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Chapter 9 Forestry

CONTENTS

EXECUTIVE SUMMARY

Unlike many other sectors, forestry can contribute both to reducing emission sources and to increasing sinks. Due to the direct link between land-use decisions and sustainable development, forestry plays a key role when addressing the climate change problem in the broader context of global change and sustainable development. As a major form of land cover globally, hundreds of millions households depend on the goods, services and financial values provided by forests. Land-use changes can negatively affect those that most closely depend on forest resources for their livelihoods.

Deforestation continues at an alarming rate; a gross loss of 13 million ha/yr is reported. This results mainly from conversion of forests to agricultural land and is the major contributor to the greenhouse gas emissions from the land use sector. Net forest area continues to decrease, but at a slower rate than earlier, at an average rate of 7.3 million ha/yr in 2000-2005. Forest planting, landscape restoration and natural expansion of forests have reduced the net loss of forest area. Production of forest products has increased, which can have positive carbon implications when sustainably produced.

There is a lack of integrated assessments of carbon mitigation potential in the literature. Based on regional modeling assessments a gradually increasing mitigation impact of forestry measures is projected globally (Figure 9.1). By 2030 the economic potential of a combination of measures in afforestation, avoided deforestation, forest management, agroforestry, and bioenergy, could yield on average an additional sink of around 3150 $MtCO_2$/yr (medium confidence). About 50% of this can be achieved at costs under 20\$/tCO_2 (= 1550 $MtCO_2$/yr). This sink enhancement/emission avoidance will be located in the tropics for 65% (high confidence) (Table 9.1), be found mainly in above ground biomass, and for 10% achieved through bio energy (medium confidence). In the short term this potential is much smaller, with 1180 $MtCO_2$/yr in 2010 (high confidence; at all prices) (Figure 9.1). Top-down global models generally give higher global economic potentials with an average of 12800 $MtCO_2$/yr in 2030 (for 36% achievable at costs under 20\$/tCO_2 = 4650 $MtCO_2$ /yr). Mitigation measures are able to avoid the biosphere going into a net source globally (Figure 9.1).

The market potential is probably a small fraction of these numbers. Institutional barriers, risks and leakage will increase the costs. The economic potential does not take these into account yet. Most likely costs will be 20-50% higher (and maybe more) in reality, because of the institutional barriers. It should be noted that our regional modelling estimates are much lower than in TAR which gave a potential of 11,670 $MtCO_2$/yr in 2010 (synthesis report p. 110). However, the latter could be regarded as a biological potential.

The regional assessments have as a set back that they are based on a wide variety of studies with different assumptions, the global top down modeling efforts provide a very large potential that does not sufficiently take into account local specific barriers, leakage, risk and institutional barriers. A large uncertainty still surrounds these mitigation estimates.

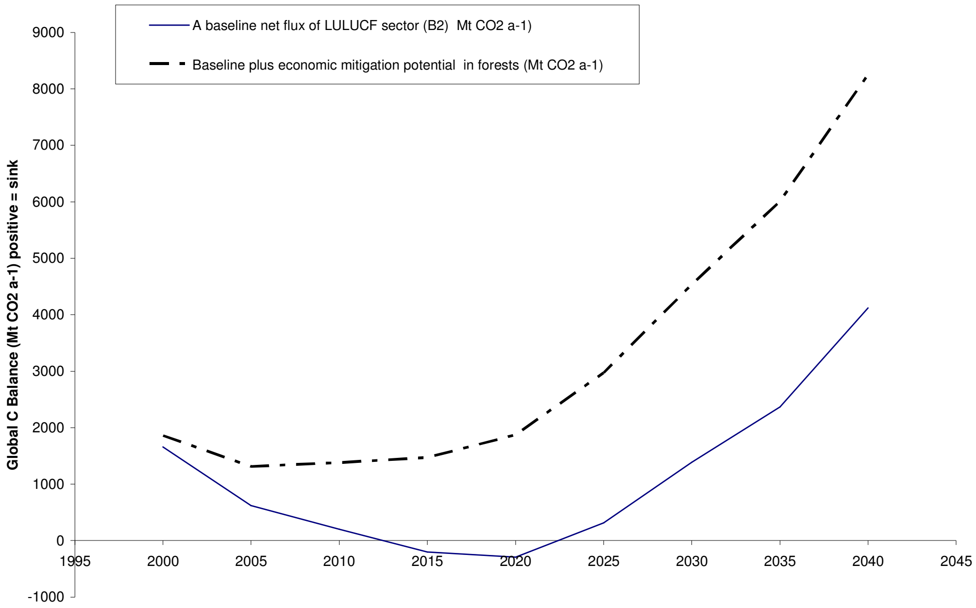


Figure 9.1 *The wedge: A hypothetical projection of the baseline of the global LULUCF sector (B2) and the economic potential of curbing of this baseline by additional measures in the forestry sector alone at a carbon price of around 20US$/tCO$_2$. Note that large uncertainty surrounds both the baseline, as well as the effect of the measures. Naturally, choosing another baseline would have an impact on the size of the curbing as well, however, literature does not allow such a dynamic approach*

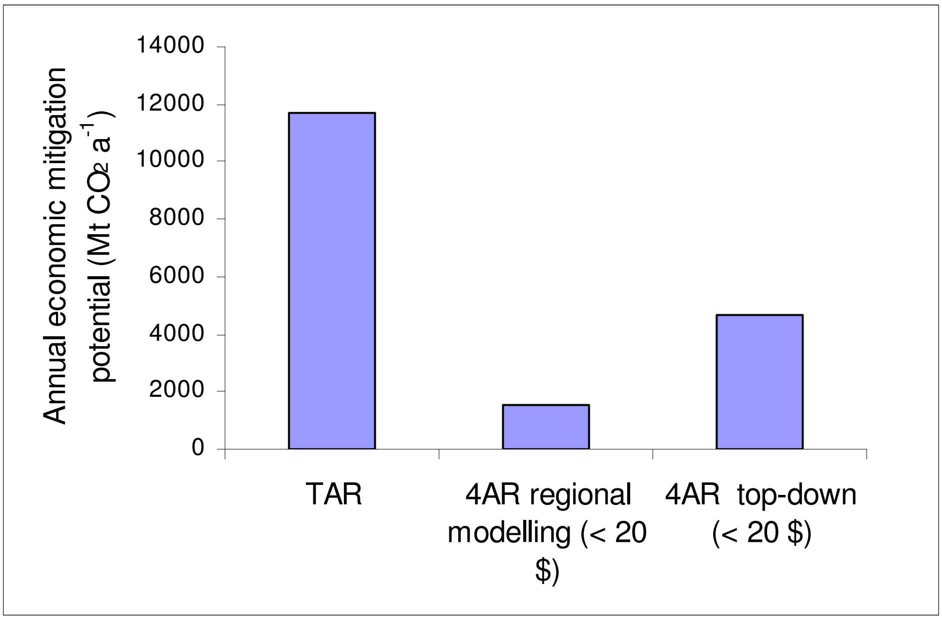
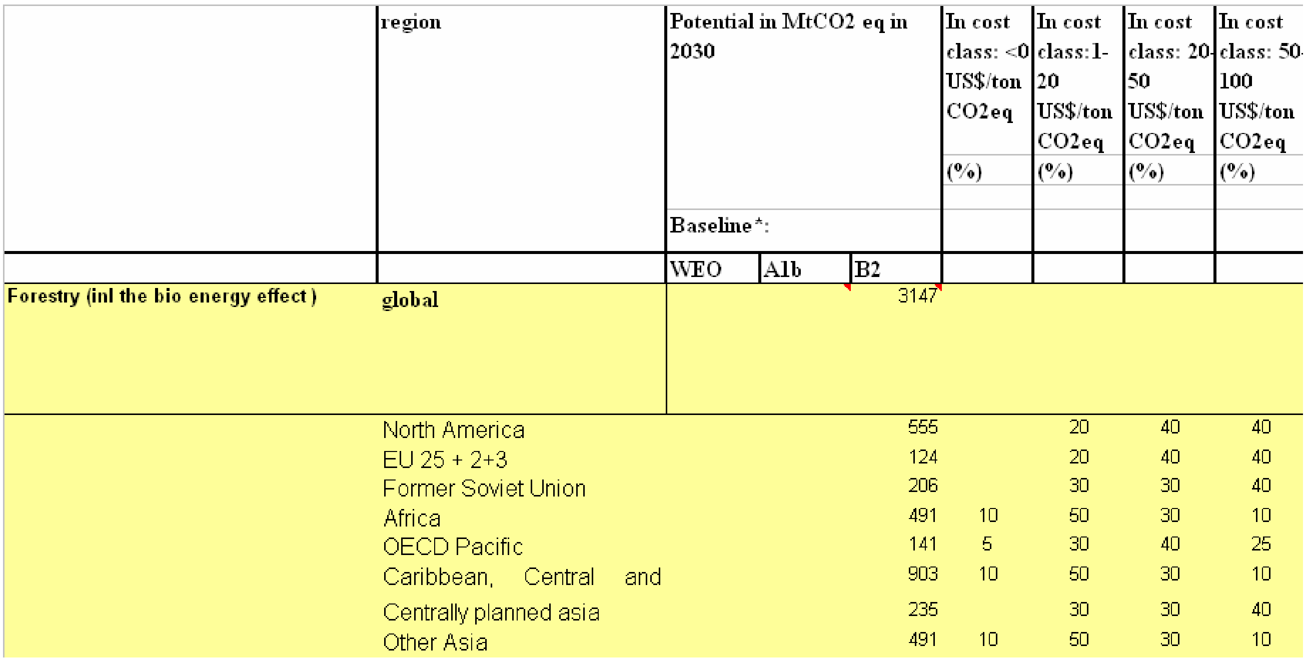


Figure 9.2 *Comparison of results as presented for forestry mitigation potential in TAR (biological potential), with the two estimates of the current chapter (economic potential < 20$ US)*

Table 9.1 *Economic mitigation potentials in forestry as assessed from regional modelling studies broken down by cost classes*



	region	Potential in MtCO2 eq in 2030			In cost class: <0 US$/ton CO2eq	In cost class:1-20 US$/ton CO2eq	In cost class: 20-50 US$/ton CO2eq	In cost class: 50-100 US$/ton CO2eq
					(%)	(%)	(%)	(%)
		Baseline*:						
		WEO	A1b	B2				
Forestry (inl the bio energy effect)	global			3147				
	North America			555		20	40	40
	EU 25 + 2+3			124		20	40	40
	Former Soviet Union			206		30	30	40
	Africa			491	10	50	30	10
	OECD Pacific			141	5	30	40	25
	Caribbean, Central and			903	10	50	30	10
	Centrally planned asia			235		30	30	40
	Other Asia			491	10	50	30	10

Within tropical regions, two thirds of the economic potential can be achieved through avoidance of emissions from deforestation and forest degradation. In the short term, this emission avoidance offers the main mitigation option in the forestry sector, combining positive ancillary benefits in terms of biodiversity conservation, sustainable rural development, other environmental services, and probably adaptation to climate change as well.

Most modelling studies mention that forest ecosystems and biodiversity are likely to be adversely impacted by climate change, constraining or threatening their mitigation potential. Thorough studies combining mitigation, adaptation and the constraining effect of climate change do not exist. Mitigation and adaptation synergy exists in the forest sector. Wherever possible, adaptation strategies or practices should be incorporated in mitigation projects.

Policies have been generally most successful in making forestry activities more sustainable where they help forestry to be more profitable than alternative uses of land, and there is sufficient political will and regulatory and institutional capacity for effective enforcement. Available evidence suggests that policies that seek to alter forestry activities where these conditions are not met have had limited effectiveness.

Promising approaches across both industrialized and developing countries include policies that combat the loss of forests to natural disturbance agents, and stimulate the use of environmental service payments to encourage the retention of forests. In both cases there are good examples where they have been successfully implemented at small scales, and the impediments to applying these measures to larger scales are beginning to be understood. In many circumstances the mitigation alternatives can reduce the potential threats of global change, for example increased use of salvage logging following natural disturbances can yield biomass for bioenergy and provide financial resources to accelerate the planting and regrowth of disturbed forests. Another example is the planting of new forests as corridors between fragmented patches of forests.

There is also a successful history of policies to create new forests, and these have lead to the creation of local carbon sinks in new forests. Care must be taken however to make sure that at plantation creation, there is no displacement of economic or subsistence activities that will lead to new forest clearing elsewhere. Policies to increase the substitution of fossil fuels with bioenergy will lead to large reduction in net emissions. Notably and despite considerable effort, integrated and non-climate policies have had minimal impact on slowing tropical deforestation in many countries.

Due to uncertainty over guidelines, bureaucracy and a society not willing to pay current carbon prices, few land-use projects have been undertaken since 2000. Clean Development Mechanism (CDM) afforestation and reforestation (A/R) was not operational before September 2004, when the first call for methodologies was issued. Literature stresses the importance of social issues for LULUCF projects. While on the one hand, LULUCF activities have the potential to improve local livelihoods, most of all in developing countries, risks and benefits are seen to be unevenly spread between different project types. Among the most important risks there is land-use competition, ownership concentration, and restricted resource access by indigenous populations.

Little experience has been gathered with CDM forest project activities to date. Out of the methodologies to be submitted for the first ten CDM A/R projects, only one was approved in 2005. Methodological problems were due in many cases, to a lack of understanding of the complex modalities and procedures, and terminology. Many issues of methodology, rules and guidelines have been addressed and solved in the past years, but often not through simplification.

However, in practice, further improvements in the net carbon balance are possible through efficient and careful harvesting, and implementation of state-of-the-art forest management techniques. Training and education will be an important part of this implementation. For carbon monitoring and accounting, several user-friendly techniques, guidelines and tools are available.

No single cook-book recipe can be given to guide the mitigation in the forestry sector. Multiple and location specific strategies are required. The optimum choices depend on the current state of the forest, the dominant drivers of forest change, and the anticipated future dynamics of the forest within each region. Participation of all stakeholders and policy makers is necessary to promote mitigation projects. Within each region combined consortia of stakeholders and policy makers can design the optimal mix of measures that reduces the ongoing emissions, protects the carbon stocks, be it in the above ground biomass, soil organic carbon, wood products or through provision of biomass for bio energy. Mitigation in the forestry sector should become an integral part of land use planning.

In the long term, carbon will be one of the goals that drive land-use decisions. Within each region, local solutions have to be found that optimize all goals and aim at integrated and sustainable land use. Developing the optimum regional strategies for climate change mitigation involving forests will require complex analyses of the trade-offs (synergies and competition) in land-use between forestry and other land uses, the trade-offs between forest conservation (carbon storage) and harvesting forests to provide society with carbon-containing fiber, timber and bioenergy resources, and the trade-offs among utilization strategies of harvested wood products aimed at maximizing storage in long-lived products, recycling, and use for bioenergy.

Higher carbon price incentives, simplified methodologies, reduction of transaction costs, capacity building among project developers, and technology transfer have the potential to drive mitigation projects in forest sector. In this way appropriately designed forest sector mitigation options provide the largest opportunities for promoting sustainable development.

9.1 Introduction

In the context of global change and sustainable development, forestry and forest management decisions play a key role in addressing both mitigation and adaptation to climate change. Forests are an engine in the global carbon cycle and they can play important roles in mitigation. But forests are also affected by global change and contribution to mitigation strategies will be influenced by stresses resulting from global change. Because forests are major form of land cover globally, many citizens depend on the goods, services and financial values provided by forests, and degradation of forests negatively affects those that most closely depend on forest resources for their livelihoods.

The world's forests have a substantial impact on the Earth's climate, through their role in the global carbon cycle, surface hydrology, albedo and other effects (IPCC WGI, Ch. 7, 2007). The terrestrial biosphere as a whole is believed to sequester 1870 $MtCO_2$/yr out of the fossil fuel emissions (1993-2003) of which forests would cover the larger part (IPCC, WGII, Ch. 4, 2007). In addition, WGI's most likely estimate of the emissions from deforestation is 3480 $MtCO_2$/yr, which is (partly) being sequestered on the land as well.

The IPCC Third Assessment Report (TAR) (Kauppi and Sedjo 2001) concluded that the forest sector can contribute an additional sequestration of 5380 $MtCO_2$/yr on average until 2050, whereas the SR LULUCF (IPCC 2000) even spoke of 11670 $MtCO_2$/yr (TAR synthesis report, p. 110). TAR mentioned the links of forestry mitigation measures to other land-use issues and stated that carbon sequestration was often most successful when part of integrated land-use strategies. However, a thorough economic analysis could not be supported by literature at that time. Neither could a thorough integration of forestry issues into other rural issues, other land uses, or the role of forestry in sustainable development. The TAR estimate of mitigation potential therefore needs to be reassessed as part of a more complex system.

Carbon mitigation in forests has been reported to be more cost-effective than mitigation options in other sectors (Kauppi and Sedjo, 2001). The activities aimed at conservation and enhancement of forest sinks and reservoirs are generally also consistent with the goals of sustainable management of forests. Where forests are managed sustainably providing an annual yield of fiber and timber, the wood products derived from the forest can substitute other materials and energy whose production would otherwise generate emissions. The forest mitigation options include reducing emissions from deforestation and forest degradation, enhancing the sequestration rate in existing or new forests, and by providing products as a substitute for fossil fuels and for more energy-intensive materials. Properly designed and implemented, forestry mitigation options may have substantial co-benefits in terms of employment and income generation opportunities, biodiversity and watershed conservation, provision of timber and fiber, as well as aesthetic and recreational services. The mitigation options have to be implemented in dynamic systems, that are affected by many competing land uses, and that themselves will be affected by climate change. Quantitative understanding of these interactions and therefore, quantification of the long-term effects at certain carbon price levels is uncertain.

Since the drafting of the Kyoto Protocol in 1997, there appear to be many barriers that preclude the full use of this mitigation potential. Examining the causes of this apparent contradiction between a large theoretical potential and substantial co-benefits versus the rather low implementation rate – constitutes one of the goals of the chapter.

