the atmosphere, he/she would then be responsible for purchasing a carbon allowance at the market price in year $t + n$ or opt to use the banked ton. This is symmetric treatment for a fossil fuel emitter (e.g., an electric power producer) who might be considering different power plant options that would have different streams of carbon emissions in the future. If the carbon stream was less than the allowance stream, the power producer could sell the extra allowances into the market. Alternatively, it could bank them against the possibility that it may not be of interest to continue the operation of the carbon-saving power plant indefinitely just as the landowner might decide to change his/her land use practice in such a way that carbon previously sequestered is released.

The alternative solutions, an established rental price or an established discount rate for land use sinks, leads to potential economic inefficiencies by asymmetrically treating fossil emitters and landowners. If a public entity setting the rental payment or discount factor knew, with complete certainty, future carbon prices and market rate of returns, as well as which sinks would leak at which rates (or at least the average physical leakage rate), then it can establish an equivalency between rental rates, the carbon price, and a discount factor. Such equivalency calculations are the basis for rental payments and discount factors in the literature.

Herzog et al. (2003) calculate the discount factor, first by calculating the NPV as in Equation (3), and then dividing it by the NPV of permanent storage (i.e. when $a(t)$ is zero for $t = 1, \dots, \infty$). Lewandrowski et al. (2004) calculate a rental payment (a) as:

$$a = rP \quad (4)$$

where: r is the discount rate and P is the price of a ton of permanently sequestered carbon. This result is derivable from a formulation like equation (3) under some highly simplified assumptions, namely that the price of carbon is constant over time. As Herzog et al. (2003) showed, if the price of carbon rises at the rate of discount, then the value of temporary storage is zero. There are conditions under which we might reasonably expect the carbon price to rise at that rate. In particular, with a stabilization target and no backstop, efficient allocation of the reduction through time would require a constant discounted price (i.e. the actual price rises at the discount rate). We do not insist that the actual carbon price will necessarily rise at the discount rate, but use this example to illustrate that the rental rate for carbon is conditional upon assumptions of the future carbon price path.

Each of these various cases derive from the same basic formulation and can be utilized in practice, namely: sell or buy permits as you go, discounted tons, or renting carbon. While the mathematics can be manipulated to derive one formulation from the other, two main problems arise.

The first problem is due to the fact that calculating the discount factor or the rental price requires an entity to observe or estimate future carbon prices and the appropriate discount rate. If a public agency is to compute the discount factor or the rental value, it is necessary

to produce a projection. This means that the public agency bears the risk of being incorrect with rental or discounted tons calculation. In contrast, when the fossil emitter's investment decisions require forecasting, the risk is borne by the private entity. One can make a case that the public agency should take steps to limit risk to private entities, but having some segment of mitigators (e.g., fossil emitters) bearing the risk, and another segment (e.g., land use sequesters or emitters) not bearing the risk leads to inefficiency.

The second problem is because, whether physical leakage occurs, and when, is not purely a phenomenon of nature that transpires at a known frequency, but is partly under the control of the landowner. This means that an up-front discounted payment with no requirement to be responsible for the future of the carbon, creates no incentive for the landowner to take actions that would prevent return of the carbon to the atmosphere. The rental formulation partly avoids this by only paying as you go. However, because it produces incentives for sequestering and not preventing emissions, it leaves land use emissions uncapped.

The discounted tons approach makes carbon sequestration less attractive. Those landowners who might be willing to assure that the carbon was permanently stored will be less willing to sequester at a discounted payment. If physical leakage were a purely natural and random phenomenon, with no ability to know what its rate was for a specific parcel or to control it, then the discount approach would on average credit the right amount. Since, with these assumptions, the landowner had no control over physical leakage, the lack of incentive to control it has no effect on leakage. However, these are unreasonable assumptions. Those landowners who, a few years after accepting the payment, decide to do something else, face no penalty for releasing the carbon.

Realistically, a program of up-front payment would likely include conditions that would limit the landowner's actions, or penalize him/her, for actions that led to sequestered carbon being emitted. The efficient penalty is for the landowner to purchase carbon permits at the market price the time the carbon is emitted. However, the notion of a penalty (i.e. that a wrong was committed) mischaracterizes the decision. Simply allowing the landowner to essentially "buy-out" of the commitment to store the carbon via purchasing credit preserves the option to use the land in another way if it is more economically efficient. From a broader economic standpoint, preserving this option is logical. If, for example, food is scarce and agricultural commodity prices rise, the landowner can switch to crop production. As long as carbon allowances are purchased to cover the emissions, the country will continue to be in compliance with its GHG mitigation targets, yet it allows land to be used to solve another pressing problem, specifically food supply. There is no net physical leakage not covered by a reduction in emissions (or more uptake) elsewhere, and so it is not necessary to discount the sequestered tons initially.

