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TEMPORARY CARBON SEQUESTRATION CANNOT PREVENT CLIMATE CHANGE

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Abstract. Storing carbon in biosphere sinks can reduce atmospheric CO_2 concentrations in the short term. However, this lowers the concentration gradient between the atmosphere and the oceans and other potential carbon reservoirs, and consequently reduces the rate of CO_2 removal from the atmosphere. If carbon is released again from that temporary storage, subsequent atmospheric CO_2 concentrations will, therefore, be higher than without temporary carbon storage. It is thus important to analyse whether temporary carbon storage in biosphere sinks can mitigate climate-change impacts. To analyse that, climate-change impacts need to be quantified explicitly.

Impacts can be quantified:
1) as the instantaneous effect of increased temperature;
2) through the rate of temperature increase;
3) as the cumulative effect of increased temperatures.

The analysis presented here shows that temporary carbon storage only reduces climate-change impacts related to the cumulative effect of increased temperature and could even worsen impacts mediated via the instantaneous effect of temperature or the rate of temperature change. This applies under both high and low greenhouse-gas emission scenarios. Because temporary carbon storage improves some, but worsens other, climate-change impacts, it achieves very little on average. For greenhouse mitigation, it is, therefore, not warranted to provide policy incentives for temporary carbon storage.

Key words: Biosphere; carbon accounting; carbon cycle; carbon sink; impacts; mitigation; permanence; tonne-year accounting.

1. Introduction

With global warming now clearly recognised as a major threat to natural and socio-economic systems, the global community is searching for cost-effective ways to slow the build-up of atmospheric CO_2 concentrations and minimise its impact. It is recognised that net emissions from the biosphere have significantly contributed to total emissions to date (Houghton 1999). These earlier emissions are now partly being reversed through expansion of forests at higher latitudes, and it has been suggested that well-supported tree plantings (or biosphere sinks) could sequester substantial additional amounts of carbon (Brown et al. 1996).

The biosphere can be a carbon sink (storing increasing amounts of carbon) or a carbon source (releasing stored carbon). The more the biosphere acts as a sink at any one time, however, the closer it will come to its maximum storage capacity and the less scope there is for absorbing more carbon in the future. Stored carbon could even be released again. That could be done intentionally (through land-use change, forest harvesting, etc.) or unintentionally (through wildfire, insect damage, etc.), thereby reversing any gains that had been made previously. Reversal of past actions is not generally a problem with fossil-fuel saving. Once savings of fossil fuels have been made, those savings are permanent even if fossil-fuel use patterns revert back to those before savings had been made.

Nonetheless, the use of biosphere sinks is often advocated in terms of ‘buying time’ (Noble and Scholes 2001; Lecocq and Chomitz 2001; Metting et al. 2001; Harvey 2004). This generally refers to the expectation that future anthropogenic CO_2 emissions could be much reduced through the use of cleaner technologies, and that biosphere sinks can be useful in bridging the gap until these new technologies become available.

However, it is not the rate of emission that constitutes a concern in terms of climate change, but the resultant atmospheric CO_2 concentration, its associated radiative forcing and the climatic changes that result from a change in radiative forcing (Ramaswamy et al. 2001). Hence, while biosphere sinks can reduce net CO_2 emissions and atmospheric concentrations in the short term, the critical question is how they affect atmospheric concentrations and resultant climate-change impacts in the longer term (Meinshausen and Hare 2002; Korhonen et al. 2002; Kirschbaum 2003a).

To address this question, it is necessary to explicitly quantify climate-change impacts, and various possibilities have been suggested in past work (Peck and Teisberg 1994, 1995; Alcamo and Kreileman 1996; Petschel-Held et al. 1999; Smith et al. 2001). In general, impacts can occur in at least three different ways (Kirschbaum 2003a):

1) by the direct and instantaneous effect of elevated temperature;

2) through the rate of temperature increase;

3) through the cumulative impact of increased temperatures.

The direct and immediate effect of temperature is the relevant measure for impacts such as heat waves and other extreme weather events. The rate of temperature increase is a concern because many aspects of a warmer world may not be inherently worse than current conditions, but the change from the current to a future, warmer world will be difficult for both natural and socio-economic systems. If change is slow enough then systems can be moved or adapted, but faster change may be too rapid for such adjustments.