Developments since TAR

Since the TAR, the science on forest-based mitigation has advanced in specific areas. New estimates have become available from local scale to global scale (Sathaye *et al.*, in press), especially concerning the carbon impact and costs of mitigation measures. Major economic reviews and global assessments have become available (Richards and Stokes 2004, Van Kooten *et al.,* 2004, Sathaye *et al.,* in press). There is early research into the integration of mitigation and adaptation options and the linkages to sustainable development (MEA, 2005). There is now more evidence that climate change impacts can also constrain the forest potential, as shown, for example in the 2003 drought in Europe (Ciais *et al.,* 2005). Furthermore, full attention is paid to substitution and bio energy (Lindner *et al.,* 2005). Fully integrated multiple land-use studies that assess larger scale economic potentials in the forestry sector are, however, rare in the literature, although some studies are moving in that direction (e.g. in Brown *et al.,* 2004). Furthermore, the literature still displays a variety in outcomes, partly due to the natural variability in the system, but partly also due to differences in (baseline) assumptions, type of potential studied, methods and data quality.

On the other hand, Parties to the Convention are improving their forest carbon balance estimates through the design and implementation of a National System for forest inventories and forest carbon accounting (Richards and Brack 2004, Kurz and Apps 2006, Nabuurs *et al.,* 2005). These systems have, amongst others, been facilitated by the release of the Good Practice Guidance for Land Use, Land-use Change and Forestry (IPCC 2003).

Basic problems remain, however. Few major forest-based mitigation analyses have been conducted at the regional or global scale using new primary data. Much of the new literature has produced improved estimates of the economic potential for forestry mitigation options based on primary data collected in the mid 90s. There is still limited insight in impacts on soils, lack of integrated views on the many site-specific studies, hardly any or no integration with climate impact studies, and limited views in relation to social issues and sustainable development. Little new effort was reported on the development of global baseline scenarios of land-use change and their associated carbon emission and sequestration dynamics- against which mitigation options could be examined. There is limited quantitative information on the investment costs of mitigation actions or the cost-benefit ratios of mitigation interventions. Finally there are still large gaps of knowledge in terms of feedback effects – such as atmospheric nitrogen fertilization, surface hydrology, and albedo- and possibly non-linear behaviour and total system collapse points in response to the stresses imposed by global change such as natural disturbances, droughts, and other impacts on forest dynamics (IPCC WGII, Ch. 4, 2007).

Forestry in itself is a multi-faceted form of land use, to which many of the other chapters in WGIII are related (Figure 9.3). These relations have to be kept in mind when drawing boundaries around this chapter and when taking into account all the effects of the often sector-specific decisions being made.

Aim

The primary aims of this chapter are a) to provide an updated estimate of the economic potential to reduce emissions of carbon and increase carbon sequestration from forests through human activity. This will be done in the frame of the stabilisation scenarios as given in Chapter 3.2, b) to examine the causes of the apparent contradiction between a large theoretical potential and a low rate of implementation and c) to integrate the estimates of the economic potential with considerations of both adaptation and mitigation in the context of sustainable development This chapter first identifies the current trends in the forest sector worldwide (9.2), then summarises the current role of forests in the global carbon cycle (9.3). In subsequent sections an assessment of mitigation options is conducted (9.4), together with their relation to adaptation (9.5). Subsequent sections address policies, opportunities and challenges (9.6), ancillary effects (9.7), technology (9.8), and the long-term outlook of the sector (9.9).

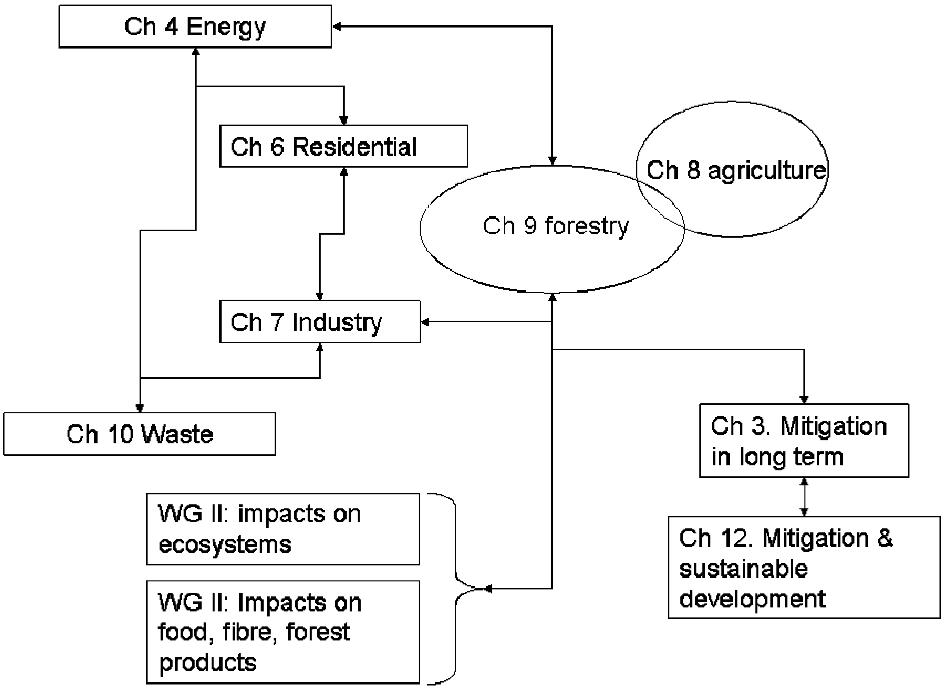


Figure 9.3 *Relationship between this chapter and other chapters of WG III and relevant chapters of WG II*

9.2 Status of the Sector and trends

9.2.1 Forest area and volume

Globally the forest area has continued to decrease, but at a decreasing rate: between 2000-2005 the net area loss was 7.3 million ha/yr compared to 8.9 million ha/yr in the 1990s (Table 9.2, (FAO, 2006). Despite this, gross deforestation continues at an alarming rate, 13 million ha/yr globally, mainly as a result of converting forests to agricultural land (FAO, 2006). Africa and South America continued to have the largest net loss of forests (Figure 9.2). Deforestation remained the major contributor to greenhouse gas emissions from land use, land-use change and forestry sector. Forest planting, landscape restoration and natural expansion of forests have reduced the net loss of forest area. Still, the global forest cover amounts to about 3,952 million ha, which is about 30 percent of the world's land area (FAO, 2006).

The area of forest plantations increased by 2.8 million ha/yr, mostly in Asia, during 2000-2005, covering about 140 million ha in 2005 (FAO, 2006). According to the MEA (2005) scenarios, forest area in the industrialised regions will increase between 2000 and 2050 by about 60 to 230 million ha, while in the developing regions forest area will decrease by about 200 to 490 million ha. Both quantitative models and qualitative analyses have been used to develop these scenarios based on different assumptions on policies addressing sustainable development, population and economic growth.

Table 9.2 *Selected regional and global estimates of change in forest area and the role of forests and other terrestrial vegetation in carbon exchange with the atmosphere. NOTES: Positive = sink*

Regions	FAO, 2001		Rate of Change in Carbon Stock of Woody Biomass				Annual Carbon Flux during 1990's	
	Forest area, million ha	Net area change 80's-90's, million ha/yr	UN-ECE, 2000		UNFCC, 2002 (1996-2002 average)		inversion of atmospheric transport models	land observations
			$MtCO_2$/yr	tCO_2/yr	$MtCO_2$/yr	tCO_2/yr	$MtCO_2$/yr	
OECD North America	525.8	-0.2					1830 ± 2190[9]	0 - 1100[5]
Separately: Canada	244.6	0	340	0.81	79.8	0.33	2080 ± 3330[2]	290 ± 730[1]
USA	226.0	0.4	610	2.1	645	2.85		
Mexico	55.2	-0.6						
OECD Pacific	192.6	-0.3	223	0.36	45[b]	0.29 [b]		0 ± 730[1]
Europe	149.7	0.7	315	2.45	207[a]	1.39 [a]	494 - 750[6]	0 ± 730[1] 510[11]
Countries in Transition	923.6	0.5	1723	1.89			3770 ± 3440[2]	1100 ± 2930[9]
Separately: Russia	851.4	0.1	1570	1.76			4760 ± 2930[9]	1180 - 1580[7] 1900 ± 470[8]
Northern Africa	67.3	-1.0					622 ± 3590[2]	
Sub-Saharan Africa	582.6	-4.2						–570 ± 235[3] –440 ± 110[4] -1280 ± 730[1]
Caribbean, Central and South America	909.1	-4.1					-2300 ± 3880[2]	–1615 ± 970[3] –1570 ± 730[4] -2745 ± 1100[1]
Separately: Brazil	543.9	-2.3						0 ± 730 [12]
Developing Countries of South and East Asia and Middle East	518.9	-0.7					-2490 ± 2710[2]	-4000 ± 1830[1] -1730 ± 550[3] -1280 ± 550[4]
Separately: China	163.5	1.8					2270 ± 2415[2]	-110 ± 730[1] 570[13] 250[15]
Global total	3869.5	-9.4					4760 ± 5490[9] 2560 ± 2930[10] 4900[2]	-8000 ± 2900[1] -3290 ± 7700[5]

[a] European Community only

[b] Australia and New Zealand only

[1] Houghton 2003a (flux from changes in land use and land management based on land inventories).

[2] Gurney *et al.,* 2002 (inversion of atmospheric transport models, estimate for Countries in Transition applies to Europe and boreal Asia; estimate for China applies to Temperate Asia).

[3] Achard *et al.,* 2004 (estimates based on remote sensing for tropical regions only)

[4] De Fries *et al.,* 2002 (estimates based on remote sensing for tropical regions only)

[5] Potter *et al.,* 2003 (NEP estimates based on remote sensing for 1982-1998 and ecosystem modelling, the range reflects interannual variability)

[6] Jansssens *et al.,* 2003 (combined use of inversion and land observations; includes forest, agricultural lands and peatlands between Atlantic Ocean and Ural Mountains, excludes Turkey and Mediterranean isles).

[7] Shvidenko and Nilson, 2003 (forests only, range represents difference in calculation methods)

[8] Nilsson *et al.,* 2003 (includes all vegetation)

[9] Cias *et al.,* 2000 (inversion of atmospheric transport models, estimate for Russia applies to Siberia only)

[10] Plattner *et al.,* 2002 (revised estimate for 1980's is 400±700)

[11] Nabuurs *et al.,* 2003a (forests only)

[12] Houghton *et al.,* 2000 (Brazilian Amazon only, losses from deforestation are offset by regrowth and C sink in undisturbed forests).

[13] Fang *et al.,* 2005

[14] Pan *et al.,* 2004.

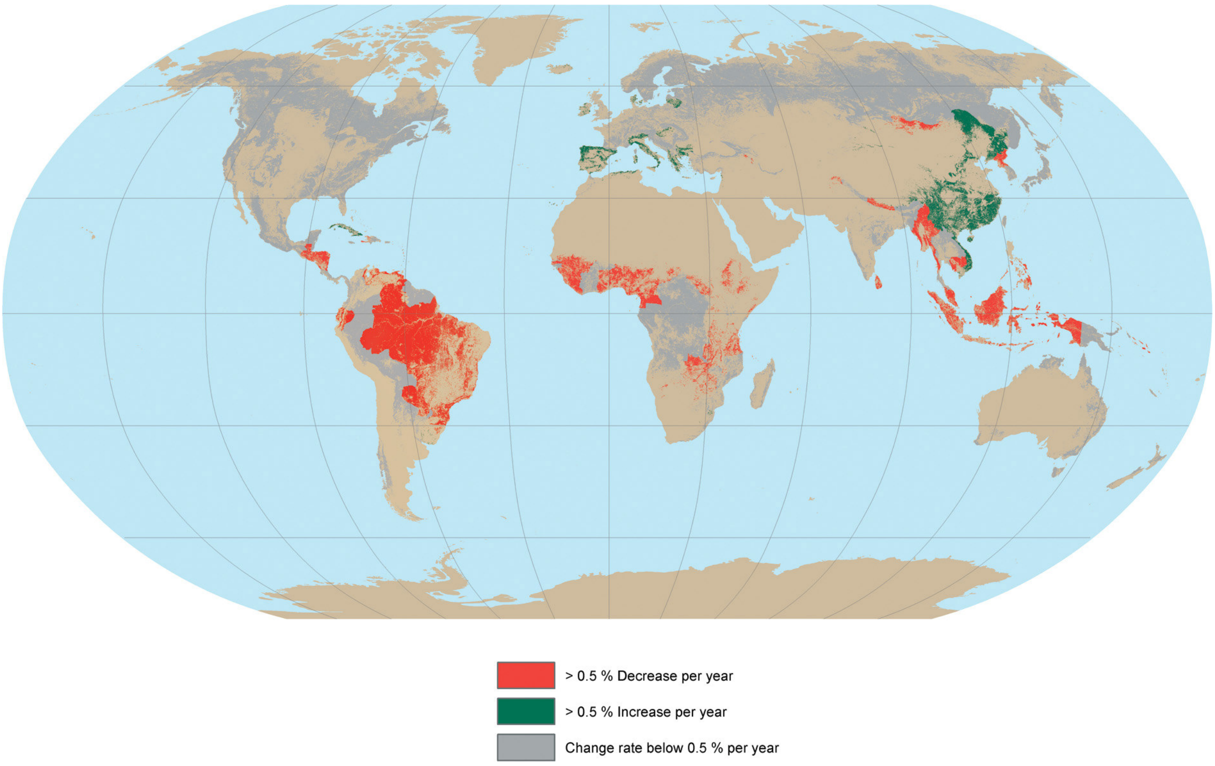


Figure 9.4: *Areas with high net change in forest area between 2000 and 2005 (FAO 2006)*

In addition to the decreasing forest area globally, forests are also severely affected by disturbances like forest fires, pests (insects and diseases) or climatic events such as drought, wind, snow, ice and floods, having also carbon balance implications as explained in Sections 9.3 and 9.4. FAO (2006) has estimated that such disturbances affect roughly 100 million ha of forests annually. Degradation, defined as decrease of density or increase of disturbance in forest classes affected in the tropics 2.4 million ha y-1 in the 1990's (FAO 2001). Even though it appears that forest degradation has reduced, it is difficult to make objective estimates of the extent or severity of degradation changes because of data limitations.

FAO (2006) has estimated the global stem wood volume of forests at 434 billion m^3, corresponding to an average of 110 m^3 per hectare, and carbon stock in forest biomass at 1,037,000 $MtCO_2$ in 2005 (Table 9.1). Since 1990 net wood volume has decreased by 11 billion m^3 or 2.5%, and carbon stock by 58,000 $MtCO_2$ or 5.5%, largely because of continued deforestation and degradation, partly offset by forest expansion and increase in growing stock per hectare in some regions [1]. Carbon stock of forest biomass has decreased on continental scale in Africa, Asia, Oceania and South America, while it has increased in Europe, and in North and Central America.

The loss of primary forests is especially devastating for biodiversity (Figure 9.5). Roughly 10-20% of current global forestland is projected to be converted to other uses by 2050 with obvious large consequences for the global carbon cycle. The primary cause lies in the expansion of agriculture; secondary causes are the expansion of cities and infrastructure (the latter partly due to forestry operations) (MEA 2005). Temperate mixed forests, tropical forests and open woodlands are among those biomes that are projected to loose habitat and species at the fastest rate; these are often the habitats richest in biodiversity.

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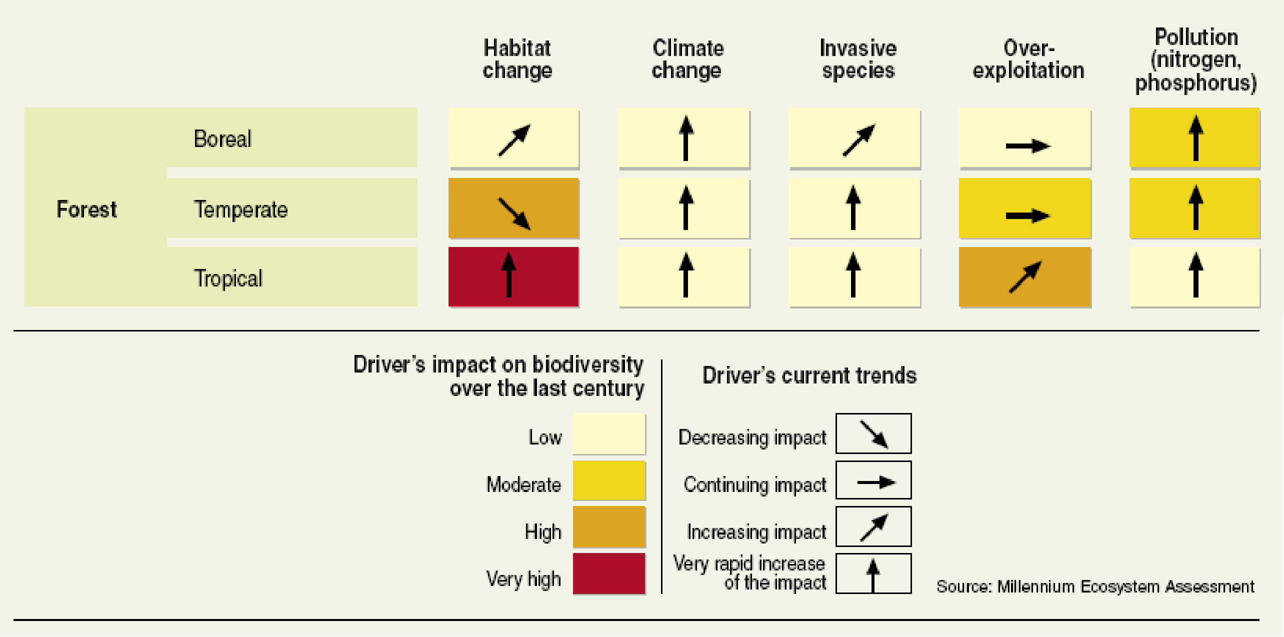
[1] We note that this is in contradiction to some of the global totals as given in Section 9.3, Table 9.3.