The concern above is relevant to a public agency implementing these formulas differently for landowners than for fossil fuel emitting sources. Market approaches in capital and investment markets may develop in a carbon market if it follows the system we propose – selling when sequestering at the then current price, and requiring allowances to cover emissions if, at some point, the carbon is released back to the atmosphere. In particular, landowners who desire an up-front payment may find intermediaries prepared to pay some amount for the future stream of sequestration. The payment would reflect the intermediary's expectations of the future prices of carbon, thereby necessitating a contract structured to describe who bore the risk if the landowner was later found not to have sequestered the carbon. In order to be successful, this requires that the sequestration agreement be legally enforced and that the sequestration is monitored over time by a public agency. Landowners might simply bank credits they have created through sequestration speculating that the price might increase. Future prices and futures' contracts may develop, and intermediaries may be willing to rent

carbon based on their speculation of what temporary storage is worth (i.e. speculating on how carbon prices would change). Such contracts and agreements between landowners and intermediaries could be negotiated, or might vary depending on the interests of the landowner, as well as the risks the intermediary is willing to accept. In short, the market could invent solutions to illiquidity or the need for up-front payments to cover investment at some price, just as it has for other investments if the overall carbon market is well-structured. Such a price is likely to be discounted because the intermediary is bearing the risk, but the discount will reflect the market assessment of that risk.

4.2 What should be done about the high variability of ecosystem uptake or large releases due to fire?

The amount of carbon taken up by plants varies dramatically from year-to-year depending on the weather (e.g. Felzer et al. 2004; Sarmiento and Gruber 2002). For example, rapid growth in one year may produce a large amount of litter subject to rapid decomposition. If followed by a year of poor growth, the result may be greater net emissions that year, with decomposition release greater than the carbon taken up by new growth. Events, such as wildfires, can also lead to sudden release of much of the carbon stored in the area subjected to the fire (Zhuang et al. 2003).

These natural phenomena that generate variability appear to be no different from the average situation landowners face. Inclement weather that leads to relatively little carbon uptake, and possibly net emissions, is no different than the situation where inclement weather leads to crop failure and financial loss because there is no revenue to cover cost of planting and other costs of farming. Similarly, the forest manager who had planted a forest in anticipation of harvesting the timber faces potentially large loss if there is a forest fire that wipes out the young forest. Limiting financial liability for these risks in the case of carbon storage would limit the incentives landowners would need to take actions to limit the effect of these events. Specifically, the prudent landowner would enter into carbon sequestration with the same set of risk calculations he/she would use in cropping or timber management, taking into account an estimate of the carbon uptake variability over time. This might include carrying a bank of credits from “good” years to cover “bad” years, the use of various financial instruments to cover the risk (e.g., saving, insurance, forward options on purchase of allowances to cover potential risks), fire prevention, or weather amelioration strategies (e.g., irrigation) that would limit the effects of these natural conditions.

One element of the variability issue deserves some serious consideration. Public monitoring and enforcement will need to create a periodicity to inventory requirements. It is not likely that land use carbon would be ‘continuously monitored’. Carbon is exchanged continuously over the day and seasons with periods of net uptake and net release. The preferred method is likely to involve estimating a stock at time t , re-estimating the stock at some later time, and the difference is the net uptake or release. Thus, there is a decision to be made as to how often that inventory must be made and reported. The KP set a five-year commitment period for countries, essentially allowing unlimited borrowing and banking within that period. Countries may require fossil emitters to provide inventories more frequently (e.g., annually). Because of the variability of land use carbon, the difficulty and cost of accurate measurement, along with the likely approach of measuring the stock instead of the continuous flow, it follows that it is preferred to have a longer required inventory periodicity for land use carbon. This would automatically allow for borrowing and banking over the established period by the landowner. For example, assume an annual inventory period is required, and the landowner has to be in compliance with the target each year. Then, if the first year is

an inclement weather year (e.g., a forest fire), the landowner might be required to make a relatively large purchase of allowances to have large net sequestration in subsequent years. This is feasible such that explicit banking and borrowing provisions are created in order to minimize this variability. However, inventory methods are likely to involve some cost, and may not be sufficiently accurate to reliably measure year-to-year changes. This suggests that the goal may be to set the periodicity of the inventory at least every five years and possible as much as every ten or twenty years.

It is not essential that the periodicity be the same as either a national target period such as in the KP or the same as for fossil emitters. If, however, one requires that allowances can only be used once the carbon is actually sequestered (and has been certified as such), this could mean that no sequestration could be credited until the second inventory was taken, possibly twenty years in the future (if that is the official reporting period). This does not present any fundamental problems, but for those hoping to use sequestration in early periods, this would prevent it. It does not necessarily imply that landowners could not find intermediaries who would pay them relatively early, on an early assessment of carbon sequestered as well as an expectation of future carbon prices. However, one way to add flexibility without requiring relatively frequent and costly inventories would be for the reporting rules to allow, while not requiring, landowners to inventory more frequently. Landowners would determine whether the cost of more frequent inventory was worthwhile given their desire to sell allowances early.