The third type of impact relates to the cumulative impact of raised temperatures. This is the critical issue for impacts such as sea-level rise. The extent of sea-level rise is related to both the magnitude of warming and the length of time over which oceans and glaciers are exposed to increased surface temperatures.

The analysis here is based on a 100-year horizon and specifically assesses how biosphere management can modify the worst climatic impacts up to the year 2100. Hence, the analysis quantifies climate-change impacts up to the year 2100 and then assesses by what land-use strategy those expected maximum impacts could be most effectively ameliorated (or made worse). The analysis does not use any discount factors and thus treats climate-change impacts in any year as equally important.

Since each of the different climate-change impacts is currently getting worse (Kirschbaum 2003a), it implies that it is more important to reduce these impacts in future years than currently. The main target of climate-mitigation policy should be the prevention of those more damaging impacts later in the 21st century (and beyond) even if that were to come at the expense of marginal worsening of the less serious impacts experienced in the near term.

2. Model Description

For the work described here, the natural CO_2 uptake is calculated using the Bern model as described by Kirschbaum (2003a) using the relationships given by Meier-Reimer and Hasselmann (1987) and Wigley (1991), with the parameters given by Noble et al. (2000) and Fearnside et al. (2000). Temperature changes follow changes in radiative forcing with some delay, and different workers have used different time constants for this delay (Hasselmann et al. 1993; Watterson 2000). The present analysis uses an intermediate single time constant of 10 years (Kirschbaum 2003a).

The instantaneous temperature impact, I_T, is simply calculated as:

$$I_T = T_t - T_{1900} \quad (1)$$

where T_t is the temperature at time t and T_{1900} is the temperature in 1900.

The impact related to the rate of temperature change, I_Δ, is calculated as the rate of temperature change since 1900. Hence,

$$I_\Delta = (T_t - T_{1900}) / (t - 1900). \quad (2)$$

Other formulations for quantifying the impact of temperature change were also tried, such as calculating it as the annual change in temperature, or as the rate of temperature change over a period of 100 years. However, calculating it as the annual temperature change was seen as unrealistic as most system would not be significantly affected by the small change in temperature that might be experiences from one year to the next, which would be generally less than the change due to natural climate variability. Calculating the change over 100 years instead from 1900 would have provided qualitatively similar outcomes and ultimate conclusions as with the formulation that was used (data not shown).

The cumulative temperature impact, I_Σ, is calculated as the sum of temperatures above those in 1900 so that:

$$I_\Sigma = \sum_{i=1900}^{t} (T_i - T_{1900}) \tag{3}$$

where T_i is the temperature in every year from 1900 to the year of interest, t.

The analysis here is based on assessing the maximum climate-change impacts for each of I_T, I_Δ and I_Σ up to the year 2100 and assesses how the use of temporary or permanent carbon storage could mitigate these maximal impacts.

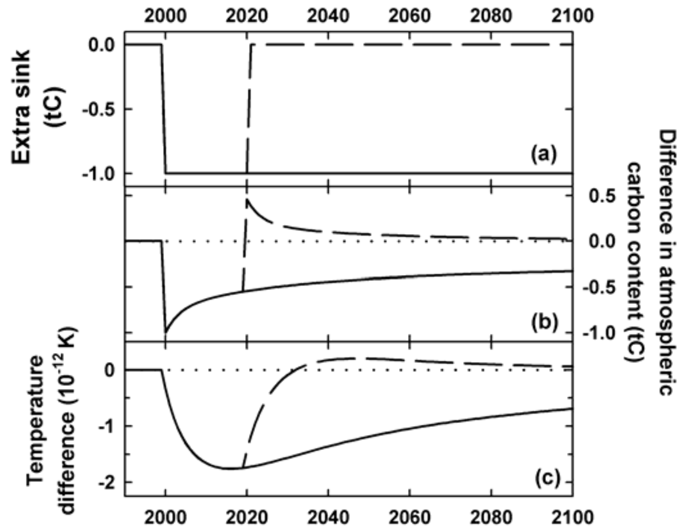
Simulations are based on the latest IPCC climate-change scenarios from the Special Report on Emissions Scenarios (IPCC 2000), with SRES A2 representing a high-emission and SRES B1 a low-emission scenario. These scenarios are often used to represent a 'Business as usual' and a more sustainable future based on lower energy use, respectively. SRES A2 assumes cumulative carbon emissions from fossil-fuel burning of about 1800 GtC between 2000 and 2100 and SRES B1 of about 900 GtC over the same time period. This would lead to global CO_2 concentrations of about 500 ppmv under SRES B1 and 900 ppmv under SRES A2. For more details, see IPCC (2000).