		Habitat change	Climate change	Invasive species	Over-exploitation	Pollution (nitrogen, phosphorus)
Forest	Boreal	⬜ ↗	⬜ ↑	⬜ ↗	⬜ →	🟨 ↑
	Temperate	🟧 ↘	⬜ ↑	⬜ ↑	🟨 →	🟨 ↑
	Tropical	🟥 ↑	⬜ ↑	⬜ ↑	🟧 ↗	⬜ ↑

Driver's impact on biodiversity over the last century	
Low	⬜
Moderate	🟨
High	🟧
Very high	🟥

Driver's current trends	
Decreasing impact	↘
Continuing impact	→
Increasing impact	↗
Very rapid increase of the impact	↑

Source: Millennium Ecosystem Assessment

Figure 9.5: Main direct drivers of change in biodiversity of forests (Millennium Ecosystem Assessment, 2005)

9.2.2 Forest management

Wood production is the primary function for about one third of the forests. However, forests are more and more managed for various uses and values. Nearly 90% of forests in industrialized countries are being managed "according to a formal or informal management plan" (FAO 2001). National statistics on forest management plans are not available for many developing countries, but preliminary estimates show that at least 123 million ha, or about 6 percent of the total forest area of developing countries, are covered by a "formal, nationally approved forest management plan covering a period of at least five years" (FAO, 2001). Proper management plans are seen as prerequisites for the development of management strategies that include carbon-related objectives.

Forest certification was initiated as a market-driven instrument to confirm that certain predefined minimum standards of forest management in a given forest area at a given point in time have been achieved. The area of forests under different certification schemes is increasing worldwide. Under the Programme for the Endorsement of Forest Certification (PEFC) and Forest Stewardship Council (FSC) nearly 7% of the forest area or 261 million ha have been certified by April 2006 (http://www.pefc.org/internet/html/index.htm, http://www.fsc.org/en/whats_new/fsc_certificates), while at the end of 2000 about 80 million ha were certified (FAO 2001). Most certified forests are located in boreal and temperate, industrialized countries. In recent years, discussion has also focused on illegal logging and trade. Countries have been urged to improve law enforcement in the forest sector and to control illegal trade in forest products. Forest Law Enforcement and Governance (FLEGT) at the East Asia Ministerial Conference and the EU Action Plan for FLEGT are the most comprehensive plans to fight illegal logging and associated trade. The world's richest nations (G8) have also agreed to implement measures to tackle illegal logging (G8 Gleneagles 2005). As much as 15% of the global timber trade has been estimated to involve illegalities and corruption practices, equal to US$10 billion losses in assets and revenues every year (Contreras-Hermosilla 2002). Sustainable forest management can be regarded also sustainable carbon management, and thus instruments supporting sustainable forest management also support mitigation of climate change.

9.2.3 Wood supply, production and consumption of forest products, employment and trade

Global wood removals are about 3 billion m^3 (far below the increment) and have been rather stable during the last 15 years. Undoubtedly the actual amount of wood removals is higher, as illegally removed wood is not recorded. About 60% of removals are industrial roundwood, the rest being woodfuel. The majority of the removals in Africa, and substantial portions in Asia and South America are woodfuels.

Although accounting for only 5% of global forest cover, forest plantations were estimated in 2000 to supply already about 35% of global roundwood. Thus there is a trend towards concentrating the harvest on a smaller forest area. Meeting society's needs for timber through intensive management of a smaller forest area creates opportunities for enhanced forest protection and conservation in other areas.

Only very few developing countries are among the major producers and consumers of forest products except in case of wood fuel production (FAO 2005). Wood energy accounts for 7 to 9% of global energy consumed, and for up to 80-95% in some developing countries. More than 2 billion people are dependent on wood fuel for cooking and heating. Some of these people will start to use other sources of energy, but the fast population growth in developing countries will compensate for this, and more people than today will likely depend on wood fuel in the future.

The increase in the global production of forest products has resulted in an increase in the value of international trade of forest products by 50% from 100 to 150 billion USD between 1993 and 2003 (Unasylva, 2004). The growth in forest products trade has been, however, less than the growth of trade in other merchandise goods. Therefore, the share of forest products in total merchandise exports declined from 2.9% in 1990 to 2.2% in 2000 (Lebedys, 2004). It should be noted that most of the roundwood and non-wood forest products are traded domestically (Mersmann, 2004). Total employment in the (formal) forestry sector increased by about 4% over the last decade, from 12.4 million in 1990 to 12.9 million in 2000 (Lebedys, 2004). In 2000, total gross value-added in the forestry sector amounted to 354 billion USD (1.2% of global GDP), the pulp and paper industry accounted for about half of the total gross value-added in the forestry sector (Lebedys, 2004). Increasing production of forest products have also positive carbon implications if raw material is coming from sustainably managed forests, i.e. increasing wood product carbon stocks and possibilities for substitution as explained in chapter 9.4.

The global picture of trade in wood and wood based products has changed substantially in recent years with the emergence of new big players such as China and the Russian Federation, and with the change of traditional exporters of primary timber products in Southeast Asia into exporters of secondary processed products due to development of processing industries and resource constraints (Hashiramoto *et al.,* 2004). China has become the world's largest importer of industrial logs (FAO 2005). Market-based development of environmental services from forests, such as biodiversity conservation, carbon sequestration, watershed protection and nature-based tourism, is receiving attention as a tool for promoting sustainable forest management. Expansion of these markets may remain slow and depends on government intervention (Katila and Puustjärvi 2004).

9.3 Regional and global trends in terrestrial greenhouse gas emissions and removals

Mitigation measures will occur against the background of ongoing change in greenhouse gas emissions and removals. Understanding current trends is critical for evaluation of additional effects from mitigation measures; moreover the potential for mitigation depends on the legacy of past and present patterns of change in land-use and associated emissions and removals. The contribution of the forest sector to greenhouse gas emissions and removals from the atmosphere remained the subject of active research, which produced a very extensive body of literature. The major scientific advances are related to (1) evolving consensus on broad global patterns of C sources and sinks on land, (2) technological advances that improved observational data, (3) consideration and in some cases quantification of previously overlooked fluxes and effects on climate, and (4) improved understanding of limitations and uncertainties of current estimates and needs for an integrated approach to evaluating the impact of terrestrial ecosystems on climate (Marland *et al.,* 2003, Canadell *et al.,* 2004).

At the global scale, during the last decade of the 20th century, deforestation in the tropics and forest regrowth in temperate and parts of the boreal zone remained the major factors responsible for emissions and removals, respectively (Table 9.3). Top-down methods based on inversion of atmospheric transport models estimate the net terrestrial carbon sink for the 1990's, which is the net balance of sinks in northern latitudes and source in tropics (Ciais *et al.,* 2000, Plattner *et al.,* 2002, Gurney *et al.,* 2002). The new estimates support the previously-found increase in the terrestrial C sink in the 1990's over the 1980's (IPCC 2000), but the new sink estimates and the rate of increase is estimated to be smaller than previously reported (Plattner *et al.,* 2002; Table 9.3). Improved spatial resolution allowed estimating the land-atmosphere C flux for some continents separately. These estimates generally suggest greater sink or smaller source than the bottom-up estimates based on analysis of forest inventories and remote sensing of change in land-cover (e.g. Houghton *et al.,* 2000, Houghton 2005, Achard *et al.,* 2002, DeFries 2002). The continued loss of forest cover in tropical regions plays an important role in C losses to the atmosphere while expanding forest areas and accumulating woody biomass contribute to C sink in the northern boreal and temperate zone (UN-ECE/FAO 2000). At the global scale the losses of forest cover continued during 1990's with net annual loss of 9.4 million ha, while the uptake of C on land apparently increased in the 1990's. The processes that could account for this increase remain unknown; the increase in woody biomass in many developed countries, Russia and China (Table 9.3, Figure 9.6) may account but for some of it. Chapter 7, WG1 reports the latest estimates for the terrestrial sink for the decade 1993 -2003 at 1870 $MtCO_2$/yr, ignoring emissions from land-use change (Brasseur *et al.,* 2007).

While the estimates of forest expansion and regrowth in the temperate and boreal zones appear relatively well constrained by available data and consistent across published results, the rates of tropical deforestation remain uncertain and hotly debated (Table 9.3, Fearnside and Laurance 2004, Mayaux *et al.,* 2005). Studies based on remote sensing of forest cover report lower rates than the UN-ECE/FAO (2000) and lower emissions of carbon (Achard *et al.,* 2002, DeFries 2002). A recent estimate puts global net emissions from land-use change in the tropics at 4000 $MtCO_2$/yr ± 1000 (see also Chapter 7, WG III) and includes emissions from conversion of forests (representing 71% of net emissions) and loss of soil carbon after deforestation (20%), emissions from forest degradation (4.4%), emissions from the 1997–1998 Indonesian exceptional fires (8.3%), and sinks from regrowth (-3.3%) (Achard *et al.,* 2004). Over the last three decades, earth observation satellites have increased in number and sophistication (Janetos and Justice 2000; Belward *et al.,* 2003). Remote sensing methods are expected to play an increasing role in future assessments, especially as a tool for mapping land cover and its change over time, however, converting these maps into estimates of C sources and sinks remains a challenge and will continue to depend on in-situ measurements and modelling.

Another tool for land-based observations are flux towers that provide information on environmental controls on C exchange of terrestrial vegetation including forests over relatively small spatial scales (e.g. Law *et al.,* 2004). Converting these measurements into large area estimates can be problematic because flux towers generally miss the major C emission events (e.g., following fires, clearcut harvest, and insect outbreaks) that tend to be short-lived and stochastic in forest ecosystems (Körner 2003). Several studies that used flux tower measurements in regional analyses therefore had to rely on other types of ground measurements and model-based scaling techniques (Law *et al.,* 2004, Janssens *et al.,* 2003, Table 9.3).

Table 9.3 *Selected regional and global estimates of change in forest area and the role of forests and other terrestrial vegetation in carbon exchange with the atmosphere. NOTES: Positive = sink*

Regions	FAO, 2001		Rate of Change in Carbon Stock of Woody Biomass				Annual Carbon Flux during 1990's	
	Forest area, million ha	Net area change 80's-90's, million ha/yr	UN-ECE, 2000		UNFCC, 2002 (1996-2002 average)		Inversion of atmos-pheric transport models	Land observations
			$MtCO_2$/yr	tCO_2/yr	$MtCO_2$/yr	tCO_2/yr	$MtCO_2$/yr	
OECD North America	525.8	-0.2					1830 ± 2190[9]	0 - 1100[5]
Separately: Canada	244.6	0	340	0.81	79.8	0.33	2080 ± 3330[2]	290 ± 730[1]
USA	226.0	0.4	610	2.1	645	2.85		
Mexico	55.2	-0.6						
OECD Pacific	192.6	-0.3	223	0.36	45[b]	0.29 [b]		0 ± 730[1]
Europe	149.7	0.7	315	2.45	207[a]	1.39 [a]	494 - 750[6]	0 ± 730[1] 510[11]
Countries in Transition	923.6	0.5	1723	1.89			3770 ± 3440[2]	1100 ± 2930[9]
Separately: Russia	851.4	0.1	1570	1.76			4760 ± 2930[9]	1180 - 1580[7] 1900 ± 470[8]
Northern Africa	67.3	-1.0					622 ± 3590[2]	
Sub-Saharan Africa	582.6	-4.2						–570 ± 235[3] –440 ± 110[4] -1280 ± 730[1]
Caribbean, Central and South America	909.1	-4.1					-2300 ± 3880[2]	–1615 ± 970[3] –1570 ± 730[4] -2745 ± 1100[1]

Separately: Brazil	543.9	-2.3						0 ± 730 [12]
Developing Countries of South and East Asia and Middle East	518.9	-0.7					-2490 ± 2710[2]	-4000 ± 1830[1] -1730 ± 550[3] -1280 ± 550[4]
Separately: China	163.5	1.8					2270 ± 2415[2]	-110 ± 730[1] 570[13] 250[15]
Global total	3869.5	-9.4					4760 ± 5490[9] 2560 ± 2930[10] 4900[2]	-8000 ± 2900[1] -3290 ± 7700[5]

[a] European Community only

[b] Australia and New Zealand only

[1] Houghton 2003a (flux from changes in land use and land management based on land inventories).

[2] Gurney *et al.,* 2002 (inversion of atmospheric transport models, estimate for Countries in Transition applies to Europe and boreal Asia; estimate for China applies to Temperate Asia)

[3] Achard *et al.,* 2004 (estimates based on remote sensing for tropical regions only)

[4] De Fries *et al.,* 2002 (estimates based on remote sensing for tropical regions only)

[5] Potter *et al.,* 2003 (NEP estimates based on remote sensing for 1982-1998 and ecosystem modelling, the range reflects interannual variability)

[6] Janssens *et al.,* 2003 (combined use of inversion and land observations; includes forest, agricultural lands and peatlands between Atlantic Ocean and Ural Mountains, excludes Turkey and Mediterranean isles).

[7] Shvidenko and Nilson, 2003 (forests only, range represents difference in calculation methods)

[8] Nilsson *et al.,* 2003 (includes all vegetation)

[9] Cias *et al.,* 2000 (inversion of atmospheric transport models, estimate for Russia applies to Siberia only)

[10] Plattner *et al.,* 2002 (revised estimate for 1980's is 400±700)

[11] Nabuurs *et al.,* 2003a (forests only)

[12] Houghton *et al.,* 2000 (Brazilian Amazon only, losses from deforestation are offset by regrowth and C sink in undisturbed forests).

[13] Fang *et al.,* 2005

[14] Pan *et al.,* 2004.

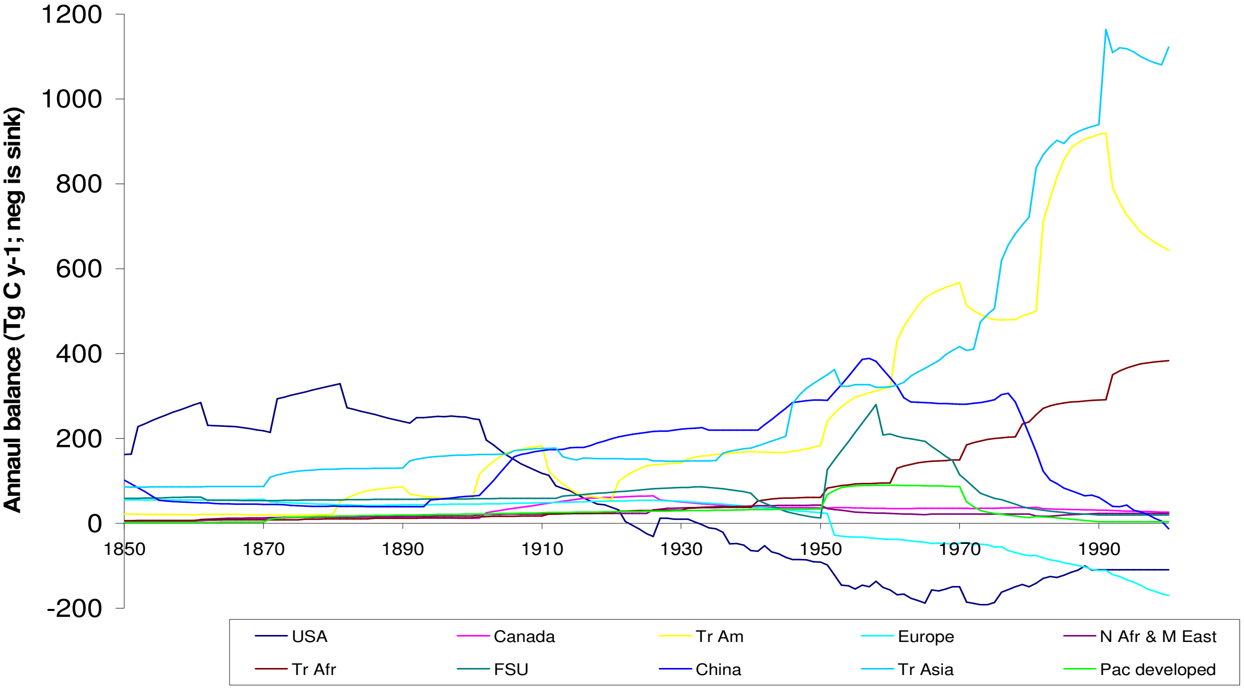


Figure 9.6: *Carbon balance of the LULUCF sector (often forests alone) per continent, historically. Pos = source. (Houghton 2003b) (data from CDIAC)*

Recent analyses highlight the important role of carbon flows that were largely overlooked by earlier research, including C export through river systems (Raymond and Cole 2003), volcanic activity and other geological processes, outgassing (Richey *et al.,* 2002), transfers of material in and out of products pool (Nabuurs *et al.,* 1997, Pacala *et al.,* 2001, Hashimoto and Moriguchi 2004), and uptake in freshwater ecosystems (Janssens *et al.,* 2003). Put together these relatively small flows were shown to be quite significant for the overall C budget of the USA (Pacala *et al.,* 2001). Janssens *et al.,* (2003) used estimates for Europe from different sources to constrain the available range of estimates. Moreover, House *et al.,* (2003) show that the differences in estimates can provide insights into the role of different processes. For example, the difference between atmospheric inversion and inventory-based estimates in northern extra-tropical regions suggest that C accumulation in soils and non-forest vegetation may account for nearly half the terrestrial uptake in this region. Estimates of the effects of land-use change in tropics may fail to fully account for the impact of CO_2 fertilization, climate change, effects of prior disturbance history, and other factors that contribute to C uptake in tropical forests.