4.3 How to resolve the problem of determining direct human responsibility for sequestration?

The KP limits sinks credits against targets to those due to “direct human-induced. . . change.” In retrospect, this may be among the most problematic passages on sinks in the agreement. Nitrogen deposition, along with increased ambient levels of CO₂, likely enhances forest growth and carbon uptake (Felzer et al. 2004). Moreover, tropospheric ozone and other pollutants likely damage vegetation and reduce uptake. Felzer et al. (2005) estimated the tropospheric ozone damage effect to be substantial. While it remains controversial as to the extent, CO₂ fertilization, as traditionally modeled, strongly enhances vegetation growth and carbon uptake. Climate change itself will affect plant growth. This is one possible interpretation of the “indirect effects” that the KP excludes. The United States’ interpretation differed markedly, proposing that simply protecting property rights constituted direct human action, and to the extent that led to carbon sequestration, that carbon reduction could be included.

Even if one were to adopt a very narrow definition of actions (e.g., a specific forest established with the express intent of sequestering carbon), and one could somehow assess “intent,” the “direct human-induced” language would seem to require the ability to attribute some portion of the carbon sequestered to the direct human action. It would mean deducting that portion due to indirect actions (e.g., nitrogen deposition, CO₂ fertilization), or even giving credit for more than was sequestered, if some indirect action (e.g., tropospheric ozone) damaged vegetation that otherwise would have taken up carbon. At some point, one would need to confront the reality that, once trees are planted, it is nature that takes-over and grows them. Thus, the distinction between what is due to direct human action and what is due to indirect natural action is highly ambiguous.

Vegetation growth is a collaborative effort of humans and nature, where the result is not uniquely attributable to either collaborator. Attempting to create rules followed by measuring and attributing carbon uptake to different causes appears to be unproductive, increasing the cost of monitoring and contributing to overall cost inefficiency. With clear property rights

for land in conjunction with the ability of the landowner to sell allowances for anything sequestered on it above the established baseline, or pay for emissions above (or sequestration less than) the baseline, that landowner (or the country in the case of national targets) has an incentive to correct the problems that lead to damage. Again drawing the comparison with forest and agricultural products, products harvested by the landowner can be sold and are not subject to a test of whether the products were “human-induced”. The public good nature of the “indirect” human affects (e.g., air pollution) requires collective action to solve. Including all carbon sequestration or emission within an incentive structure would not automatically solve these problems. However, with landowners losing or gaining, depending on whether these other environmental problems are solved, it would at least provide a motivation for them to support collective action on pollution.

4.4 To use a broad cap or sinks as credits?

In the experience with emissions trading systems, two types of approaches to creating tradable emissions reductions are identified (Ellerman et al. 2000). The first is a cap-and-trade system that distributes allowances that must be used by entities under the cap to cover their emissions; trading is among these allowances. Entities to whom they are originally distributed may purchase more if they need them or sell extras they do not need, though they must hold allowances to match their emissions.

The second type of system is a credit system. In a credit system, credits are earned by reducing emissions below a baseline that is somehow established. Traditionally, entering the credit system is voluntary. There is a market for the credits and it is in the economic interest of an entity to produce credits at the market price if they can do so. However, other entities may choose not to enter the credit system and, hence, they are not required to make any reductions. A credit system is often an “add-on” to an allowance cap-and-trade system. The cap-and-trade system forces the entities under the cap to reduce emissions regardless of whether it is economically desirable. Hence, allowances have a positive market price. Those entities outside the cap, though allowed to produce credits, can observe the price and sell credits in if they chose to do so. Since producing credits is voluntary, no entity covered under the credit system should bear net costs, unless they have miscalculated their own cost of producing the credits. Those under the cap can be shown to gain from trading (as compared with trying to meet the allocation without trading). However, in most cases, they are bearing costs compared with not having the policy at all. In short, trading is beneficial because it reduces costs. Of course, a generous allowance allocation can mean that, even under the cap, there may be some entities that benefit from the policy compared to the case with no policy. Despite these limits of a credit system, all of the major initiative for cap-and-trade systems in place or proposed use a credit system to create incentives for sinks.

4.5 Permanence and leakage: A special problem for carbon sequestration?

Watson et al. (2000), Lewandrowski et al. (2004), and McCarl et al. (2005, 2006) provide reviews and extensive discussion of the leakage issue. Here we discuss the leakage issue in the context of a cap-and-trade system. Physical leakage, as discussed in Section 4.1, relates to the idea of a specific project or land parcel where, over time, some of the carbon originally stored returns to the atmosphere. This phenomenon is also often discussed as an issue of the permanence of the sink. Leakage is a term that has also been applied to problems faced by cap-and-trade systems where, having set a cap, presumably based on a solid assessment

of acceptable emissions of carbon to the atmosphere, more emissions enter the atmosphere because reductions taken by some entities are offset by an increase in emissions by entities not under the cap. If the leakage occurs in a different place during the same period, we refer to it as spatial leakage. There can also be a phenomenon of temporal leakage whereby entities are induced to make reductions or sequester carbon in one period, but are outside the incentive system in a later period. In the case of temporal leakage, the increase may be from the entities that reduced emissions in an earlier period or from other entities. If the former, it would also appear as physical leakage. In this case, however, it is a problem for the broader carbon reduction goal because the increase is not offset by reductions by other entities and, hence, the atmospheric goal is not achieved. From a public policy standpoint, a well-designed carbon mitigation program should be concerned with whether the overall environmental goal, in terms of reduced atmospheric carbon, is met.