The present work extends an earlier analysis (Kirschbaum 2003a) that was based on the earlier IPCC scenarios released in 1992. The present analysis also specifically concentrates on assessing the value of temporary carbon storage and adds the specific policy relevant comparison of the mitigation potential of biosphere carbon storage against credits under tonne-year accounting. Temporary carbon storage in this context is specifically defined as carbon that is stored in the biosphere for some years and then released again before the most serious impacts of climate change have been experienced. In the present simulations, carbon was retained in temporary storage for 20 year before being emitted back to the atmosphere. This could represent a typical short-rotation plantation used for the production of wood fibres for paper production, for example. Permanent carbon storage refers here to storage beyond the time when the most severe climate-change impacts are experienced.

3. Results

Figure 1 illustrates the effect of a 1 tC biosphere sink, with carbon either retained permanently, or released again after 20 years. When 1 tC is stored in the biosphere (Fig. 1a), the atmospheric content is initially lowered by 1tC (Fig. 1b). This reduces the concentration gradient between the atmosphere and the oceans so that subsequently, less carbon is removed from the atmosphere than without the biosphere sink. One year after the initial sink activity, the atmospheric content is, therefore, reduced by less than 1 tC and diminishes progressively further so that after 20 years, the atmospheric content is reduced by only about 0.5 tC (Fig. 1b).

Figure 1. Illustration of the effect of creating a 1 tC biosphere sink on atmospheric carbon content (b) and resultant temperature (c). The calculations are done for a sink established in 2000, and with carbon either released again in 2020 (dashed lines) or retained permanently (solid lines). All numbers are expressed relative to the situation without sink activity.

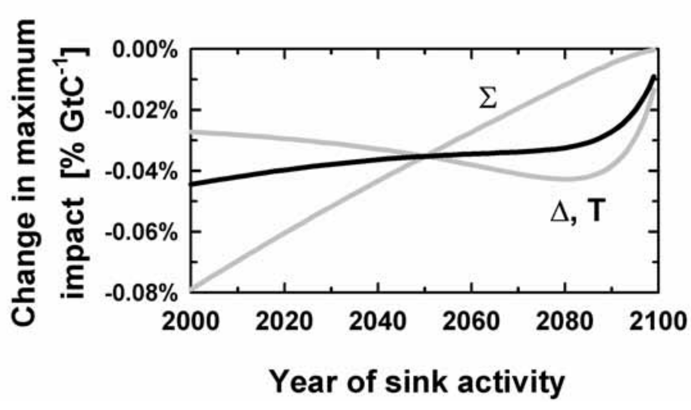


If carbon is then released again, the atmospheric CO_2 content will be higher than it would have been without the temporary storage (Fig. 1b), which ultimately also results in slightly increased temperatures after the re-release of carbon from the temporary storage (Fig. 1c).

In reality, carbon release is not generally as rapid as shown in Figure 1a but somewhat delayed because of slow decomposition of wood or roots, or delayed use and eventual destruction and decay of wood products. The effect of inclusion of delayed decomposition causes response functions to be smoothed, but it does not alter the basic response patterns (Kirschbaum 2003b).

Simulations show that carbon stored permanently can be useful in mitigating climate change, but the different climatic-change impacts are affected differently (Fig. 2). For mitigating cumulative temperature impacts, sink action early during the 21st century is more effective than later action. For mitigating instantaneous temperature impacts and impacts via the rate of change, however, delayed sink activity would bring greater benefits. On average, across the three types of impacts, the benefit is fairly constant at -0.04% GtC^{-1} for sink activity at any time over the next 80 years.