The attribution of the estimated carbon sink in forests to the cascading effects of the historic land-use change and shifting natural disturbance patterns on one hand and to the effects of N and CO_2 fertilization and climate change on the other remains problematic (Scholes and Noble, 2001, Houghton 2003b). For the US, for example, the fraction of carbon sink attributable to changes in land-use and land management might be as high as 98% (Caspersen *et al.,* 2000) or as low as 40% (Schimel *et al.,* 2001, Houghton *et al.,* 2003b). Forest expansion and regrowth and associated sinks of carbon were reported in many regions. In Western Europe, US, some countries with economies in transition, and several other regions forest expansion was reported and was largely driven by declining need for agricultural land (Goldewijk, 2001). Quantitative estimates of this process are often lacking because these lands are generally not covered by forest inventories. The expanding tree cover in the southwestern US is attributed to the long-term effects of fire control but the gain in C storage was smaller than previously thought because woody encroachment may lead to loss of carbon from soils (Jackson *et al.,* 2002).

Large year-to-year and decadal scale variation of regional carbon sinks was reported (Bousquet, *et al.,* 2000, Houghton *et al.,* 2000, Kurz and Apps, 1999, Nabuurs *et al.,* 2003a, Pacala *et al.,* 2001, Rodenbeck *et al.,* 2003, Shvidenko and Nilsson, 2003) making it difficult to define distinct trends. The variation reflects the effects of climatic variability, both as a direct impact on vegetation and through the effects of wild fires and other natural disturbances. Fires in tropical forests are reported to grow in area and frequency (Cochrane 2003). During the 1997/98 El Nino, global emissions from fires were an estimated 7700 $MtCO_2$/yr, 90% from tropics (Van der Werf *et al.,* 2004). During 1998, an extreme fire year in the boreal zone released an estimated 1000-1400 $MtCO_2$/yr into the atmosphere (Kasischke and Bruhwiler 2003). There are indications that higher temperatures in boreal regions will increase fire frequency and associated greenhouse gas emissions (Flannigan *et al.,* 2000, Flannigan *et al.,* 2005); possible drying of the Amazon basin would increase fire frequency there as well (Cox *et al.,* 2004, Nepstad *et al.,* 1999, WG III, ch 4).

The growing understanding of the complexity of the effects of land-surface change on climate system showed the importance of considering the role of the surface albedo, the fluxes of sensible and latent heat, evaporation, and other factors in formulating the policy for climate change mitigation in the forest sector (Marland *et al.,* 2003). In particular, Betts (2000) raised the question whether the warming effect of increased forest cover in high latitudes will offset the cooling effect of C sequestration in forest biomass; on the other hand, tropical forests may cool the local environment by enhancing transpiration. Present mitigation strategies (IPCC 2001) focus on greenhouse gas concentrations and on global average climate, although other factors and other spatial scales are clearly important, given the goal of mitigating climate change. To fully consider the climatic effect of changing land surface and managing C stocks in the biosphere would require complex modelling tools not yet available (Marland *et al.,* 2003) and the present analysis therefore continues to focus on carbon.

The potential effect of projected climate change on the net carbon balance in forests remains uncertain (WGII, ch 4), available evidence indicates that for several decades (1) deforestation in the tropics will continue to be a major source of carbon emissions (Canadell *et al.,* 2004), (2) fire and pest disturbances may produce GHG emissions as large as those from deforestation in some (especially El Nino) years (Achard *et al.,* 2004); (3) degradation of C stocks from unsustainable logging, fuelwood and fodder collection will continue; (4) the carbon sink in some or all countries with economies in transition may decrease as forests mature but this trend may reverse if their rebounding economies cause increased logging; (5) C stocks in forests of many developed countries will continue to grow unless they choose to rely more on their forests to meet the demand for timber, however the strength of C sink may gradually decrease as forests age; (6) reforestation programs in previously deforested countries (e.g. Europe, China) (Nabuurs *et al.,* 2003b, Fang *et al.,* 1998) can produce new C sinks. The timing, extent, and impacts of future net emissions from forests are in part contingent upon the application of mitigation options described below.

Box 9.1 Countries in Transition: closing the carbon budget

The forests resource in the former Soviet Union represent about 20% of the global forest resource and include a large area of primary (mostly boreal) forests. Most estimates indicate that the Russian forests are neither a large sink nor a large source. Natural disturbances (fire) play a role in the carbon balance with emissions of up to 150-200 $MtCO_2$/yr (Zhang *et al.,* 2003). Large uncertainty surrounds the estimates for the current C balance. A long-term comprehensive analysis based on forest inventory data showed, for example that between 1961 and 1998 the stock of carbon on forest lands in Russia increased by 1580 $MtCO_2$/yr mostly due to changing patterns of land-use with half of the net change found in soils (Shvidenko and Nilsson 2003). For the decade 1990-2000 the range of C sink values for Russia is 370-740 $MtCO_2$/yr (Nisson *et al.*, 2000, Izrael *et al.*, 2002, Lelyakin *et al.,* 1997, see also Table 9.3) with future projections ranging between the decline in C sink by 440 $MtCO_2$/yr in case of significant increase in logging (Izrael *et al.,* 1997) to additional sink of up to 720 $MtCO_2$/yr in case of strong positive impact of global warming on carbon sink in boreal forests (Lelyakin *et al.,* 1997).

9.4 Assessment of Mitigation Options

9.4.1 Conceptual introduction

All organic carbon stored in the above and belowground biomass, dead wood, litter and soil carbon pools of terrestrial ecosystems has, at one point, been removed from the atmosphere through photosynthesis. An estimated 220,000 $MtCO_2$/yr cycle through forest ecosystems globally as Net Primary Productivity (NPP), but only the net balance of the large emission and removal fluxes contributes to net C storage or net C losses. Net primary production and hence carbon sequestration in forests[2] occurs through photosynthesis that removes carbon dioxide from the atmosphere (1 m^3 of wood stores ~ 0.82 tCO_2). Depending on the stage of stand development, individual stands are either sources or sinks of carbon. For most of the immature and mature stages of stand development, stands are C sinks, and at very old ages, ecosystem C will either decrease or continue to slowly increase with accumulations mostly in dead organic matter and soil C pools. In the years following clear-cut harvest or other major disturbances, the losses from decay of residual dead organic matter exceed the C uptake by regrowing trees. While individual stands in a forest may be sources or sinks, the carbon balance of the forest is determined by the sum of the net balance of all stands. The theoretical maximum carbon storage (saturation) in a forested landscape is attained when all stands are in old-growth state, but this rarely occurs as natural or human disturbances maintain stands of various ages within the forest.

Terrestrial carbon fluxes are characterised by relatively small rates of C uptake per hectare, operating over long periods of time, that are interrupted by periods of rapid and high releases of C during disturbances or harvest. Forest management activities aimed at mitigating the rate of carbon increase in the atmosphere include targeted measures to alter the net balance by reducing sources and increasing sinks.

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[2] In this chapter, stand refers to an area of trees of similar characteristics (e.g. species, age, stand structure or management regime) while forest refers to a larger estate comprised of many stands.

Forest management activities can, however, affect the net GHG balance of other sectors (Figures 9.7 and 9.3). For example stopping all forest harvest results in increases in forest C stocks, but reduces the amount of timber and fiber available to meet other societal needs, which would be replaced by other energy-intensive products (concrete, aluminium, steel, plastics) with higher GHG emissions. Afforestation or avoided deforestation activities aimed at increasing or maintaining forest area may affect the net GHG balance in other sectors as well if, for example, forest expansion reduces agricultural land area and leads to farming practices with higher emissions (e.g. more fertiliser use), conversion of land for cropland expansion elsewhere, or increased imports of agricultural products (McCarl and Schneider, 2001).

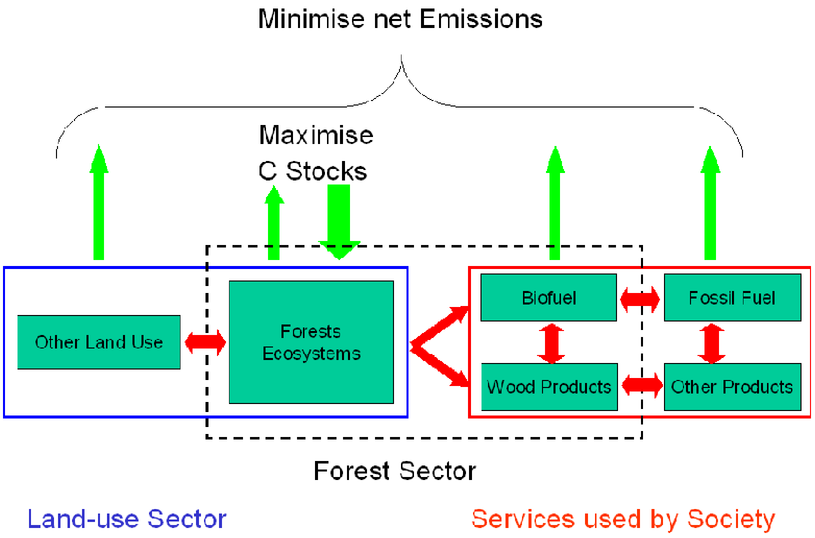


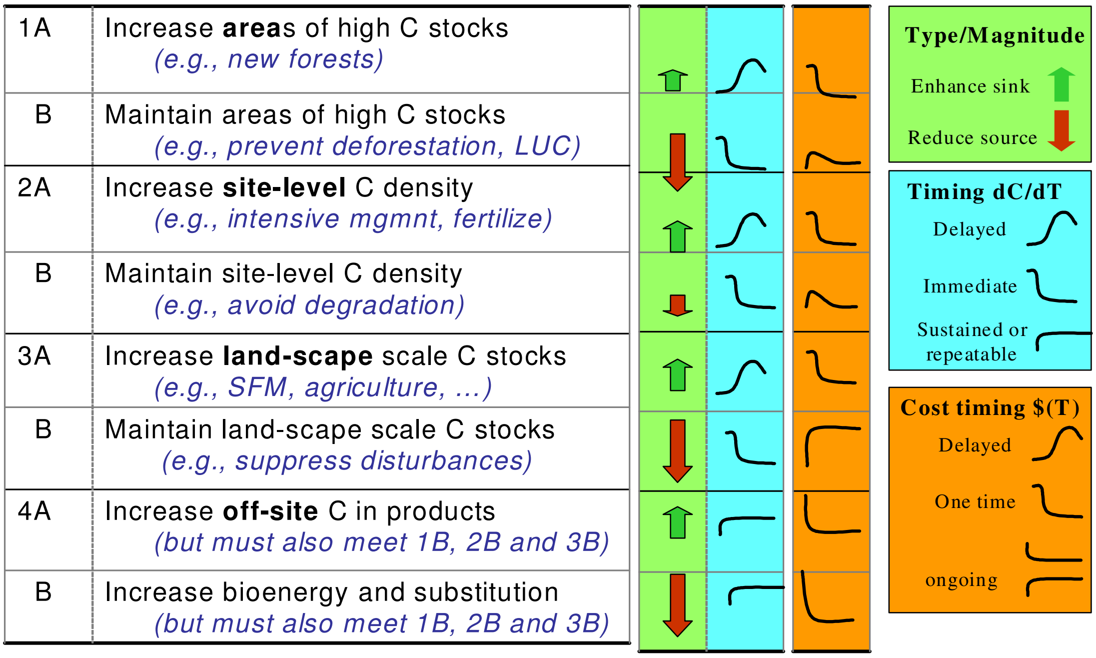
Figure 9.7: *Mitigation strategies aimed at maximizing carbon storage in forest ecosystems need to be assessed with regard to their impacts on net GHG emissions across all sectors. The optimum strategy may change as the system boundaries are expanded from forest ecosystems, to the entire forest sector, to all services provided by the forest sector, and ultimately to all land-use decisions*

Mitigation strategies involving forests ideally should assess the implications on net greenhouse gas emissions across all affected sectors. Forest mitigation strategies should be assessed within the framework of sustainable forest management, and with consideration of the climate impacts of other changes such as albedo and the hydrological cycle (Marland *et al.*, 2003). At present, however, few studies if any provide such comprehensive assessment.

For the purpose of this discussion, the options available to reduce emissions by sources and/or increase removals by sinks in the forest sector are grouped into four general categories (Figure 9.8):

- **maintaining or increasing the forest area** through the avoidance of deforestation and degradation and through afforestation/reforestation;
- **maintaining or increasing the stand-level carbon density** (tonnes of C per ha) through the avoidance of forest degradation and through planting, site preparation, tree improvement, fertilization, uneven-aged stand management, or other silvicultural techniques that contribute to sustainable forest management;
- **maintaining or increasing the landscape-level carbon density** using forest conservation, longer forest rotations, fuel management, protection against fire and insects, and

- **increasing carbon stock in wood products and enhancing product substitution** using forest-derived biomass to substitute products with high fossil fuel requirements and increasing the use of biomass-derived energy to substitute fossil fuels.



1A	Increase **areas** of high C stocks *(e.g., new forests)*
B	Maintain areas of high C stocks *(e.g., prevent deforestation, LUC)*
2A	Increase **site-level** C density *(e.g., intensive mgmnt, fertilize)*
B	Maintain site-level C density *(e.g., avoid degradation)*
3A	Increase **land-scape** scale C stocks *(e.g., SFM, agriculture, …)*
B	Maintain land-scape scale C stocks *(e.g., suppress disturbances)*
4A	Increase **off-site** C in products *(but must also meet 1B, 2B and 3B)*
B	Increase bioenergy and substitution *(but must also meet 1B, 2B and 3B)*

Figure 9.8: *Conceptual diagram of the options available in the forest sector and their characteristics in affecting the sink, their timing of effects and the timing of costs. (Apps 2006)*

Each mitigation option has a characteristic time sequence of actions and (carbon) benefits (Figure 9.8). Relative to a baseline, the largest short-term gains are always achieved through mitigation options aimed at avoidance of emissions (e.g. avoidance of deforestation, degradation, fire protection, slashburning, etc.). But once an emission has been avoided, e.g. not deforesting a mature forest, C stocks on that forest will be merely maintained or increased slightly. In contrast, the benefits from afforestation and reforestation accumulate over years to decades but require up front action and expenses. And depending on the required site preparation afforestation and reforestation may even lead to short-term emissions. Most forest management activities aimed at enhancing sinks require up-front investments and the duration and magnitude of their carbon benefits differs by region, type of action and initial condition of the forest. In the long term, a forest sustainable management strategy aimed at maintaining or increasing forest carbon stocks, while producing an annual yield of timber, fiber or energy from the forest, will generate the largest sustained mitigation benefit.

The reduction in fossil fuel use in forest management activities, forest nursery operations, transportation and industrial production provides additional opportunities that are similar to those in other sectors and will not be discussed here. The options available in agro-forestry systems are conceptually similar to those in other parts of the forest sector and in the agricultural sector (e.g. non-CO_2 GHG emission management). Mitigation using urban forestry includes increasing the carbon density in settlements but indirect effects must also be evaluated such as reducing heating and cooling energy use in houses and office buildings, and changing the albedo of paved parking lots and roads.

Box 9.2

The mitigation scenario in energy sector assumes a process that burns 200 tC per year initially. At time zero an emission reduction activity is implemented that reduces the emissions to 100 tC per year, so that the annual mitigation is 100 tC. Assuming that in the baseline scenario (without activity) the greenhouse-gas efficiency improves by 1% per year, the effect of mitigation project declines by 1% annually. After 50 years (a likely lifetime of large power plants) another emission-reduction activity takes place, reducing emissions by another 50% and the emission reductions for the subsequent 70 years are projected assuming 1% annual increase in greenhouse gas efficiency for the baseline scenario as above (Figure 9.9).

Carbon sequestration in a planted forest assumes a conservative rate of 4 tCO_2 ha^{-1} per year over 100 ha. Each year 0.5% of the forest plantation area is lost to fire; the entire forest area that was not burned is harvested after 50 years, after that the harvested and the burned area re-grows and sequesters carbon at the same rate. The net mitigation effect shown on graph includes carbon sequestration in live tree biomass only (no soils or detritus) and product and energy substitution with harvested wood (Schlamadinger and Marland, 1996). The dotted line shows sequestration in a planted forest with no timber harvest and fire on 0.5% of the forest area in each year.

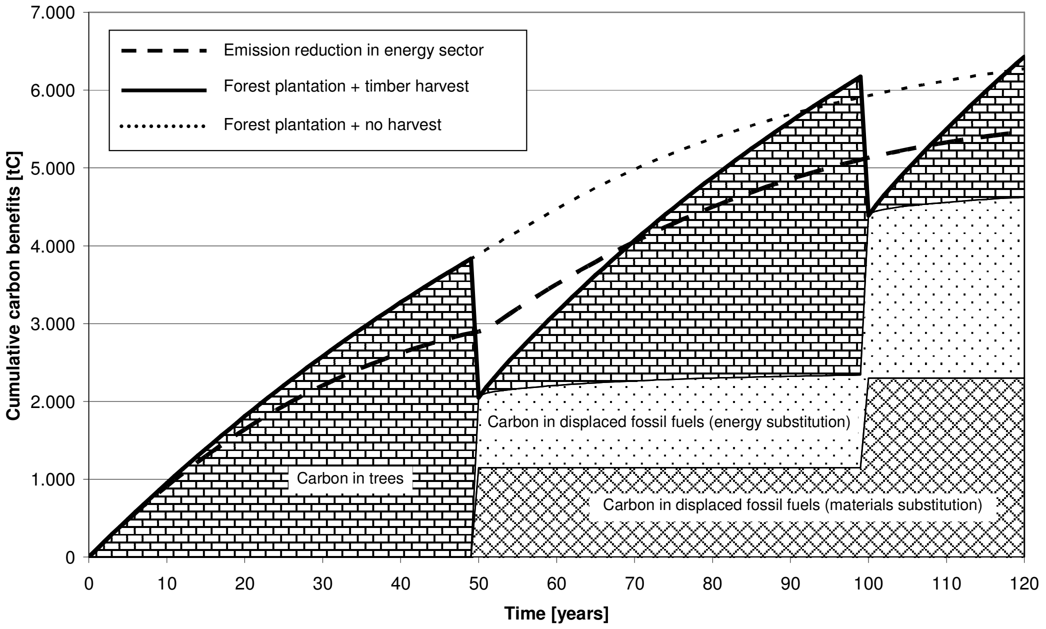


Figure 9.9: *Conceptual diagram of the options available in the forest sector and their characteristics in af ing the sink, their timing of effects and the timing of costs. (Apps 2006).*

9.4.2 Description of mitigation measures

Below, the mitigation options are described case by case. However, one should keep in mind that a portfolio of measures may be preferable. The development of a portfolio of forest mitigation options should keep in mind the long-term dynamics of the carbon benefits of the various mitigation options. For example, a portfolio could combine avoided deforestation with an afforestation programme. Avoided deforestation brings large immediate benefits that are not sustained into the future while afforestation yields small (or negative) initial benefits in the short term, but generates a continuing C sink on the afforested areas. The portfolio should also consider the benefits of C storage in HWP and bioenergy from forest biomass.