Both spatial leakage (i.e. landowners not voluntarily entering the credit system) and temporal leakage (i.e. a landowner selling credits this period with the sequestered carbon being emitted in later periods) are particularly problematic with credit systems. A forest landowner who forgoes harvesting to sequester carbon, reduces the supply of lumber. However, the demand for lumber remains unchanged and, therefore, other lumber suppliers produce more lumber. As a result, most of the sequestered carbon may be offset by higher emissions from the forest harvest elsewhere, even though the carbon remains physically sequestered by the landowner under the cap or credit system. Leakage will potentially occur anytime the policy is incomplete spatially or temporally. Cap-and-trade systems that are not geographically comprehensive also suffer leakage. If a cap-and-trade system were only going to be in place for a few years, one might expect temporal leakage in such a system as well. A meticulously structured policy that covers all potential emitters and sinks across space and time eliminates the problem of leakage. A credit system with voluntary coverage does not assure this whereas, in contrast, a cap-and-trade can be easily structured to do so.

4.6 Pre-existing distortions

Equating marginal costs of carbon reduction and sequestration across the economy is an economically efficient solution in an idealized economy where all other prices appropriately reflect the real marginal cost of goods. Taxes, subsidies, and unregulated externalities (positive or negative) result in prices not reflecting the full marginal cost of all inputs. Therefore, an idealized policy that results in equating marginal costs of carbon reduction among countries or across sectors may not be the most effective policy (Babiker et al. 2004). Some fuels are taxed heavily in some countries and these pre-existing distortions affect the cost-effectiveness of carbon policy (Paltsev et al. 2006). Agricultural subsidies likely interact to affect the efficiency of carbon pricing as well but there has been no study of this effect. There also exists the possibility of positive externalities (ancillary benefits) of both carbon sequestration and emissions reductions. For example, emissions reductions by fuel switching may reduce the emissions of many other air pollutants (Yang et al. 2005). In addition, carbon sequestration may reduce soil erosion and leaching agricultural chemicals, thereby, reducing water pollution (Marland et al. 2001).

All of these externalities and distortions mean that equating carbon prices across sectors and economies is unlikely to result in textbook economic efficiency. The “first-best” solution in these cases is to find a way to eliminate the other distortions by appropriately pricing other externalities or to reduce the distorting effects of taxation. Clearly, this is an area that requires more research attention. Our view is that it is important to avoid the initial impulse of adding

a markup/markdown on carbon prices from activities with different pre-existing distortions. The danger of such markups/markdowns is that the ancillary benefits (or additional costs) are likely to vary by: fuel for fossil emissions, particular site where the emissions occur, and sequestration option for land use activities; they may also change over time. Thus, it seems preferable to work toward correcting the other problems directly, and pricing the “partial interest” in the carbon mitigation options for its equivalent climate benefit. Wiebe et al. (1996) provided a discussion of pricing such partial interests in land. There may be reasons to make exceptions to this rule in some cases, but it seems most preferable to focus the carbon cap instrument primarily on climate policy rather than to use it to collectively solve a myriad other problems for which it may not be an effective instrument.

4.7 Measurement, monitoring, and enforcement

Much scientific attention is directed at developing and improving the reliability of techniques to estimate the stock of soil carbon at a particular time, with Watson et al. (2000) providing an extensive discussion. It is inevitable that there will continue to be uncertainty and inaccuracy in these measurements. However, measurement error need not prohibit the inclusion of carbon sequestration in a cap-and-trade system. A trading system can operate as long as the measurement process is accepted as defining an authoritative measurement. The process might include a technical approach to measurement, the ability to challenge a measurement, a process for resolving questions/challenges, as well as final certification. While error in measurement can be tolerated, it would be relatively difficult to create legal authority if errors appeared to be so large and random that they lack any scientific foundation.

A subtle problem is compromise of the effectiveness of the system if there is a bias in the measurement process. If, on average, the measurement process systematically underestimates carbon stored, the system will provide too little incentive to sequester carbon. In contrast, if it systematically overestimates carbon, the cap will be legally attained provided that the measurement system is legally accepted, though the effect on the atmosphere will be less than expected. This can be remedied by further tightening of the cap to meet the atmospheric target. However, the carbon sequestration will be over-employed compared to emissions reductions because pricing is not reflecting the actual carbon sequestered.

Another subtle problem is a measurement process that has been constructed to be unbiased based on experimental measurement, but the incentives to participate lead to bias in the actual application. Consider the following hypothetical situation. A practice is extensively evaluated through experiment and an average sequestration level is attached to that practice. The average sequestration achieved by the practice becomes a part of the measurement method (i.e. part of the model by which carbon inventory is estimated). Under real conditions, the vigor with which the practice is implemented may be subject to variation. If it costs more to vigorously implement the practice, actual landowners may have an incentive to minimally implement the practice. As a result, less carbon is stored on average under real conditions than the average experimental result. Another way this may happen is if the cost of implementing the option is correlated with an environmental condition that also affects the amount of carbon stored. If the correlation is such that lower costs are associated with lower carbon uptake, the average uptake under real conditions will again be less than the experimental average. The reason is because the activity will be implemented at the relatively low cost sites, but it may not be economic to implement at the relatively higher cost sites. Reliance on practice, as opposed to actual measurements, tends to increase the chance of these incentive effects to create bias in the estimates.