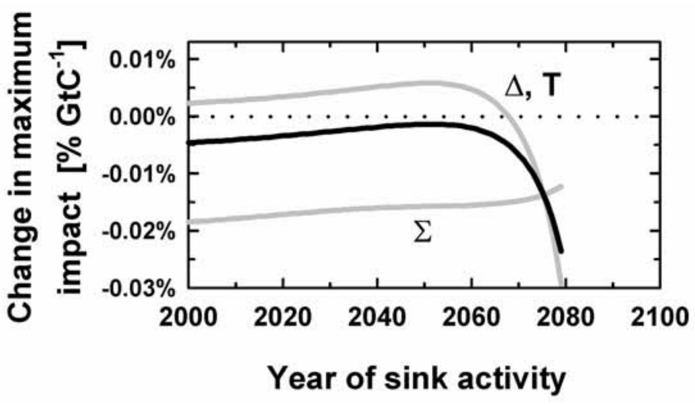
Figure 2. The effect of permanent biosphere sinks, established at different times throughout the 21st century, on maximum climate-change impacts under the SRES A2 emissions scenario. Data are expressed as a percentage change in the maximum impact per unit of carbon stored in permanent sinks. Absolute impact reduction can be calculated by multiplying the change given here by an assessed magnitude of total global sink activity. Percentage impact reductions are the same for instantaneous temperature impacts (T) and impacts via the rate of change (Δ). Impacts via cumulative temperature are shown by the symbol Σ. The average of the three types of climate-change impacts is shown as the black line.



These savings are not large but still contribute towards climate-change mitigation. The SRES A2 scenario assumes that about 1800 GtC will be emitted to the atmosphere over the next 100 years (IPCC 2000). Removal of just 1 GtC through sink management could therefore have only a small effect in preventing climate change, and the size of the calculated effect is consistent with the relative magnitude of the sink activity and cumulative emissions under the SRES scenario. Over 100 years, it would be possible, of course, to store many GtC in different biosphere sinks and thus have a more sizeable overall mitigating effect.

The effect is fundamentally different for temporary storage, however. Unlike permanent biosphere storage, temporary storage only reduces cumulative temperature impacts and even worsens climatic impacts via instantaneous temperature impacts or impacts via the rate of change (Fig. 3). This is because future CO_2 concentrations will be higher with than without temporary carbon storage (see Fig. 1). On average over the three kinds of climate impacts, the effect of temporary storage in sinks established before about 2060 is very slight and at least an order of magnitude smaller than savings by permanent storage. More substantial benefits are only obtained if temporary sinks are established close to the time of maximum impacts late in the 21st century. When assessing the merits of specific biospheric sink activities, it is, thus, critically important to not only quantify the initial carbon sequestration rate but also consider the length of time over which it can be retained in biospheric storage.

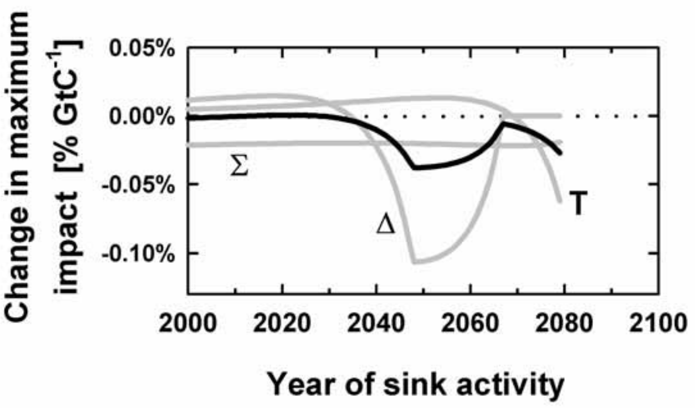
Figure 3. Change in maximum climate-change impact under the SRES A2 emissions scenario resulting from 20-year temporary biosphere sinks established at different times throughout the 21st century. Symbols as for Figure 2.



The use of biosphere sinks to 'buy time' is often advocated as part of a strategy to move towards a more sustainable future with lower anthropogenic CO_2 emissions. Such a future is represented by the SRES B1 emissions scenario (IPCC 2000), under which maximum rate-of-change impacts would occur by the middle of the 21st century, and maximum instantaneous temperature impacts by the end of the century (data not shown). Under this scenario, maximum impacts via the rate of change would be increased by temporary storage in sinks established before about 2040 (Fig. 4). Temporary storage in sinks established over the next few decades could affect some mitigation of impacts, but sinks would have no effect if they were established after about 2070 because the most serious impacts would have already been experienced before then.