9.4.2.1 Maintaining or increasing forest area: Reducing deforestation and degradation

Deforestation, the human-induced conversion of forest to non-forest land uses, is typically associated with large immediate reductions in forest C stock, through land clearing. Biomass is either transferred out of the forest in the form of wood products , or burned on site. It is usually followed by continued longer-term losses of C. Dead organic matter pools decrease due to reduced litter input, and increased decomposition because of soil disturbance. Forest degradation, the reduction in forest biomass through non-sustainable harvest or land-use practices, can also result in substantial reductions of forest C stocks from selective logging, fire and other anthropogenic disturbances, and fuelwood collection (Nepstad *et al.*, 1999; Asner *et al.*, 2005) Degradation can be difficult to monitor using standard remote sensing techniques used for deforestation,, since the forest canopy often remains even though a substantial fraction of forest C can be removed via degradation (DeFries *et al.*, 2005).

Deforestation and degradation can in some circumstances be delayed or avoided through complete protection of forests (Soares-Filho *et al.*, 2004), sustainable forest management policies and practices, or reduced economic returns from deforestation compared to other activities (e.g., rising crop yields and/or prices). Protecting forest from all harvest typically results in maintained or increased forest C stocks but also reduces the wood and land supply to meet other societal needs. But even when fully protecting the forest C stocks emissions will occur as each natural system exists of both emissions and removals over time. Ideally, sustainable forest management can provide a supply of forest products and services for the long term while maintaining or increasing forest carbon stocks.

Avoided deforestation and degradation is the forest mitigation option with the largest and most immediate C stock impact in the short term per ha and per year globally (see Section 9.2 and global mitigation assessments below), since large C stocks (c. 350-900 tCO_2/ha) are not emitted. Avoided deforestation needs to be expressed in comparison to a baseline of anticipated rates of deforestation, and leakage needs to be considered in GHG accounting. The mitigation costs of avoided deforestation depend on the cause of deforestation (timber or fuelwood extraction, conversion to agriculture, settlement or infrastructure), the opportunity cost of forest (i.e., returns from its potential alternative uses), and on any compensation paid to the individual or institutional landowner to change land use practices. These costs vary by country or region (Sathaye *et al.,* in press), as discussed below.

9.4.2.2 Maintaining or increasing forest area: Afforestation/Reforestation

Afforestation and reforestation are the direct human-induced conversion of non-forest to forest land through planting, seeding and/or the human-induced promotion of natural seed sources. The two terms are often distinguished by how long the non-forest condition has prevailed (e.g., under the Marrakech Accords to the Kyoto Protocol). To date, carbon sequestration has rarely been the primary driver of afforestation or reforestation, but future changes in C valuation could result in large increases in the rates of afforestation (US EPA, 2005). While C stock losses of deforestation are immediate and large on a per hectare basis, C uptake resulting from afforestation is relatively slow--20-50 years in most tropical and temperate moderate growing conditions, to a century or more at high latitudes or elevations. Clearing of biomass and site preparation prior to afforestation at the forest stand scale may lead to short-term C losses, so it is important to quantify the gross changes in forest area and emissions (not just net changes).

Afforestation typically leads to increased C density in biomass and dead organic matter, and to a lesser extent in soil C pools, whose small, slow increases are often hard to detect within the uncertainty ranges (Chen *et al.,* 2000, Paul *et al.,* 2003 a,b, Zhang and Xu 2003). However, if the initial soil C stocks are low (e.g., after prolonged cultivation), then afforestation can yield considerable soil C accumulation rates (e.g., Post and Kwon (2000) report rates of 0.3 to 0.4 Mg C ha^{-1} y^{-1}. Once harvesting of afforested land commences, forest C may be transferred into wood products that store C for years to many decades before release.

Afforestation costs vary by the cost of available land (Robertson *et al.,* 2004), largely driven by its alternative uses or opportunity costs, site preparation, and labor costs, and vary by land type and region. A major economic constraint to afforestation is the high initial investment to establish new stands coupled with the several-decade delay until afforested areas generate revenue. The secondary benefits of afforestation, however, can be as high as afforestation cost, according to a review study by Richards and Stokes (2004).The economic potential of afforestation depends largely on the availability of agricultural land under land use competition, and the C market price signal. Van Kooten *et al.,*(2004) concludes that economic costs are largely underestimated and will restrict both forestry activities and bioenergy opportunities. Loza-Balbuena (2005) has also highlighted the importance of economic factors such as land value and discount rates.

9.4.2.3 Forest management to increase stand- and landscape-level C density

Forest stands are C sinks for most of the immature and mature stages of stand development. In the years following clear-cut harvest or other major disturbances, the losses from decay of residual dead organic matter exceed the C uptake from regrowing trees. Forest management activities to increase stand-level forest C stocks include harvest systems that maintain partial forest cover, minimise losses of dead organic matter (including slash) or soil C by reducing soil erosion, and by avoiding slash burning and other high-emissions activities. Assisting regeneration after harvest or natural disturbances accelerates tree growth and reduces C carbon losses. Silvicultural options to increase stand-level C density include extending forest rotation lengths (i.e., age of harvest) beyond maximum sustainable yield, tree species selection and clonal improvements, avoidance of regeneration delay (Figure 9.10 and & 9.11), fertilization, and drainage and irrigation.

All forest management activities aimed at increasing stand level C density are common practices that are technically feasible, but the extent and area over which they can be implemented could be increased considerably. Economic considerations are typically the main constraint, since retaining additional C on site may delay production of and revenues from wood products for markets. Those activities aimed at increasing sinks all operate over long time scales and at relatively low rates, while those activities aimed at reducing sources (e.g. avoid slash burning) can result in substantial average stock increases in the short term.

The effects on GHG mitigation are generally positive, but the magnitude and the duration of the benefits depend on the specific measure and local conditions. For example, the potential benefits of C sequestration can be diminished where increased use of fertiliser causes increased emissions of N_2O. Also, drainage of forest soils, and specifically of organic soils like peatlands may lead to substantial carbon loss from the soil due to enhanced respiration (e.g., Harden *et al.,* 2000, Ikkonen *et al.,* 2001), although counterevidence also suggest increased peat C accumulation in case of moderate drainage (Minkkinen *et al.,* 2002). Thus a net GHG accounting approach is necessary.

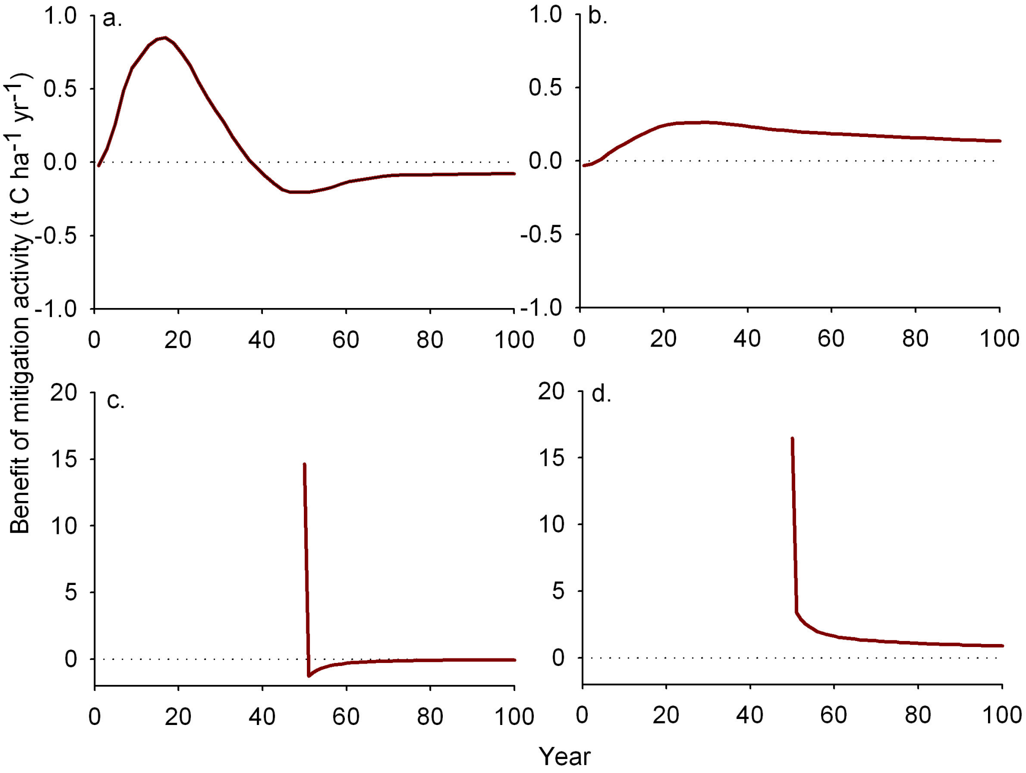


Figure 9.10: *Temporal patterns of cumulative emission reductions in energy sector (dashed line) and carbon sequestration in an afforestation project (solid line for option with timber harvest, dotted line for no-harvest option). Given the equal initial mitigation effect (e.g. 100 tC/yr), the long-term cumulative emission reductions in the energy sector and carbon sequestration on land follow a similar pattern with a tendency to saturate over long term (>100 years)*

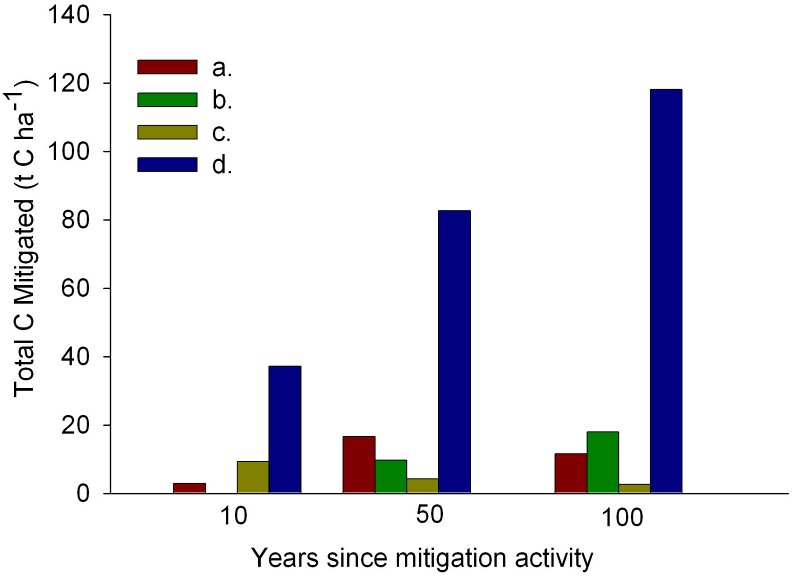


Fig. 9.11: *Examples of the time dynamics of the carbon benefits of stand-level mitigation activities. The carbon benefit is calculated as the difference in annual net C balance of a baseline compared to the mitigation activity. a) avoided regeneration delay: a stand is planted immediately after clearcut thus*

reducing the regeneration delay. In the early years after the activity the planted stand takes up more carbon than the stand with natural regeneration, but after about 40 years the C uptake in the stand with natural regeneration is higher than the planted stand, thus the cumulative benefit decreases beyond that point. b) enhanced growth: where planting is done with higher yield growing stock the C benefit in creases in the years after planting and remains positive, c) avoided slash burn: Avoiding burning of slash left after clearcut logging yields a high initial benefit followed by years of higher decomposition emissions. d) avoided deforestation equally yields a high initial benefit followed by years of continuing benefits as the protected stand continues to accumulate some carbon, while the deforested stand continues to lose C. These scenarios are examples for illustrative purposes - the absolute values of the C benefit will differ between regions and ecosystem types. Although the absolute values of the C benefit will differ between sites, regions and species, the relative carbon benefits of the four activities are ranked correctly. All graphs are based on simulation runs with the Carbon Budget Model of the Canadian Forest Sector (CBM-CFS3)

Landscape-level C stock changes are the sum of stand-level changes, and the impacts of forest management on C stocks ultimately need to be evaluated at the landscape-level. Forest conservation, i.e., the elimination of all harvest, will generally increase landscape-level C stocks, but reduce C in forest products. Increasing harvest rotation lengths has a positive influence in some carbon pools (e.g., tree boles) and negative in others (Liski *et al.*, 2001, Kurz *et al.*, 1998).

9.4.2.4 Increasing wood products carbon stock and product substitution

As discussed above (Figure 9.8), minimizing net greenhouse gas emissions in the forest sector could involve a portfolio of activities that includes consideration of both forest ecosystem C stocks and the ability of these systems to provide wood products that meet a variety of society's needs. Usually wood products stocks are small compared to C stocks in the forest ecosystem. Wood products derived from sustainably managed forests address the issue of saturation of forest carbon stocks: the annual harvest can be set equal or below the annual forest increment, thus allowing forest C stocks to be maintained or to increase while at the same time providing an annual flow of C to meet society's needs.

Harvest and transfer of carbon from forest to wood products avoids saturation of the forest ecosystem sink. Wood products are a C stock and serve to meet society's needs that would otherwise have to be met using concrete, steel, aluminium or plastics. The production of these alternatives is associated with greenhouse gas emissions that often exceed those from wood products.

The EU forest sector (Anon, 2005) suggests that a wooden house could contain up to 150 tonnes of CO2 and that each house built with timber instead of brick reduces carbon emissions by 10 tonnes CO2 because of avoided emissions from not producing steel and bricks. Studies in Australia suggest each new house could be built with a saving of 25 tCO2 eq if predominantly wood products were used (Anon, 2004). Using a cubic metre of wood rather than construction alternatives (concrete, blocks or bricks) results in an average of 0.8 tonnes of CO2 savings (see also Chapter 6, housing). However, Chapter 6 also notes that during the life time of a wooden building more energy is needed for heating and/or cooling. This would offset the savings from building houses with wood.

9.4.2.5 Bio energy

Forest biomass and 'waste' products from wood processing can be used to produce energy either as heat (steam) or electricity. There is an increasing research on the use of cellulosic materials to produce liquid fuels, such as ethanol and methanol. In its optimal model this is always done in a cascading mode where the raw material is first used for the highest quality application possible, and only at later stages used to generate energy (Masera *et al.,* 2003). Chapter 4 describes a number of bioenergy pathways to generate energy both directly (e.g. harvesting residues, processing wastes, construction and demolition waste) and via intermediate biofuels (e.g. wood pellets, bioethanol, biogas). The industrial use of bioenergy has increased greatly over the past decade: for example the pulp and paper sector uses black liquor, which was in the past considered a waste product, to generate electricity and steam.

Wood for bioenergy is globally an important energy carrier. In its non-industrial version, much of the global population depends on it for domestic heating and cooking. Large interest has arisen in the use of logging residues or additional fellings for production of commercial bio energy (IEA Bioenergy 2002). Residues, which consist of stem and branch waste and smaller residue occur in piles scattered throughout the forest. This residue is potentially recoverable, though is not currently used for energy to any significant degree due to the high collection and transportation cost. Also side effects on biodiversity should be considered.

The benefit of biomass for bioenergy is that the C emissions associated with fossil energy use are prevented. When sustainable harvested, bioenergy is much less carbon intensive than fossil fuels per unit of energy delivered (some emissions are still present as fossil fuels are often used for harvest, transport and processing). Chapter 4 in this reports estimates that if fossil fuels with an average carbon intensity at 75 tCO_2/TJ were used to provide the energy services presently provided by using 46 EJ of biomass (primary energy), about 3.7 $GtCO_2$ would be released to the atmosphere (assuming the same efficiency as for biomass and that all biomass is produced sustainably). Since much of the biomass is used less efficiently than a fossil-fuel replacement, the actual savings is lower".

The economics of bioenergy differ between the types of forest biomass used: salvaged wood following fire or insects, harvest residues, bark, sawdust, black liquor and other wood processing by products. The costs also differ based on the technology used to produce energy (see Chapter 4 for details). While some forms of bioenergy have in the past been considered economically not viable, the recent increases in fossil energy costs are creating new opportunities for increased bioenergy use.

9.4.3 Reference cases for forests globally

Land use is crucial in understanding and managing climate stabilization. Land use affects the global climate both through biogeophysical pathways (e.g. albedo) and biogeochemical pathways (CO2 emissions and sinks), but land use and its ecosystems are themselves affected by climate change as well. Despite these feedbacks and the large role of land use, this sector has received little attention in SRES (IPCC 2000). Widely accepted baselines are thus not available against which we could assess the literature on mitigation options.

Only a few global studies have focused on long-term (century) land use projections. The most comprehensive studies are the SRES implementation with the IMAGE model (Strengers *et al.*, 2004), the scenarios from the Global Scenarios Group (Raskin *et al.*, 2002), UNEP's Global Environment Outlook (GEO3, 2002) the Millennium Ecosystem Assessment (MEA, 2005), and the study by Kainuma *et al.,*(2003) with the AIM model.