Lastly, enforcement is a necessary element of a successful system and must be part of the design. One of the surprising aspects of a cap-and-trade system as described by Ellerman et al. (2000) is that enforcement has been relatively successful. Although there is no direct economic reason for this, it appears regulators are more willing to enforce a cap when they can identify allowances that can be purchased to meet the cap. Since all entities have opportunities to purchase in the same market, the claim of “special hardships” by some entities that prevent them from complying is less compelling. Hardship is more compelling in systems where entities must comply with an individual limit. Consider the hypothetical case of wildfire that resulted in carbon emissions. If the landowner were required to meet some level of sequestration, as well as keep the carbon sequestered for some minimum period of time, enforcement in the face of fire becomes problematic. The landowner may have little ability to actually comply. The enforcement agency can levy a fine, but this can appear unreasonable given the landowner could not prevent the fire. This would likely give rise to hardship exclusions. In any event, the carbon is in the atmosphere, and levying a fine will not remove it. With a cap-and-trade, where the landowner can purchase or sell allowances, a fire is still a hardship. However, the landowner can still comply by purchasing allowances and, thus, does not face a situation where there was no way to actually comply.

Once again, homeowners and businesses that choose to locate in areas prone to disasters face the economic consequences of them. In doing so, they presumably try to limit their exposure to, and the effects of, these disasters. The same principles should be applied to carbon sequestration. To the extent emergency aid or disaster assistance would apply to carbon losses, care is required to structure the aid so as not to undermine the incentives to reduce the chance of losing the carbon. Completely exempting the landowner from any responsibility to cover these emissions with credits would certainly undermine these incentives. One relief-generating alternative worth further consideration would be if the landowner demonstrated effort to reestablish the forest and restore the carbon. He/she could borrow against that planned future replacement of carbon to cover the large loss; such borrowing automatically occurs within the inventory period. Thus, a long-term period such as 20 years suggested in Section 4.2 automatically gives the landowner an opportunity to restore carbon released in, say, year three into the inventory period. Although the fixed period still creates the possibility that a fire in year nineteen or twenty would create a severe hardship. An additional borrowing provision may ease this concern.

4.8 Carbon stored in products

Harvested material from forests and farms end up in a variety of product streams. Some are relatively short-lived such as food or pulp and paper. Others may remain “stored” for decades or hundreds of years (e.g., lumber used in buildings or furniture). Schlamadinger and Marland (1999) provide some estimates and discuss issues related to carbon in the product stream. This raises the key question: In harvesting a forest, should the harvested product be tracked until it actually decomposes, and only then counted as an emission of carbon requiring an allowance? In principle, the answer is “yes” because this would provide an incentive to not finally dispose of these products if they can be salvaged or reused. In doing so, it would accurately account for the time between harvest and decomposition when the carbon remained out of the atmosphere. In practice, this would require a complex tracking system both of the product and of the product owners to ensure that they were liable for emissions, if and when, they dispose of the product in such a way that the carbon was released to the atmosphere.

Simpler approaches would be to ignore this storage and assume the carbon will ultimately return to the atmosphere. Another approach is to try to apply an average discounted ton factor as an offset to the total harvest. Neither approach creates an incentive to prolong the life of carbon stored by not destroying structures or by recycling used lumber. Crediting via a discounted ton approach returns us to the problem of estimating this discount factor, which we rejected earlier.

Bio-energy is a carbon-containing product of vegetation that has the potential to become more important as a “carbon-free” energy source in a carbon-constrained world. It can be carbon-free if the biomass used is from areas where the crops are continually regrown. The carbon in the soil is not being depleted, and fossil energy is not used in its production. Given the potential importance of bio-energy as a solution to climate change, creating incentives for bio-energy is particularly important. If one simply exempted biomass energy producers from the cap, ignoring emissions that occur in processing and combustion on the basis that these are being taken up by next year’s biomass crop, it would provide no incentive to regrow the biomass.⁴ Schlamadinger and Marland (1999) find that, in cases of clear cutting forest stands with large amounts of biomass, the loss of carbon may never return to the pre-disturbance level even when accounting for energy and long-lived stocks. Similarly, disturbed cropland often has significantly less carbon than in its pre-disturbed state. To correctly account for such land conversion losses of carbon or non-sustainable management of land, land used to produce biomass would need to come under a cap to provide correct incentives to maintain carbon stocks in soils or in standing vegetation/detritus. Because the bio-energy would be combusted relatively quickly (e.g., weeks, months, a few years at most) after production, one could then exempt emissions from combustion of the fuel completely (e.g., at power plant or by vehicles using a liquid fuel). This approach could be applied to other product streams that are short-lived, reducing the monitoring problem to the land parcel without the need to follow the product stream.

The long-lived product streams create a more severe problem of tracking and monitoring. More investigation is needed to determine the importance of long-lived product streams. An important issue is whether this carbon pool would be substantially affected by creating proper incentives to manage it. Any gain should then be balanced against the cost of establishing the necessary monitoring and tracking system for the carbon.