Maximum instantaneous temperature impacts would be slightly worsened by temporary storage in sinks established before about 2070 (Fig. 4) and decreased by temporary storage in sinks established later than 2070. Maximum cumulative temperature impacts would be slightly reduced, with little difference for sinks established at different times.

Figure 4. Change in maximum climate-change impact under the SRES B1 emissions scenario by using 20-year temporary biosphere sinks at different times throughout the 21st century. Symbols as for Figure 2.



For the average across the three types of climate-change impacts, there is virtually no effect for sinks established before about 2030 with benefits for some impacts negated by worsening other impacts. Temporary sinks established between 2040 and 2070 would achieve some climate-change mitigation because it reduces impacts via the rate of change, but that mitigation effect ends once the most extreme rates of change have passed.

4. Discussion and Policy Implications

The simulations shown here show that permanent (Fig. 2) and temporary (Fig. 3) biosphere storage achieves very different climate-change mitigation even if their initial rate of carbon uptake is the same (as was assumed for these simulations). While it is not possible to predict fossil-fuel based CO_2 emissions for all of the next century, it is clear that temporary biosphere storage in sinks established over the next few decades would achieve very little climate-change mitigation under either high (SRES A2) or low (SRES B1) emission scenarios.

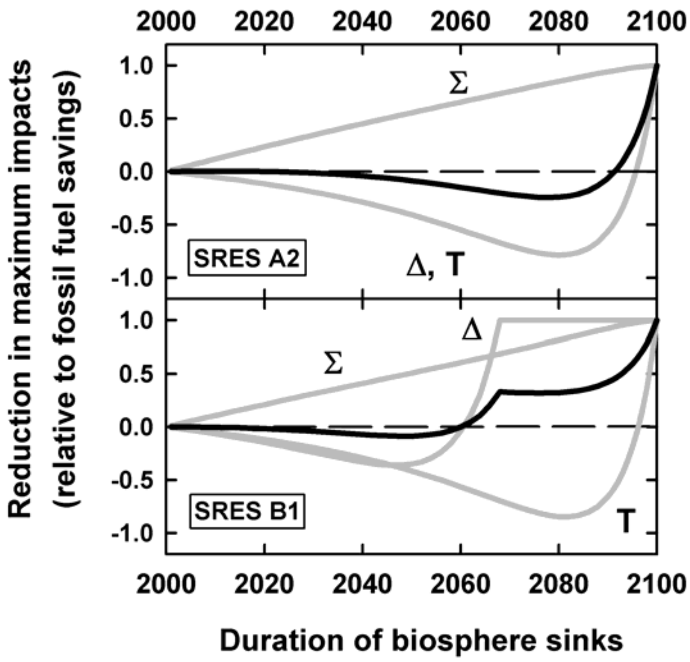
While the present analysis has been carried out formally only up to 2100, it is well recognised that climate-change impacts could become even worse beyond 2100, at least if emission will be as high as under scenarios like SRES A2. If the present analysis had been extended beyond 2100, it would have altered the calculated numeric values in terms of the percentage change in maximum climate-change impacts due to the temporary storage, but it would not have altered the fact that temporary carbon storage worsens climate-change impacts via direct temperature effects and via rates of change while improving impacts via the cumulative effect of increased temperatures.

The important policy relevant question concerns the mitigative effect of the establishment of temporary carbon sinks early in the 21st century. The important outcome is that there is virtually no climate-change mitigation value in temporary carbon storage (Figs 3-5). That outcome is the same under calculations based on either high or low-emission scenarios, and it would be the same under different lengths of assessment horizons.

It, therefore, needs to be questioned how biospheric carbon storage should be credited under carbon-accounting rules. Some biospheric carbon-accounting schemes, such as tonne-year accounting (Noble et al. 2000; Moura Costa and Wilson 2000; Fearnside et al. 2000; Fearnside 2002), do not factor in the permanence of biospheric carbon storage. They would, therefore, be inconsistent with the long-term aim of managing atmospheric concentrations to "*avoid dangerous anthropogenic interference with the climate system*" as stated in the United Nations Framework Convention on Climate Change (see also Meinshausen and Hare 2002; Korhonen et al. 2002).