Only the AIM and IMAGE models offer spatial resolution of mitigation. The coarseness of land use in the SRES scenarios was improved in the post SRES runs with IMAGE V2.2 (Strengers *et al.,* 2004). These runs (adapted by Brinkman *et al.,* 2005 for the current report) are depicted in Figure 9.12. Since each model has its own reference case assumptions and drivers of land use change, mitigation estimates generally are presented relative to a model's own reference case - not against a common baseline. Several key parameters of reference cases pertinent to projecting mitigation are discussed below, included deforestation projections, etc.

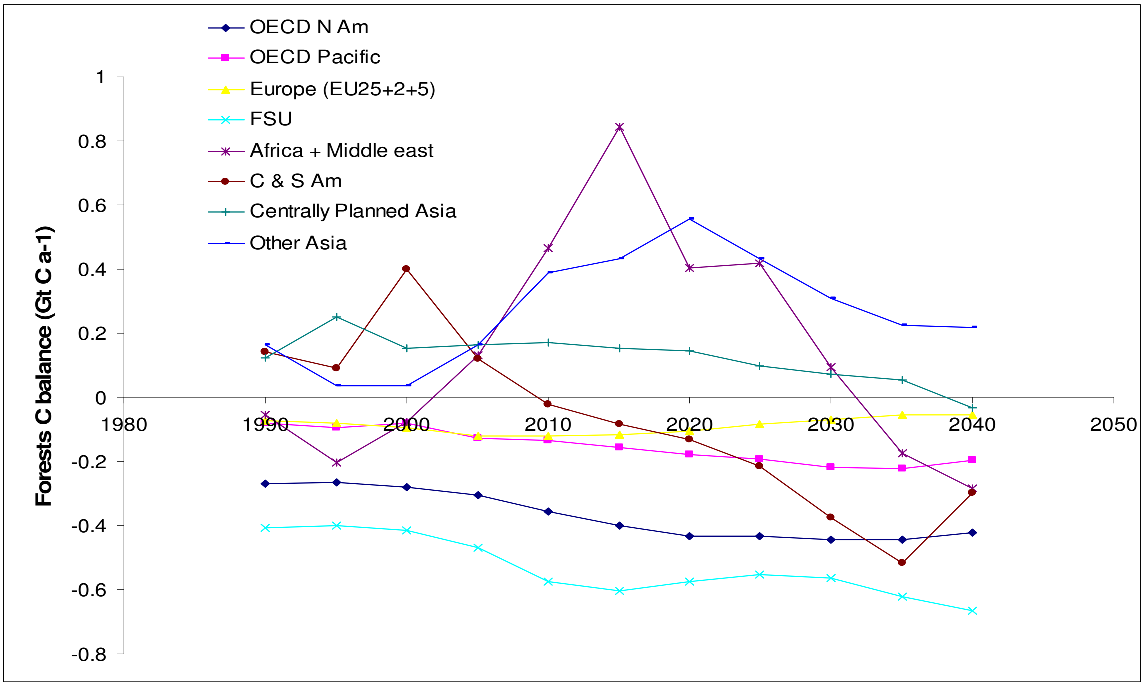


Figure 9.12: *Reference case example for forest C balance by global region, using the SRES A1f scenario, as depicted by IMAGE. Negative values = sink) (Brinkman et al., 2005, Strengers et al., 2004)*

9.4.4 Putting global and regional estimates in an economic perspective

In order to compare forestry mitigation potential with the potential in other sectors, estimates of the economic or market potential—rather than the biophyscial or technical potential--are needed. Evaluation of forestry mitigation options at the project, national and global scales is complicated by a number of factors, including which carbon pools are assessed (Van Kooten *et al.*, 2004), the carbon sequestration and emissions methods used (Prisley and Mortimer, 2004), the types of costs and benefits included (e.g., opportunity cost of land targeted for mitigation option) (Richards and Stokes, 2004), and which mitigation options are assessed.

Few studies within each of the three scales above, let alone across these scales, use consistent, directly comparable definitions, assumptions, and methods for estimation of mitigation potential. In addition, the eligibility of mitigation activities, carbon pools, and GHG accounting methods (e.g., GHG benefits relative to a baseline) is likely to be specified by any given mitigation policy or program window (e.g., the Clean Development Mechanism under Article 12, or the EU's Emissions Trading System) (Kolshus, 2001; Kurz et al, 2002).

Five types of mitigation potential are considered by the IPCC, In descending order from largest to smallest, they are (1) physical potential (the theoretical upper limit to mitigation), (2) technical potential (the amount emissions could be reduced or sequestration enhanced by implementing proven technologies or practices), (3) economic potential (cost-effective mitigation when non-market costs and benefits are included with market costs and benefits in assessing options), (4) enhanced market potential (baseline market potential enhanced by policies designed to promote market efficiency or reduce market or other hidden costs), and (5) market potential (mitigation expected to occur under forecast market conditions, including policies and measures in place at the time).

Evaluating existing forestry mitigation estimates in terms of these mitigation potential types is challenging. Clearly some fraction of the biophysical and of the technical potential could be realized for a given mitigation option, but no estimates of the full five potentials above are available. Several major review articles compare bottom-up engineering cost estimates with top-down sectoral model estimates of national and global forestry mitigation potential (e.g., Richards and Stokes, 2004; Kolshus, 2001). These studies generally evaluate the economic potential response by forest land owners or users to a potential market price for GHG benefits (carbon price), and do not directly compare technical vs. economic potential estimates.

Previous IPCC or other technical potential assessments, however, can be used for a range of biome and national contexts to provide estimates of the relationship between technical and economic potential. No estimates are available of the enhanced market or market potential, which take policies and measures into account. Only a limited number of actual studies performed to date are summarized in Table 9.3, and only results for carbon prices less than $200/tC are reported.

Some patterns emerge from the range of estimates reviewed. The technical potential estimates are generally larger than the economic potential, although some of the latter exceed the technical potential (since each are estimated using different assumptions, by different analysts). Economic models used for these analyses are capable of generating mitigation potential estimates in competition to other forestry or agricultural sector mitigation options, but generally do not specify or account for specific policies and measure and market penetration rates, etc, so few market potential estimates are generated. Many studies do not clearly state which of the potentials they are estimating.

While the range of economic potential as a percentage of technical potential is 2%-100% (the latter against al costs). This ratio varies with the carbon price assumed. At carbon prices less than $25/tC, the highest estimate of economic potential is 16% of the technical potential - a small fraction. At carbon prices from $100/tC to $183/tC, the range of economic potential is estimated to be 58%-150% of the technical potential (Table 9.4), a much higher fraction as C prices rise.

Table 9.4: *Technical and economic potential forestry mitigation estimation, by biome*

Geographic Region, and Mitigation Option (reference)	**Technical potential (Option potential with current practices, all available land) (Gt C/yr)**	**Economic potential (Single option, or multiple forest-agriculture sector options in competition) (Gt C/yr average)**	**Economic Potential as % of Technical Potential (%)**	**Reference and notes**
		Temperate and Boreal Regions		
A/R, Annex I	-0.007 to -0.046 [a] (26 midpoint)	-0.009 [b] in 2010, at $10/tC	35%	a. Noble and Scholes, 2001, and Kolshus, 2001 b. Sathaye et al., 2005; Sathaye et al., 2005a. Values are average/yr of cumulative C flux to given date. Scenario 2 mitigation results used, where C price is $10 in 2010 and rises at 5%/yr to reach $70/tC by 2050.
A, U.S., 15 year program	-0.091 to -0.203 [c] (-0.147 midpoint)	-0.003 [d] at $18.3/tC -0.022 [c] at $25/tC -0.086 [c] at $100/tC -0.220 [d] at $110/tC	2% 15% 58% 100%	c. Lewandrowski et al., 2004, using Birdsey, 1996 and cropland and pasture land available defined by Moulton and Richards, 1990 d. USEPA, 2005. Values are annualized over 2010-2100.
FM U.S.A.	-0.190 [f] biological opportunities on private timberland	-0.029 [d] in 2010, at $18.35/tC -0.105 in 2010, at $183/tC [d] -0.110 [g] (C price NA)	15% 58%	f) Vasievich and Alig, 1996, in Birdsey *et al.,* 2000 g) Richards and Stokes, 2004. Values are annual, for various time periods that vary by model results reported.
		Tropical Regions (including China)		
A/R, non-Annex I	-0.614 [a]	-0.096 [b] in 2040, at $10/tC rising at 5%/yr	16%	
D, non-Annex I	-1.7 [a] in 2010	-0.104 [b] in 2010, at $10/tC -0.177 [b] in 2040, at $10/tC rising at 5%/yr	6% NA	
FM, non-Annex I	-0.200 [h] in 2040	-0.090 [b] in 2040, at $10/tC rising at 5%/yr	4%	h) IPCC 2000
		Global Estimates		
A/R Global	-0.399 [a] in 2010	-0.042 [b] in 2010, at $10/tC -0.184 [b] in 2040, at $10/tC rising at 5%/yr	10% NA	
D Global	-176 [a] in 2010	-0.104 [b] in 2010, at $10/tC -0.177 [b] in 2040, at $10/tC rising at 5%/yr	6% NA	
Global A/FM/D	-2.3 [a]in 2010	-0.146 [b] in 2010, at $10/ -0.361 [b] in 2040, at $10/tC rising at 5%/yr	6% NA	

Notes: D: avoided deforestation, FM: forest management, A: afforestation, R: reforestation
NA: not available

Below we review global and then regional assessments of mitigation potential, and attempt to identify the type of potential estimated when possible.

9.4.5 Global assessments: top down approach

Since TAR several new global assessments of forest mitigation potential were produced. These include Benitez *et al.,* (2004, 2005), Waterloo *et al.,* (2003), Sohngen and Sedjo (in press), Sathaye *et al.,* (in press), Rokytianski *et al.,*(2006), Strengers *et al.,* (2006) and van Vuuren *et al.,* (in press). They provide us with independent estimates for the globe, and across countries and regions. Furthermore, they provide us in some cases with detailed insight into where mitigation options are likely to occur (Figure 9.13).

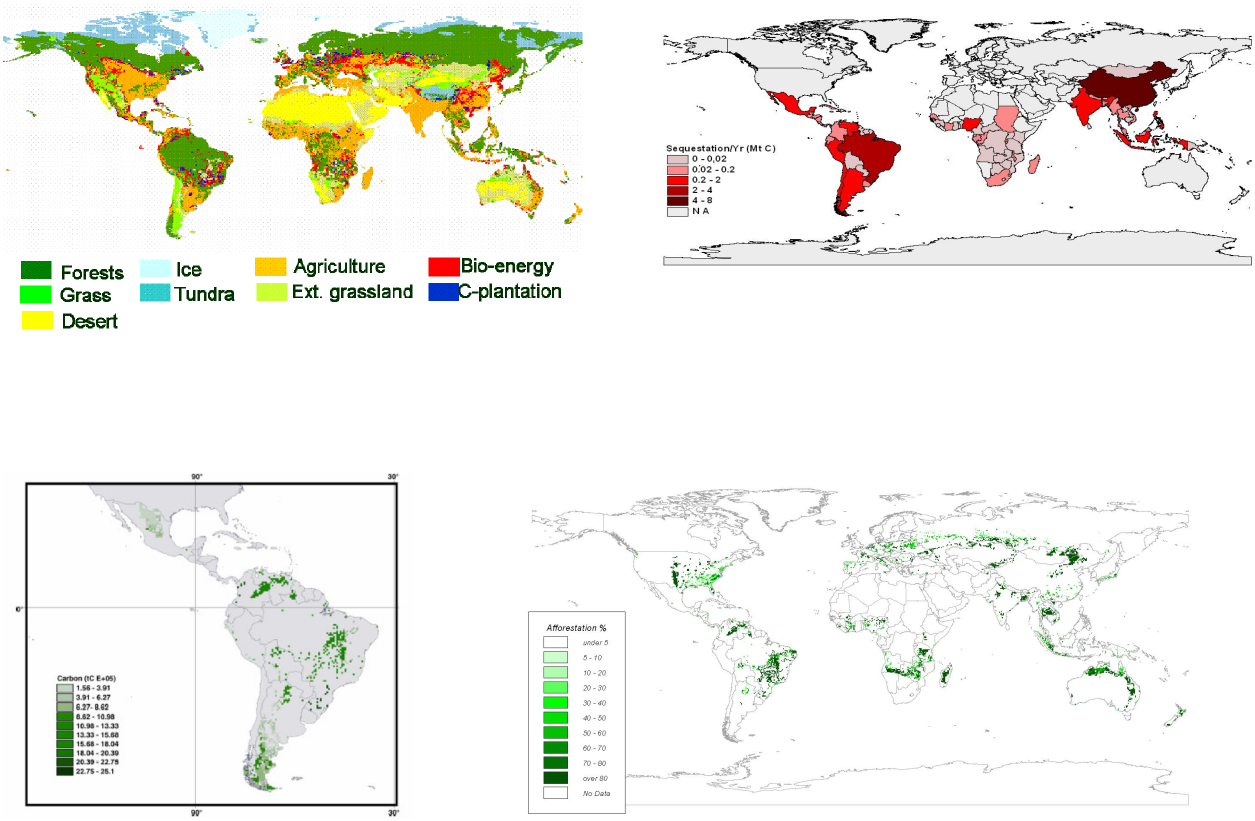


Figure 9.13: *A comparison of allocation of global afforestation activities in various studies (From top left, clock wise: Strengers et al.,2006, Waterloo et al.,2003 (only tropical countries), Sathaye et al.,in press, Benitez et al., 2006*

Several models produced roughly comparable assessments for a set of constant and rising C price scenarios in the EMF 21 modeling exercise, from \$1.4/tCO$_2$ in 2010 rising by 5% per year to 2100, to a \$27 constant CO$_2$ price, to \$20/tCO$_2$ rising by \$1.4/yr though 2050 then capped. This exercise allowed more direct comparison of modeling assumptions than usual. Caveats include: (1) models have varying assumptions about deforestation rates over time, land area in forest in 2000 and beyond, and land available for mitigation; and (2) have different drivers of land use change (e.g., population and GDP growth for IMAGE, vs. land rental rates and timber market demand for GTM).

Global models provide broad trends, but less detail than national or project analyses, and generally do not address implementation issues like transaction costs (likely to vary across activities, regions), barriers, and mitigation program rules, which will tend to drive mitigation potential downward toward true market potential. Consideration of political and financial risk of implementing forestation by country was undertaken by Benitez *et al.,* (2006), for example. They found that the quantity of sequestration was reduced by 59% once the risk index requiring higher returns to forestry investment in risky countries was incorporated.

At a price of 5$/t$CO_2$, Sathaye *et al.*, (in press) project a cumulative carbon gain of 10,400 MtCO_2 by 2050 (Figure 9.14b). The mitigation results from a combination of avoided deforestation (68%) and afforestation (32%). These results are typical in the very high fraction of mitigation from reduced deforestation. Sohngen and Sedjo (in press) estimate some 80% of C benefits in some scenarios from land use change (e.g. reduced deforestation and forestation) vs. some 20% from forest management.

Benitez *et al.,* (2006) project (Figure 9.14a) that at a price of \$13.6/tCO_2 the annual sequestration from afforestation and reforestation for the first 20 years amounts on average to 510 MtCO_2/yr. For the first 40 years, the average annual amounts to 805 MtCO_2/yr. The single price of \$13.6/tCO_2 that Benitez *et al.* (2005) use should make afforestation an attractive land use option in many countries, since it covers the range of median values for sequestration costs that Richards and Stokes (2004) give of \$1 to \$12/tCO_2, although Van Kooten *et al.,* (2004) present marginal cost results rising far higher from some studies. By 2050, Sathaye *et al.,* project cumulated carbon gains as an economic potential from afforestation and avoided deforestation together. In the moderate carbon price ranges, the cumulated carbon gains by 2050 add up to 55000 MtCO_2 to 102000 MtCO_2.