5 Summary and conclusion

Many of the problems and concerns that analysts and policy makers have spent enormous effort trying to solve relate to how sinks have been included in climate policy architecture. Their limited inclusion in the architecture of the KP has been borrowed for further policy proposals in domestic legislation in the United States. Most of these issues vanish if the one brings land use fully under a cap-and-trade system. Doing so creates incentives to control both land use emissions and enhance land use sinks. Whether the area is a defined as a forest or not is irrelevant – all that matters is changes in the stock of carbon. The problem of market leakage

⁴ Ethanol as currently produced often results in significant CO₂ emissions from fossil fuels because they are used in various parts of the processing cycle such as in distillation. If fossil fuel use is fully under a cap – including that potentially used in biomass, then this is not a problem because those emissions will be controlled under the cap covering energy use emissions. In other policies where this carbon is not priced properly, the net CO₂ emissions from ethanol production could render it to be worse than using petroleum products in the first place. So, this is an important concern in many policy contexts but here we are assuming carbon from fossil emissions are priced appropriately.

is best seen as a problem of incomplete policy, either in space or time; bringing land use fully under the cap eliminates the problem of leakage. Physical leakage is not in itself a problem if landowners are required to cover leakage by purchases of allowances. Any net effect on atmospheric concentrations is eliminated. This treatment of physical leakage has the virtue of maintaining the atmospheric carbon goal as well as preserving an important flexibility in how land can be used in the future should economic conditions unexpectedly change. Coverage under a cap allows landowners to sell current allowances at current prices, but requires them to cover future emissions with allowances when the emissions occur. Although land use carbon sinks/sources are subject to much variability, owners are accustomed to dealing with variability regarding current uses of land. Specifically, farmers and foresters face risks of natural disasters that damage their crops or their forest stands, and they make investments in the face of these uncertainties. Increasingly, market intermediaries have come into being to bear or pool risk, or to allow hedging against these uncertainties. There is reason to believe that these same types of intermediaries would participate if there is a robust market in carbon allowances. Cost-effectiveness in carbon mitigation actions requires, not only an equal carbon price across sectors, but also that the risk of estimating future conditions be borne equally across sectors. Publicly determined rental rates or discount factors applied to land use emissions/sinks are unlikely to reflect the market assessment of future carbon prices that are the basis for investments in fossil fuel emissions reductions, and would provide a certain assessment of that future whereas fossil fuels sources would operate under uncertainty.

Redesigning the inclusion of land use activities in a cap and trade system requires careful assessment of the implications for the appropriate level of a cap and has implications for the distribution of the burden of reductions. The seven percent below 1990 fossil emissions in the KP, or a return to 2000 emissions as in the proposed McCain-Lieberman Bill, have very different implications if applied to the total of fossil and land use emissions (net of sinks) than if applied to just fossil carbon with land use entering through a credit system that is quantitatively limited. We argue that the inventory period for land use should be longer than for carbon emissions. A required reporting requirement of every ten or twenty years may be appropriate with the flexibility to produce an inventory more frequently (if so desired by the landowner).

Measurement, monitoring, and enforcement for land use sources and sinks are also important issues. Measurement need not be exact, but the measurement process needs to be unbiased, and more accurate measurements will be more broadly accepted. The measurement process needs to include the ability to challenge results along with established procedures to resolve those challenges. The ancillary benefits/costs and interactions with taxes and subsidies are potentially important issues that can affect the cost-effectiveness of an idealized system with an ultimate goal of achieving equal marginal cost abatement across sectors and countries. The “first-best” solution in these circumstances is to correct these problems with instruments designed to address them specifically, rather than attempt to markup or mark-down different mitigation activities because they are associated with other benefits or costs. There is inevitably interest group resistance to such “first best” solutions. It may still be preferable to develop a clean carbon trading system, rather than to try to adjust the carbon price from different sources to account for negative or positive externalities when there is likely to be significant error in such an assessment. In particular, the value of these externalities are likely to vary by source, site, and the practice used for reducing carbon emissions or increasing sinks. Inefficiency in using an average factor for ancillary benefits or costs, when the actual levels were known poorly, could easily outweigh the hoped for gains seen in studies that precisely differentiate carbon prices based on known externalities. Finally, the issue of carbon contained in products presents a further measurement and monitoring issue

that could add considerable complexity to any system. The lifetime of the product matters, and further investigation is needed as to whether a monitoring system for long-lived products, tracking their fate until their eventual decomposition, would improve efficiency or present a costly burden with little benefit.

In our opinion, the role of sinks in climate policy has been made unnecessarily complex. In part, this appears to be a relic of history, resulting from the fact that sinks were added relatively late in the negotiation process that led to the KP. It was designed and emissions targets advanced around the goal of reducing fossil fuel emissions. Accommodating sinks later in the process led to rules that limit the impact their inclusion would have on the agreed targets and on the distribution of the burden among countries. In addition, there was a relative vacuum of information as to how large these sinks were, and how they might change over time for the Parties involved. The Kyoto model for sinks has been borrowed in other proposals such as the McCain-Lieberman Bill in the United States, which again, because of concern for the impact of such credits, placed quantitative limits on their use. The crediting approach in these climate policies has well-known problems that are difficult to correct. Therefore, it seems worthwhile to rethink this approach and, if cap-and-trade is the proposed approach for climate mitigation, to bring emissions from land use and land use change fully under such a cap.