Figure 5 compares the benefits of temporary carbon storage in sinks established in 2000 and maintained for different lengths of time. In this comparison, carbon storage in sinks maintained for 100 years provides the same benefit as fossil fuel savings as the analysis is based on a 100-year assessment. It shows that temporary carbon storage achieves useful mitigation only for impacts related to cumulative temperature effects, for which benefits accrue more or less linearly with time over the number of years for which carbon is stored (Figure 5). For instantaneous temperature impacts and impacts via the rate of change, however, temporary storage actually worsens maximum climate-change impacts, and the longer carbon is stored the worse the effect becomes. Temporary storage begins to have beneficial effects only if it is maintained for so long that it approaches the time when maximum impacts are experienced. On average across the three kinds of climatic impacts, there is almost no mitigation potential for carbon storage for less than 50 years.

Figure 5. Comparison between fossil-fuel savings and temporary biosphere sinks maintained over different lengths of time. This is shown under both the SRES A2 and SRES B1 scenarios. Each point represents a sink of 1 tonne carbon established in 2000 and maintained up to different years before the carbon is released again. The contribution of each sink is then compared with fossil-fuel savings in terms of its effect on maximum climate-change impacts up to the year 2100. Symbols as for Figure 2. The black line gives the average for the three kinds of climate-change impacts.



As temporary carbon storage achieves no climate-change mitigation, it is important that carbon-accounting rules ensure that they do not generate carbon credits, either. This would conflict with some approaches such as tonne-year accounting. It is unfortunate that COP9 agreed to accept carbon credits (CER – certified emission reductions) for afforestation and reforestation in CDM projects without an explicit requirement to ensure the long-term maintenance of sequestered carbon. The maximum time frame for projects is even set at 60 years, which is within the time frame where temporary storage achieves no climate-change mitigation at all (see Figure 5).

It is, of course, extremely difficult to make contractual arrangements for periods exceeding a few decades. However, contractual expediency must be a secondary consideration while the over-riding consideration must be that any accepted activity must indeed lead to climate-change mitigation as stipulated in Article 12.4 of the Kyoto Protocol (*"Emission reduction… shall be certified… on the basis of … b) real, measurable long-term benefits related to the mitigation of climate change"*). Figure 5 would indicate that the accepted definition of CERs, especially temporary CERs, do not conform to that requirement of long-term climate-change mitigation.

The problem of temporary carbon storage would be partly overcome if there is a rolling progression of different carbon-sink projects on different parcels of land so that, put together, the total of all individual stands more closely approaches the situation of permanently increased carbon storage. However, such a landscape-level compensation for individual stand-level processes will only eventuate if future climate policy continues to value biospheric carbon storage sufficiently highly for the size of the pool of established carbon stocks to be maintained or increased at the landscape level. Otherwise, if climate-mitigation based incentives to maintain carbon stocks are discontinued, then the total pool of biospheric carbon stocks may revert back to a lower level under the pressure from other socio-economic factors. It may, therefore, not be warranted to adopt short-term climate change policy that can only lead to desirably climate-change mitigation if supportive climate-change policy is adopted in future as well.

This is particularly troublesome in the context of the CDM as its rules, or even the distinction between Annex I and non-Annex I countries, may not be sustained beyond the first Commitment Period. Short-term carbon-sink projects that are supported without a need for an obligation of long-term maintenance of carbon stocks therefore risk the expenditure of scarce funds for climate-change mitigation without leading to any ultimate mitigation benefit.

To achieve meaningful climate-change mitigation, it is, therefore, essential that carbon accounting rules for biosphere sinks are specifically formulated to ensure that there is long-term storage of carbon stocks before credits can be generated (Cannell and Milne 1995; Nabuurs and Mohren 1995; Maclaren 1996; Kirschbaum et al. 2001; Kirschbaum and Cowie 2004). With biospheric carbon storage, indefinite storage cannot be assumed, and the permanence of storage must be explicitly addressed. Carbon-accounting assessments need to specifically question to what extent biospheric carbon is to be permanently stored. Credits should only be provided for management and land-use changes that permanently increase carbon stocks (Kirschbaum et al. 2001; Kirschbaum and Cowie 2004).