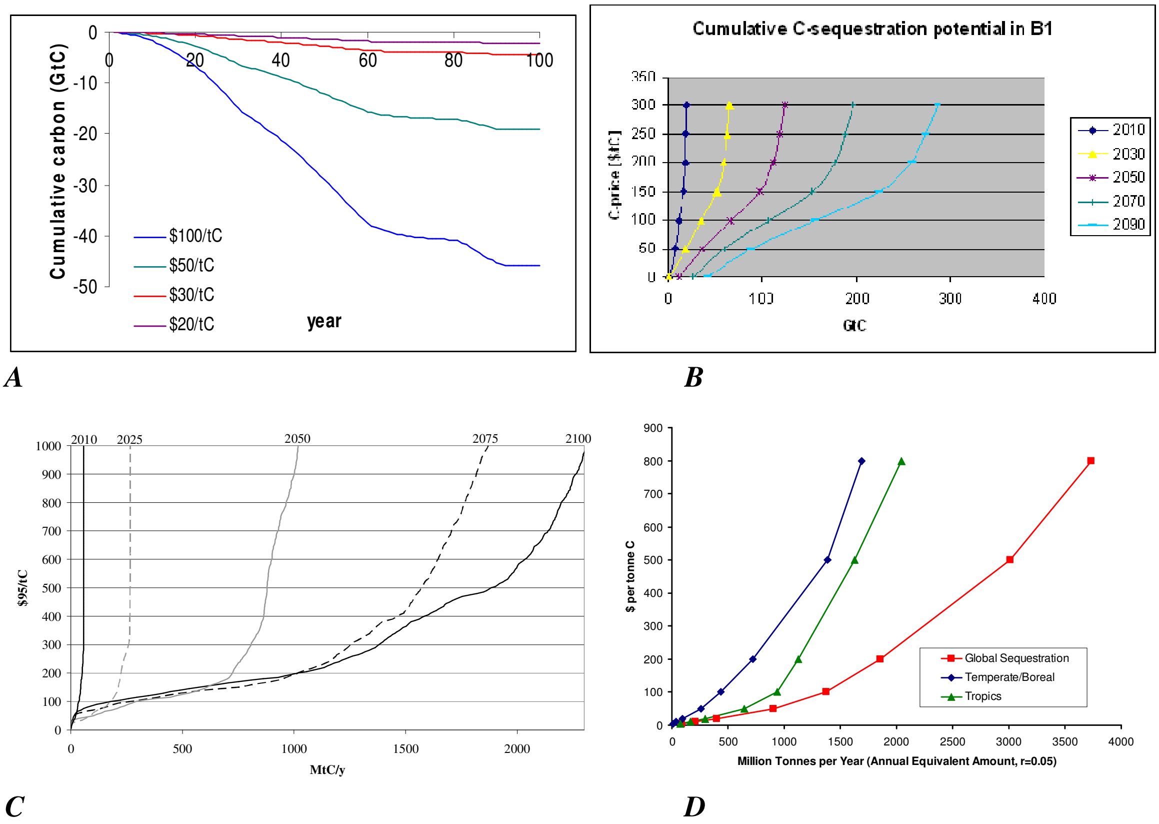


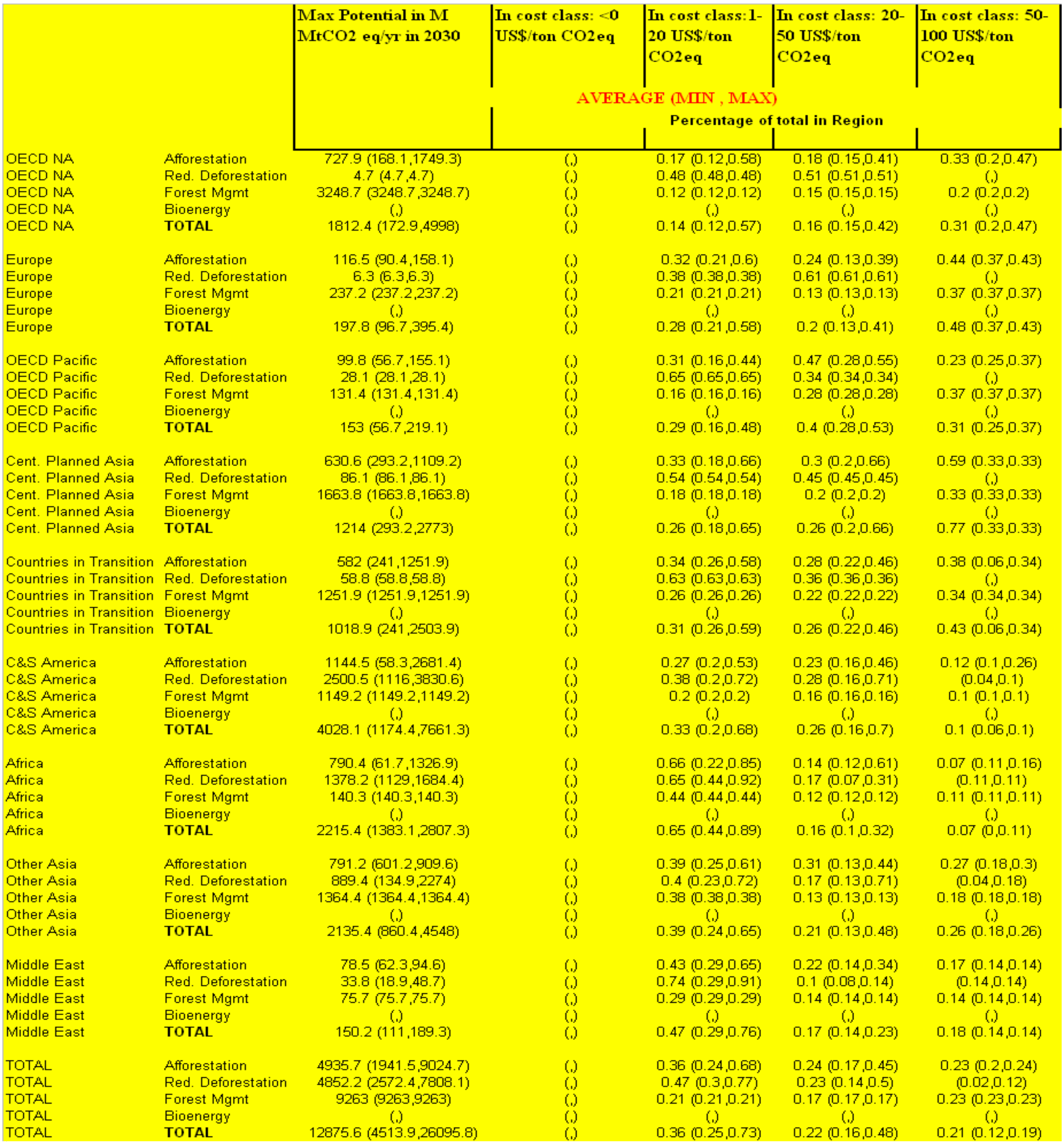
Figure 9.14: *Comparison of carbon supply curves globally. Graphs to be harmonized in final draft*

a. *cumulative C supply curves (Benitez et al., 2005): afforestation and reforestation.*
b. *Global cumulative C supply curves (Sathaye et al., in press) , afforestation as well as reducing deforestation*
c. *Annual cost-supply curves for abandoned agricultural land in the B2-scenario (Strengers et al.,2006).*
d. *Sohngen and Sedjo Marginal Cost Curves for Carbon Sequestration in Forests: Estimates for Boreal, Temperate, and Tropical Regions of the World." http://aede.osu.edu/people/sohngen.1/forests/ccforest.htm*

The spatial distribution of mitigation in response to carbon price signals is generally consistent across models and studies, and is presented in Figure 9.13. Several models generally report at the regional level, and project strong avoided deforestation in Africa, the Amazon, and to a lesser extent in SE Asia (where land opportunity costs in the timber market are relatively high). Benitez *et al.,* (2005) use datasets resolved to a 0.5° global grid to map the geographic distribution of forestation, adjusted by country risk estimates, under a $50/tC price. Forestation activity in their results is not evenly distributed, but is clustered in bands in the SE USA, SE Brazil and northern South America, West Africa, north of Botswana and East Africa, the steppe zone grasslands from Ukraine through European Russia, northeastern China, and parts of India, SE Asia, and northern Australia. Hence forest mitigation is likely to be patchy and not evenly distributed, but predictable using an overlay of land characteristics, land rental rates and opportunity costs, varying country risk assessment (e.g., as in Benetiz et al., 2005), and infrastructure capacity.

Table 9.5 summarizes mitigation results for four major global forest analyses for a single near-term date of 2030: two forest sector models (GTM (Sohngen and Sedjo, in press; and GCOMAP (Sathaye *et al.*, in press), one recent detailed spatially resolved analysis of forestation (Benitez et al, 2006), and one integrated assessment model with detail for the forest sector (IMAGE 2.2, van Vuuren et al, in press). These studies offer roughly comparable results, including global coverage of the forest sector, and land use competition across at least two forest mitigation options (except Benitez *et al.*). All but the Benitez *et al.,* study have been compared by the modeling teams in the EMF 21 modeling exercise as well.

Table 9.5: *Potential Carbon Sequestration from global forestry actions. Results indicate annual amount sequestered, above business as usual, in the year 2030. Note that results for individual components of total sequestration do not necessarily sum to total regional sequestration because not all models calculate all components. Models include GCOMAP (Sathaye et al., 2006); IIASA - DIMA (Benitez et al. 2006); and Global Timber Model (Sohngen and Sedjo, 2006)*



		Max Potential in M MtCO2 eq/yr in 2030	In cost class: <0 US$/ton CO2eq	In cost class:1-20 US$/ton CO2eq	In cost class: 20-50 US$/ton CO2eq	In cost class: 50-100 US$/ton CO2eq
				AVERAGE (MIN , MAX)		
				Percentage of total in Region		
OECD NA	Afforestation	727.9 (168.1,1749.3)	(,)	0.17 (0.12,0.58)	0.18 (0.15,0.41)	0.33 (0.2,0.47)
OECD NA	Red. Deforestation	4.7 (4.7,4.7)	(,)	0.48 (0.48,0.48)	0.51 (0.51,0.51)	(,)
OECD NA	Forest Mgmt	3248.7 (3248.7,3248.7)	(,)	0.12 (0.12,0.12)	0.15 (0.15,0.15)	0.2 (0.2,0.2)
OECD NA	Bioenergy	(,)	(,)	(,)	(,)	(,)
OECD NA	**TOTAL**	1812.4 (172.9,4998)	(,)	0.14 (0.12,0.57)	0.16 (0.15,0.42)	0.31 (0.2,0.47)
Europe	Afforestation	116.5 (90.4,158.1)	(,)	0.32 (0.21,0.6)	0.24 (0.13,0.39)	0.44 (0.37,0.43)
Europe	Red. Deforestation	6.3 (6.3,6.3)	(,)	0.38 (0.38,0.38)	0.61 (0.61,0.61)	(,)
Europe	Forest Mgmt	237.2 (237.2,237.2)	(,)	0.21 (0.21,0.21)	0.13 (0.13,0.13)	0.37 (0.37,0.37)
Europe	Bioenergy	(,)	(,)	(,)	(,)	(,)
Europe	**TOTAL**	197.8 (96.7,395.4)	(,)	0.28 (0.21,0.58)	0.2 (0.13,0.41)	0.48 (0.37,0.43)
OECD Pacific	Afforestation	99.8 (56.7,155.1)	(,)	0.31 (0.16,0.44)	0.47 (0.28,0.55)	0.23 (0.25,0.37)
OECD Pacific	Red. Deforestation	28.1 (28.1,28.1)	(,)	0.65 (0.65,0.65)	0.34 (0.34,0.34)	(,)
OECD Pacific	Forest Mgmt	131.4 (131.4,131.4)	(,)	0.16 (0.16,0.16)	0.28 (0.28,0.28)	0.37 (0.37,0.37)
OECD Pacific	Bioenergy	(,)	(,)	(,)	(,)	(,)
OECD Pacific	**TOTAL**	153 (56.7,219.1)	(,)	0.29 (0.16,0.48)	0.4 (0.28,0.53)	0.31 (0.25,0.37)
Cent. Planned Asia	Afforestation	630.6 (293.2,1109.2)	(,)	0.33 (0.18,0.66)	0.3 (0.2,0.66)	0.59 (0.33,0.33)
Cent. Planned Asia	Red. Deforestation	86.1 (86.1,86.1)	(,)	0.54 (0.54,0.54)	0.45 (0.45,0.45)	(,)
Cent. Planned Asia	Forest Mgmt	1663.8 (1663.8,1663.8)	(,)	0.18 (0.18,0.18)	0.2 (0.2,0.2)	0.33 (0.33,0.33)
Cent. Planned Asia	Bioenergy	(,)	(,)	(,)	(,)	(,)
Cent. Planned Asia	**TOTAL**	1214 (293.2,2773)	(,)	0.26 (0.18,0.65)	0.26 (0.2,0.66)	0.77 (0.33,0.33)
Countries in Transition	Afforestation	582 (241,1251.9)	(,)	0.34 (0.26,0.58)	0.28 (0.22,0.46)	0.38 (0.06,0.34)
Countries in Transition	Red. Deforestation	58.8 (58.8,58.8)	(,)	0.63 (0.63,0.63)	0.36 (0.36,0.36)	(,)
Countries in Transition	Forest Mgmt	1251.9 (1251.9,1251.9)	(,)	0.26 (0.26,0.26)	0.22 (0.22,0.22)	0.34 (0.34,0.34)
Countries in Transition	Bioenergy	(,)	(,)	(,)	(,)	(,)
Countries in Transition	**TOTAL**	1018.9 (241,2503.9)	(,)	0.31 (0.26,0.59)	0.26 (0.22,0.46)	0.43 (0.06,0.34)
C&S America	Afforestation	1144.5 (58.3,2681.4)	(,)	0.27 (0.2,0.53)	0.23 (0.16,0.46)	0.12 (0.1,0.26)
C&S America	Red. Deforestation	2500.5 (1116,3830.6)	(,)	0.38 (0.2,0.72)	0.28 (0.16,0.71)	(0.04,0.1)
C&S America	Forest Mgmt	1149.2 (1149.2,1149.2)	(,)	0.2 (0.2,0.2)	0.16 (0.16,0.16)	0.1 (0.1,0.1)
C&S America	Bioenergy	(,)	(,)	(,)	(,)	(,)
C&S America	**TOTAL**	4028.1 (1174.4,7661.3)	(,)	0.33 (0.2,0.68)	0.26 (0.16,0.7)	0.1 (0.06,0.1)
Africa	Afforestation	790.4 (61.7,1326.9)	(,)	0.66 (0.22,0.85)	0.14 (0.12,0.61)	0.07 (0.11,0.16)
Africa	Red. Deforestation	1378.2 (1129,1684.4)	(,)	0.65 (0.44,0.92)	0.17 (0.07,0.31)	(0.11,0.11)
Africa	Forest Mgmt	140.3 (140.3,140.3)	(,)	0.44 (0.44,0.44)	0.12 (0.12,0.12)	0.11 (0.11,0.11)
Africa	Bioenergy	(,)	(,)	(,)	(,)	(,)
Africa	**TOTAL**	2215.4 (1383.1,2807.3)	(,)	0.65 (0.44,0.89)	0.16 (0.1,0.32)	0.07 (0,0.11)
Other Asia	Afforestation	791.2 (601.2,909.6)	(,)	0.39 (0.25,0.61)	0.31 (0.13,0.44)	0.27 (0.18,0.3)
Other Asia	Red. Deforestation	889.4 (134.9,2274)	(,)	0.4 (0.23,0.72)	0.17 (0.13,0.71)	(0.04,0.18)
Other Asia	Forest Mgmt	1364.4 (1364.4,1364.4)	(,)	0.38 (0.38,0.38)	0.13 (0.13,0.13)	0.18 (0.18,0.18)
Other Asia	Bioenergy	(,)	(,)	(,)	(,)	(,)
Other Asia	**TOTAL**	2135.4 (860.4,4548)	(,)	0.39 (0.24,0.65)	0.21 (0.13,0.48)	0.26 (0.18,0.26)
Middle East	Afforestation	78.5 (62.3,94.6)	(,)	0.43 (0.29,0.65)	0.22 (0.14,0.34)	0.17 (0.14,0.14)
Middle East	Red. Deforestation	33.8 (18.9,48.7)	(,)	0.74 (0.29,0.91)	0.1 (0.08,0.14)	(0.14,0.14)
Middle East	Forest Mgmt	75.7 (75.7,75.7)	(,)	0.29 (0.29,0.29)	0.14 (0.14,0.14)	0.14 (0.14,0.14)
Middle East	Bioenergy	(,)	(,)	(,)	(,)	(,)
Middle East	**TOTAL**	150.2 (111,189.3)	(,)	0.47 (0.29,0.76)	0.17 (0.14,0.23)	0.18 (0.14,0.14)
TOTAL	Afforestation	4935.7 (1941.5,9024.7)	(,)	0.36 (0.24,0.68)	0.24 (0.17,0.45)	0.23 (0.2,0.24)
TOTAL	Red. Deforestation	4852.2 (2572.4,7808.1)	(,)	0.47 (0.3,0.77)	0.23 (0.14,0.5)	(0.02,0.12)
TOTAL	Forest Mgmt	9263 (9263,9263)	(,)	0.21 (0.21,0.21)	0.17 (0.17,0.17)	0.23 (0.23,0.23)
TOTAL	Bioenergy	(,)	(,)	(,)	(,)	(,)
TOTAL	**TOTAL**	12875.6 (4513.9,26095.8)	(,)	0.36 (0.25,0.73)	0.22 (0.16,0.48)	0.21 (0.12,0.19)

[1] Total potential is ecological potential based on running the models at a high carbon price.

[2] Columns represent the proportion available in the given cost class.

The global forestry models present a large potential for climate mitigation through forestry activities. The global annual economic potential by 2030 is estimated at 12,900 $MtCO_2$/yr (all price levels). 36% of this can be achieved under a price of 20 US$/$tCO_2$. Reduced deforestation in C&S

America is the most important measure in a single region with 2,500 $MtCO_2$/yr. The total for the region is by far the largest for C&S America with an estimated total potential of 4000 $MtCO_2$/yr.Apart from C&S America, the regions with a second largest potential of each around 2000 $MtCO_2$ are Africa, other Asia and OECD North America.

9.4.6 A specific case globally: commercial biomass for bio energy

9.4.6.1 Type of forest residues

There are various types of biomass that can be used for energy purposes, e.g. see Figure 4.3.6, Chapter 4. In this chapter we only focus on forest residues available for energy. Based on the place where the biomass becomes available for energy, one can distinguish three categories: primary residues (available after or with harvest), secondary residues (available when processing the forest products) and tertiary residues (available after end use). For forest residues there is furthermore an additional potential category, namely the flow that can be extracted additionally from managed forests.

One can distinguish following items that determine the potential availability of biomass for energy from the forestry sector:

- The amount of forest area and amount of wood harvested;
- The way the forests are managed and the resulting forest productivity;
- The recoverability of the residues, both primary, secondary and tertiary;
- The demand for other bio-material products that compete with the use of energy, e.g. for fiber, or for feedstock in the steel or petrochemical industry.
- The demand for fuelwood, mainly extracted from natural forests or produced with the purpose of using it for cooking, a situation that is particularly relevant for many developing countries.

9.4.6.2 The use of fuelwood

There are more than 2 billion people that rely on fuelwood for their basic energy supply. In around 16 countries -such as Bhutan and Nepal- the share of traditional biomass in the energy mixture is over 80% (UNDP/UNDESA/WEC, 2000). The total consumption of fuelwood is difficult to estimate as no regular records are kept, particularly regarding the large portion of fuelwood that is consumed out of the formal markets. Current estimates are mostly based on limited samples and extrapolations of per capita consumption in case studies. Projections for the future use are therefore also difficult to build. They depend on assumptions regarding economic development, population growth, interfuel substitution, and technological development regarding e.g. efficient cookstoves. Smeets *et al.*, (2005) present an overview of fuelwood estimates in the literature, indicating that the current use is around 1Gton fuelwood (around 16 EJ/y). For the short term (2020 – 2030) various estimates have been found, resulting in a range of around 1.1 – 2.3 Gton of fuelwood (17-34 EJ/y). These values are in the order of a few percent of current total primary energy use.