Acknowledgements Comments of five anonymous reviewers greatly improved the paper, but, as usual, any remaining errors are the responsibility of the authors. This research was supported by the U.S. Department of Energy, U.S. Environmental Protection Agency, U.S. National Science Foundation, U.S. National Aeronautics and Space Administration, U.S. National Oceanographic and Atmospheric Administration; and the Industry and Foundation Sponsors of the MIT Joint Program on the Science and Policy of Global Change: Alstom Power (France), American Electric Power (USA), BP p.l.c. (UK/USA), Chevron Corporation (USA), CONCAWE (Belgium), DaimlerChrysler AG (Germany), Duke Energy (USA), J-Power (Japan), Electric Power Research Institute (USA), Electricité de France, ExxonMobil Corporation (USA), Ford Motor Company (USA), General Motors (USA), Murphy Oil Corporation (USA), Oglethorpe Power Corporation (USA), RWE Power (Germany), Shell Petroleum (Netherlands/UK), Southern Company (USA), Statoil ASA (Norway), Tennessee Valley Authority (USA), Tokyo Electric Power Company (Japan), Total (France), G. Unger Vetlesen Foundation (USA).

References

- Babiker M, Jacoby HD, Reilly JM, Reiner DM (2002) The evolution of a climate regime: Kyoto to Marrakech. *Environ Sci Pol* 5(3):195–206
- Babiker M, Viguier L, Reilly JM, Ellerman AD, Criqui P (2003) The welfare costs of hybrid carbon policies in the European Union. *Environ Model Assess* 8:187–197
- Babiker M, Reilly JM, Viguier L (2004) Is emissions trading always beneficial. *Energ J* 25(2):33–56
- Betz R, Eichhammer, W, Schleich J (2004) Designing national allocation plans for EU-emissions trading – a first analysis of outcomes. *Energ Environ* 15(3):375–425
- Birdsey R, Cannell M, Galinski W, Gintings A, Hamburg S, Jallow B, Kirschbaum M, Krug T, Kurz W, Pringle S, Schulze D, Singh KD, Singh TP, Solomon AM, Villers L, Yamagata Y (2000) Afforestation, reforestation, and deforestation (ard) activities. In: Watson RT, Noble IR, Bolin B, Ravindranath NH, Verardo DJ, Dokken DJ (eds) *Land use, land-use change, and forestry, Chapter 3. Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge, pp 125–179
- Bohringer C (2001) Climate politics from kyoto to bonn: from little to nothing?!. working paper. Center for European Economic Research, Mannheim, Germany
- EC (2003) Directive 2003/87/EC establishing a scheme for greenhouse emission allowance trading within the community and amending council directive 96/61/EC, European Commission, Brussels
- EC (2005) EU emission trading. an open scheme promoting global innovation to combat climate change, European Commission, Brussels