In addition to its effect through the storage of carbon in live biomass, vegetation can affect atmospheric CO_2 concentrations also through the provision of biofuels for replacing fossil fuels in energy generation (Vitousek 1991; Hall 1997; Kirschbaum 2003b), or for material substitution of wood for other materials with higher embodied energy costs such as steel or aluminium (Schopfhauser 1998; Kirschbaum 2001). If wood from temporary biosphere sinks can be used to replace fossil fuels, it can make an additional contribution to lowering atmospheric CO_2 concentrations. This benefit is best quantified through the amount of fossil fuels that can be replaced. In an assessment over 100 years, it was found that a short-rotation plantation used repeated for the provision of biofuels would provide a similar climate-change mitigation benefit as a forests maintained permanently (Kirschbaum 2003b). Thus, in addition to the important distinction between permanent and temporary carbon storage, it must further be considered whether fossil fuels can be substituted. If wood from a temporary sink is used for fossil-fuel substitution, it can provide an important and on-going benefit for climate-change mitigation.

For carbon accounting, it is essential to recognise the essential differences between fossil-fuel use and biospheric carbon management. Human actions directly control the rate at which fossil fuels are utilised, and any release cannot generally be reversed. Similarly, if savings are made in fossil-fuel use, those savings tend to be permanent. Biospheric carbon management, on the other hand, may increase or decrease the carbon stocks on a given area of land, and this sequestration or release can be reversed either inadvertently or through subsequent land-use decisions.

Fossil-fuel use and biospheric carbon management also differ in the degree of control over emissions. Fossil-fuel use is generally under direct and immediate human control. An engine can be switched on or off, with immediate effect on carbon emissions. Biospheric carbon management, on the other hand, is under less direct human control. An area of land may be replanted, but the immediate consequence of that decision is only small. There may be more substantial carbon gain over many subsequent years, but the realisation of that potential depends on subsequent human action and on a range of influences beyond the control of land managers, such as whether there are droughts, storms or insect attacks, and growth may be influenced by changes in temperature, CO_2 concentration or atmospheric nitrogen deposition.

While the present analysis has shown that temporary carbon storage achieves effectively no climate-change mitigation, biosphere management can have other associated benefits that may make it desirable to assist revegetation (Hardner et al. 2000; Noble et al. 2000) even where the permanence of vegetation cover could not be guaranteed. Where the combination of such other benefits provides a sufficient justification for establishing more vegetation even without consideration of climate-change mitigation, increasing tree cover would be a desirable outcome.

Most benefits of revegetation, such as prevention of erosion and salinisation, or protection of biodiversity, are, however, associated with permanently restoring vegetation cover with higher carbon stocks. The findings of the present analysis might, thus, have the indirect beneficial outcome of drawing attention to the long-term tenure of vegetation under diverse circumstances. The non-carbon benefits of biospheric management might, thus, also gain greater protection in addition to ensuring that biospheric carbon management does, indeed, achieve the best possible outcomes for climate-change mitigation.

5. Conclusions

Various studies have shown that under certain circumstances, management of the biosphere can make a useful and cost-effective contribution to the management of atmospheric CO_2 concentrations (Marland and Schlamadinger 1997, 1999; Hardner et al. 2000; Noble and Scholes 2001; Lecocq and Chomitz 2001; Harvey 2004). However, the present analysis suggests that, unlike reductions in fossil-fuel emissions, the issues surrounding the use of biosphere sinks are more complicated and long-term benefits are not always certain.

The analysis shows that permanent biospheric carbon storage can, indeed, make a valuable, and quantitatively important, contribution to mitigating climate-change impacts. However, temporary carbon storage does not bring the same benefits. This conclusion does not depend on the exact time course of future CO_2 emissions, and calculations based on both the high-emissions SRES A2 and the low-emissions SRES B1 scenarios lead to similar conclusions. It is, therefore, necessary to conduct a critical analysis before deciding whether, or under what circumstances, to establish biosphere sinks. Creation of new biosphere sinks can, therefore, only play a useful role in minimising climate-change impacts under circumstances that need to be well defined. Policy tools need to be carefully tailored to ensure that biospheric carbon management does, indeed, achieve desirable long-term mitigation outcomes.

For now, emphasis should more usefully remain firmly on reducing fossil-fuel emission through improving energy efficiency, reducing unnecessary energy usage and generating energy by alternative means such as wind, solar, hydro, or from biofuels. Climate change is emerging as a serious threat over the 21st century and beyond, and it is essential that the limited resources available for climate-change mitigation are used where they can most effectively achieve their intended outcomes.

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