- EIA (2003) Analysis of S. 139, the climate stewardship act of 2003. energy information administration, office of integrated analysis and forecasting. U.S. Department of Energy, Washington DC
- Ellerman AD (2001) Le defi europeen: Issues in the implementation of greenhouse gas emissions trading in Europe. *Revue de l'Energie* 524:105–111
- Ellerman AD, Joskow PL, Schmalensee R, Montero JP, Bailey EM (2000) Markets for clean air: the U.S. acid rain program. Cambridge University Press, Cambridge
- Felzer B, Kicklighter DW, Melillo JM, Wang C, Zhuang Q, Prinn R (2004) Effects of ozone on net primary production and carbon sequestration in the conterminous United States using a biogeochemistry model. *Tellus B* 56(3):230–248
- Felzer B, Reilly JM, Melillo J, Kicklighter D, Sarofim M, Wang C, Prinn R, Zhuang Q (2005) Future effects of ozone on carbon sequestration and climate change policy using a global biogeochemical model. *Clim Change* 73(3):345–373
- Herzog H, Caldeira K, Reilly JM (2003) An issue of permanence: Assessing the effectiveness of ocean carbon sequestration. *Clim Change* 59:293–310
- Houghton JT, Ding Y, Griggs DJ, Noguer M, van der Linden PJ, Dai X, Maskell J, Johnson CA (eds) (2001), *Climate change 2001: the scientific basis*. Cambridge University Press, Cambridge, UK
- Kyoto Ratification Advisory Group (2003) Report of the kyoto ratification advisory group: a risk assessment. The Cabinet Office of New South Wales Government Printer
- Lewandrowski J, Peters M, Jones C, House R, Sperow M, Eve M, Paustian K (2004) Economics of sequestering carbon in the us. agricultural sector economic research service technical bulletin no. (tb1909). USDA, Washington DC, pp 1–69 (March) (<http://www.ers.usda.gov/publications/tb1909/tb1909.pdf>)
- Manne A, Richels R (2001) US rejection of the kyoto protocol: the impact on compliance cost and co2 emissions. working paper. AEI-Brookings Joint Center for Regulatory Studies, pp 1–12 (October)
- Marland G, McCarl B, Schneider U (2001) Soil carbon: policy and economics. *Clim Change* 51(1):101–117
- McCarthy JJ, Canziani OF, Leary NA, Dokken DJ, White KS (eds) (2001) *Climate change 2001: impacts, adaptation, and vulnerability*. Cambridge University Press, Cambridge UK
- McCarl BA, Murray BC, Schneider UA (2005) The comparative value of biological carbon sequestration. (<http://agecon2.tamu.edu/people/faculty/mccarl-bruce/papers/915.pdf>)
- McCarl BA, Kim M-K, Lee H-C, Murray BC, Sands RD, Schneider UA (2006) Insights from agricultural and forestry GHG offset studies that might influence IAM modeling. In: Schlesinger M, Kheshgi H, Smith J, de al Chesnaye F, Reilly JM, Wilson T, Kolstad C (eds) *Integrated assessment of human induced climate change*. Cambridge University Press, Cambridge UK (forthcoming)(<http://agecon2.tamu.edu/people/faculty/mccarl-bruce/papers/1171.pdf>)
- Metz B, Davidson O, Swart R, Pan J (eds) (2001) *Climate change 2001: Mitigation*. Cambridge University Press, Cambridge UK
- Paltsev S, Reilly JM, Jacoby HD, Ellerman AD, Tay KH (2003) Emissions trading to reduce greenhouse gas emissions in the united states: the mccain-lieberman proposal. MIT Joint Program for the Policy and Science of Global Change Report No. 97. MIT, Cambridge MA (June) (http://web.mit.edu/globalchange/www/MITJPSPGC_Rpt97.pdf)
- Paltsev S, Reilly JM, Jacoby HD, Tay KH (2006) How (and why) do climate policy costs differ among countries?. In: Schlesinger M, Kheshgi H, Smith J, de al Chesnaye F, Reilly JM, Wilson T, Kolstad C (eds) *Integrated Assessment of human induced climate change*. Cambridge University Press, Cambridge, UK (forthcoming)
- Pew Center (2005) The european union emissions trading scheme (EU-ETS): Insights and opportunities. Pew Center, Alexandria, VA
- Point Carbon (2005a) Carbon market Europe, September 23, 2005. A point carbon Publication (<http://www.pointcarbon.com>)
- Point Carbon (2005b) Carbon market Europe, September 30, 2005. A point carbon publication (available at: <http://www.pointcarbon.com>)
- Reilly JM (2003) Reconstructing climate policy: beyond Kyoto. (Book Review). *Colorado Journal of International Environmental Law and Policy* 2003 Yearbook 117–124
- Reiner DM (2001) Climate impasse: how the hague negotiations failed. *Environment* 43(2):36–43
- Sarmiento JL, Gruber N (2002) Sinks for anthropogenic carbon. *Phys Today* 55(8):30–36
- Schlamadinger B, Marland G (1999) Net effect of forest harvest on CO₂ emissions to the atmosphere: a sensitivity analysis on the influence of time. *Tellus* 51B, 314–325
- UNFCCC (1997) The Kyoto protocol. Climate Change Secretariat, Bonn
- UNFCCC (2000) Methodological issues: land –use, land-use change, and forestry. FCCC/SBSTA/2000/9 (Aug. 25)
- UNFCCC (2005) Kyoto protocol: status of ratification. (Updated January 20, 2005) (http://unfccc.int/essential_background/kyoto_protocol/status_of_ratification/items/2613.php)

- US DOE (2002) Voluntary reporting of greenhouse gas emissions, reductions, and carbon sequestration. Fed Register 67(87):30370–30373 (May 6)
- Watson RT, Noble IR, Bolin B, Ravindranath NH, Verardo DJ, Dokken DJ (eds) (2000) Land use, land-use change, and forestry, intergovernmental panel on climate change. Cambridge University Press, Cambridge
- Wiebe K, Tegene A, Kuhn B (1996) Partial interests in land: policy tools for resource use and conservation. Economic Research Service, USDA Agricultural Economic Report No AER744, Washington DC (November)
- White House (2002) U.S. climate strategy: a new approach. policy briefing book. Washington DC (February)
- Yang T, Matus K, Paltsev S, Reilly J (2005) Economic benefits of air pollution regulation in the USA: An integrated approach. MIT Joint Program for the Policy and Science of Global Change Report No. 113. MIT, Cambridge MA (January) (http://web.mit.edu/globalchange/www/MITJPSPGC_Rpt113.pdf)
- Zhuang Q, Melillo JM, Kicklighter DW, Prinn RG, Steudler PA, McGuire AD, Felzer BS, Hu S (2003) A process-based analysis of methane exchanges between alaskan terrestrial ecosystems and the atmosphere. MIT Joint Program for the Policy and Science of Global Change Report No. 104. Cambridge, MA (http://web.mit.edu/globalchange/www/MITJPSPGC_Rpt113.pdf)