9.4.6.3 Assessment of future technical potential of biomass for energy from the forestry sector

Various studies have assessed the future potential of biomass for the forestry sector both at a global level; Yamamoto *et al.*, 2001; Smeets *et al.*, 2005; Fischer and Schrattenholzer, 2001; Hall et al, 1993; Williams, 1995; Dessus, 1992. Furthermore, some global biomass potential studies include forest residues aggregated with crop residue and waste (Swisher and Wilson, 1993; Sørensen, 1999). At a regional or national scale studies are more detailed and often also include economic considerations (Koopman, 2005; Bhattacharya, 2004; Lindner, *et al.*, 2005; Cuiping *et al.*, 2004; Nord-Larsen *et al.*, 2004; Walsh *et al.*, 1999.)

Most global assessment studies use a timeframe between 30-100 years. They combine bottom-up insight on the recoverability of residues and growth levels of forests with more top down analyses on the future demand for wood based on GDP and population factors. Residue to product ratios are used combined with recoverability factors. The latter are also used to assess the availability from the processing residues. Typical values used are between 25-50 % of the logging residues and between 33-80% of the processing residues. Lower values are often assumed for developing regions (Williams, 1995; Hall *et al.*, 1993; Yamamoto *et al.*, 2001; Smeets *et al.*, 2005, Sørensen, 1999, Swisher and Wilson, 1993). Higher values up to 100% have been assumed for instance for black liquor, a processing residue in the pulp and paper industry (Yamamoto *et al.,* 1999). At a global level, scenario studies on the future energy mixture (IPCC 2000, Sørensen 1999, WEC, 1998) have also included residues from the forestry sector in their energy supply (market potential). However in most scenario studies, the distinction between the contribution of residues and the contribution of energy crops is not made explicit. Most regional studies use comparable approaches, but have shorter timeframe and include more detail especially in the production levels of the forests, the ecological constraints and the costs.

9.4.6.4 Comparison of results

The technical potential of primary biomass sources given by the different global studies has been disaggregated by region in Table 9.6. In this table the low and high estimates of regionally aggregated results for the timeframe 2020-2050 are presented. This extended timeframe has been used as the results among the studies differ more than the variations among the timeframe. Based on this table one can conclude that biomass from forestry can contribute from about a few percent to about 15% (12 to 74 EJ/yr) of current primary energy consumption (400 EJ/yr).

Table 9.6. *The technical potential of primary biomass for bioenergy from forestry sector at a regional level for the year in EJ/y, in* $MtCO_{2\ avoided}$ [3]*2020-2050 based on: (Hall et al., 1993; Fischer and Schrattenholzer 2001; Ericsson and Nilsson 2006; Yoshioka et al., 2006; Dessus 1992; Yamamoto 2001; Williams 1995; Walsh et al., 1999; Smeets and Faaij 2005) The economic potential is in the range of 10-20% of these numbers*

Regions	EJ/yr		Avoided $MtCO_2$-eq	
	LOW	HIGH	LOW	HIGH
OECD			300	1200
North America	3	11		
OECD Europe	1	4		
Japan + Australia + NZ	1	3		
EIT			100	600
F USSR + Eastern Europe	2	10		
Non-OECD			400	3200
Latin America	1	21		
Africa	1	10		
Centrally planned Asia	1	5		
Other Asia	1	8		
Middle East	1	2		
World low and high estimates[#]	*12*	*74*	800	4900
World based on global studies	**14**	**65**		

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[3] When converted from m^3 or ton, we have used the assumptions of 0.58 ton/m^3 and a LHV of 15 GJ/ton, and a percentage of 49% C of dry matter wood. We furthermore assessed the amount of C avoided by assuming that it is used in a biomass combustion plant of 25% conversion efficiency and replaces a coal combustion plant with an efficiency of 35% and a CO_2 content of 94.6 $kgCO_2$/GJ.

The figures represent the sum of each row within Low and High estimates. However, this total may not be correct as the categories are different and the geographic aggregation is slightly different. Furthermore, differences between trade patterns may exist. Therefore we also included the range of separate global studies results in levels of 14-65 EJ/yr.

9.4.6.5 CO_2 emissions avoided

The CO_2-eq emissions avoided have been calculated using the baseline of the World Energy Outlook 2004 (see also Chapter 4 on methodology). It is assumed that the residues are used in the electricity sector and replace fossil fuels and are additional compared to the biomass already assumed in the baseline. Based on these calculations, the CO_2-eq emissions avoided range from 800 – 4900 Mt CO_2/yr for the year 2030. This is about 5-30% of the total CO_2 eq emissions originate from electricity production in 2030 as reported in the World Energy Outlook (2004).

9.4.6.6 Economic assessments

There are no global studies that include the production costs of forestry residues. Even at a regional basis there are limited studies on the costs of biomass from forestry sector. This is mainly because the costs are complex. The cost of biomass from residues depends on one hand on the physical aspects, e.g. costs of collecting, cost for transporting and cost of chipping. But furthermore it depends on the opportunity costs of the residues; e.g. on the competing options of residues. Some assessments of the costs in Europe indicate levels ranging from 2.2-7.4 US$_{2000}$/GJ[4] (Lindner *et al.*, 2005). For Denmark costs have been assessed below 1 US$_{2000}$/GJ (Nord-Larson *et al.*, 2004). For the US, estimates indicate that almost 0.5 EJ/yr forest residues would be available at cost levels below 1.2 US$_{2000}$/GJ and around 1 EJ/yr would cost below 2,9 US$_{2000}$/GJ. An amount of 1.7 EJ/yr of mill residues would become available at same cost levels. The latter type of residues is barely available at cost levels below 1.8 US$_{2000}$/GJ. Biomass forest residues calculations for New Zealand including transportation costs indicate that thinnings from forestry may be delivered at costs around 1-2 US$_{2000}$/GJ depending on the transportation costs (Sims, 2004). In general one can conclude that the delivery or production costs of forestry residues are expected to be at a level of 1-7.7 US$_{2000}$/GJ for the short and medium term, with most estimates at the lower level of this range, from 1-3 US$_{2000}$/GJ. Smeets *et al.*, (2005) concluded that at a global level the economic potential of all types of biomass residues is 14 EJ/yr, or about 3% of current primary energy use.

9.4.7 Global assessment: regional modelling approaches

Stand level carbon sink estimates (of section 9.4.2) cannot simply be multiplied with a certain area to obtain an estimate for economic potential of the carbon sequestration of a given region. In order to do this type of upscaling, many more factors need to be taken into account. These include a.o. the wide variety in sites and forest types, trends and issues in the forest sector regionally, trends in other land based sectors, socio economic factors amongst which the carbon price, and the mutual exclusion of the different measures. A varying mix of these factors is taken into account in regional studies available in literature. As such, these regional assessments vary from projecting the total area forest sector sink trend (Karjalainen *et al.,* 2003) to studies that assess the economic potential carbon sequestration of specific measures (Benitez *et al.,* 2006, McKenney *et al.,* 2004, Sathaye *et al.,* in press, US-EPA 2005). We gathered regional carbon sequestration assessments. From this compilation we attempted to make a best guess for the economic potential of carbon sequestration in the forestry sector by region.

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[4] Assessed at 25-85 €/m^3

9.4.7.1 Wet and dry tropics

A large number of mitigation options are available for tropical countries, and substantial synergies can be built with sustainable development goals. The dominant mitigation options are reducing or avoiding deforestation, followed by afforestation/reforestation (Brown et al, 1996). An inventory of a large number of country level mitigation options for several tropical countries was given in the Third Assessment Report (Kauppi and Sedjo, 2001).

A recent estimate puts global net emissions from land-use change in the tropics at 1.1 ± 0.3 GtC (4,030 $MtCO_2$/yr) (see also Ch 7, WG III) and includes emissions from conversion of forests (representing 71% of budget) and loss of soil carbon after deforestation (20%), emissions from forest degradation (4.4%), emissions from the 1997–1998 Indonesian exceptional fires (8.3%), and sinks from regrowth (-3.3%) (Achard *et al.,* 2004). Considering tropics as a whole, the forest cover gained is only 2.34 Mha annually, compared to a forest cover loss of 11.67 Mha (Section 9.2), highlighting the large potential to mitigate climate change by avoiding deforestation and enhancing afforestation and reforestation.

Assumptions of future forest cover and rates of deforestation are key drivers of both estimates of GHG emissions form forest lands and of mitigation benefits, and vary significantly across studies by model structure and factors driving land use change. Forest area can be determined exogenously from the literature and input into a model (e.g., GCOMAP method, Sathaye *et al.*, 2001). Alternatively forest area or area loss can be generated endogenously by a model's assumptions about population growth, GDP and demand for cropland (e.g. for IMAGE) or forest land rental rates and demand for timber (e.g., GTM). Using this last approach under a spatial-explicit model Soares-Filo *et al.,* (2006) predict that under a business-as-usual scenario, by 2050, projected deforestation trends will eliminate 40% of the current 5.4 million km^2 (540 million ha) of Amazon forests, releasing approximately 32 ± 8 GtC of carbon to the atmosphere (Box 9.3).

The assumed land availability for forestry mitigation options (e.g., low-profitable crop, grazing and unstocked forest lands) depends on the price of carbon and how that competes with existing or other land use financial returns, barriers to changing laud uses or practices including availability of capital stock (e.g., site preparation or alternative harvest equipment) and capital, land tenure patterns and legal status, commodity price support or other incentives or disincentives, and other social and policy factors (for example, Benitez *et al.,*(2006) review four land cover datasets, exclude lands considered unsuitable -as highly productive or densely populated-, IMAGE, on the other hand, assumes that only abandoned agricultural land is available as crop yields improve annually).

Using a scenario of Carbon price of US$ 10 + 5% annual carbon price increment, Sathaye *et al.,*(in press) estimated the cumulative maximum land area available for mitigation options (forestation and avoiding deforestation) in 2050 in Africa, Asia and Latin America (Af+As+La) to be 567 Mha, accounting for 67% of global total. The potential area under the Scenario considered for Forestation is estimated to be 203 Mha and the area for avoiding deforestation to be 364 Mha, respectively. Af+As+La account for 52% of the global potential area for Forestation and 100% of the global area for Avoided deforestation. The feasible area available for Forestation for selected countries of South and South-east Asia is estimated to be 134 Mha, with India and Indonesia dominating with 63 Mha and 32 Mha, respectively (Figure 9.15).

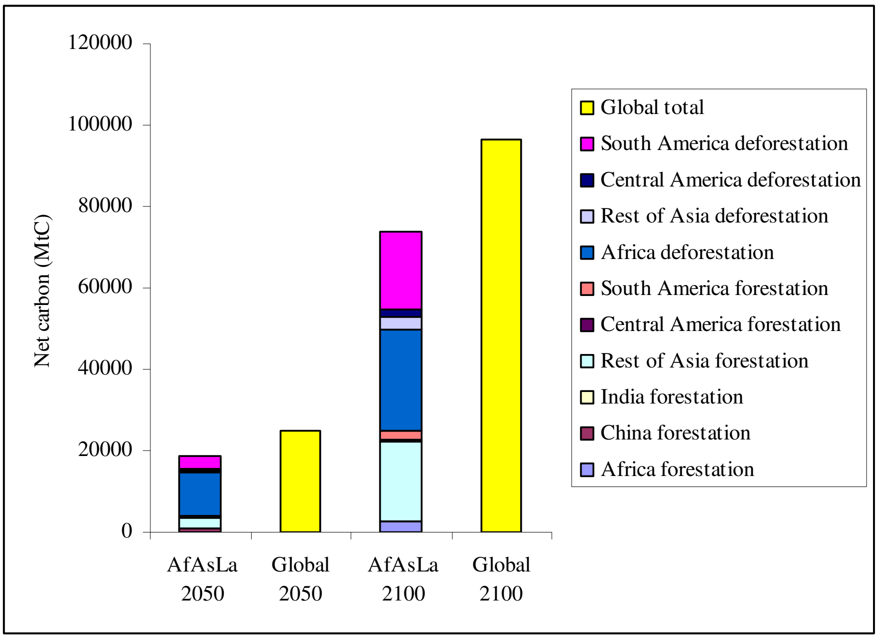


Figure 9.15: *Cumulative mitigation potential (2000-2050 and 2000-2100) in different regions according to mitigation options under the Scenario US$10 + 5%/yr price increase (i.e., C starts at $10 and rises 5% per year) (Sathaye, et al, 2005). AfAsLa: Africa, Asia and Latin America. Deforestation = avoided deforestation*

Mitigation potential on per hectare basis is given in many studies. Richards and Stokes (2004) present a recent review. As an illustration, studies in India and Mexico show that the mitigation potential (including biomass and soil carbon pools) is low for short rotation at 25-61 t C/ha and highest for avoided deforestation at 176-188 tC/ha (Table 9.7). Short rotation and long rotation options involve harvesting and replanting at the end of rotation period. Forest regeneration through natural regeneration and forest protection (avoided deforestation) either do not involve harvesting or felling of trees (India) or involve low impact logging methods (Mexico). Similarly the mean annual carbon mitigation benefit for the 7 developing countries analyzed ranged from 3.8 to 19.2 t C/ha/year for short rotation and 1.6 to 11.1 t C/ha/year for long rotation forestry.

Table 9.7 *Mitigation potential per hectare for forest mitigation options in selected countries*

Mitigation options	Mitigation potential *tC/ha*		Mitigation potential *tC/ha/year*
	India	Mexico	Seven tropical country average
	Ravindranath et al, 2001	*Masera et al., 2001*	*Sathaye et al, 2001*
Short rotation	25	61	3.8 to 19.2
Long rotation	80	98	1.6 to 11.1
Afforestation		67	
Forest Regeneration	162		
Forest protection or Avoided deforestation	182	141-188	

Notes: The tropical countries are: India, Indonesia, Thailand, Tanzania, Brazil, China and Mexico

Cost estimates for carbon sequestration projects for different regions compiled by Cacho *et al.*, (2003) given in Table 9.8 show a wide range. The cost is in the range of $2 to $25/tC for forestry projects in developing countries, compared to $5 to $82 for forestry projects in industrialized countries. The cost value for industrial plantation or short rotation projects is < $5/tC (Table 9.8).

Table 9.8: *Cost estimates for carbon sequestration projects (From Cacho et al., 2003)*

Projects	**Cost range ($/tC)**	**Source**
Farmers to conserve forests on their farm	7-24	Smith and Mourata (in press)
Adopt multi-strata agro-forestry, Peruvian Amazon	8-31	Smith and Mourata (in press)
Profafor, Ecuador	16	Various sources, Smith *et al.,* (2000)
Scolel Te, Mexico	10-12	De jong *et al.,* (2000)
Forestry projects in developing countries	2-25	De jong *et al.,* (2000)
Forestry projects in industrialized countries	5-82	De jong *et al.,* (2000)
Reforestation with short rotation species in land with low opportunity cost	<5	Various sources reviewed by Smith and Scherr (2002)
Industrial plantations in China, Thailand, India and Brazil	<5	Hardner *et al.,*(2000) and Austin *et al.,*(1999) cited by Smith (2002)

The type of mitigation options considered, as well as the time frame of the study affects the total mitigation potential for the tropics. For example, Jung (2003) estimates a potential mitigation of four mitigation options (plantations, agroforestry, regeneration, and avoided deforestation) and comes up with a total of 131- 227 MtC/yr for the period 2008-2012 for the tropics as a whole. 93% of the total potential corresponds to avoided deforestation. In a very detailed study for the Amazon basin, Soares- Filo *et al.,* (2006) estimate that the cumulative avoided deforestation potential for this region reaches 17 GtC (0.36 GtC/yr) under a "governance" scenario (see Box 9.3).

More detailed estimates of economic or market potential for mitigation options by region or country within the tropics are needed, to enable policy makers to make realistic estimates of mitigation potential under various policy, carbon price, and mitigation program eligibility rule scenarios. Examples to build on include Benitez *et al.,* 2006, Waterloo *et al.,*(2003), and Benitez *et al.,* (2006). Sathaye *et al.,* (in press) estimate the cumulative carbon mitigation benefits by 2050 under a $10 + 3% annual increase carbon price scenario to be 15.6 GtC -64% of it coming from avoided deforestation. The figure increases to 28.6 Gt under a $20+ 3% annual increase carbon price scenario -67% of total mitigation comes from avoiding deforestation.

The contribution of different tropical regions to the mitigation potential is given for the carbon price scenario US$ 10+5% annual price increase. During the period 2000-2050, avoided deforestation in South America and Africa dominate by accounting for 49% and 21% out of the total mitigation potential. When forestation is considered Asia dominates. The mitigation potential of the continents Africa, Africa and Latin America dominates the global total mitigation potential for the period up to 2050 and 2100 respectively (Figure 9.12). Thus the insight that developing or tropical countries dominate the future mitigation potential in the forest sector remains.

Box 9.3 Deforestation scenarios for the Amazon: implications for future carbon emissions and conservation strategies

The Amazon is entering an era of rapid changes as new transportation corridors traverse the region, stimulating the expansion of logging and agricultural frontiers. The declining cost of transportation has important implications for biodiversity, greenhouse gas emissions, and the long-term prosperity of the Amazon and global societies. To analyze this context, an empirically based, policy-sensitive simulation model of deforestation for the Pan-Amazon - defined as the Amazon river watershed, the Legal Amazon in Brazil, and the Guiana region was developed (Soares-Filho *et al.*, 2006). Model output for the worst-case scenario (business-as-usual) shows that, by 2050, projected deforestation trends will eliminate 40% of the current 5.4 million km^2 of Amazon forests, releasing approximately 32 ± 8 Gt of carbon to the atmosphere. Conversely, under the best-case "governance scenario", 4.5 million km^2 of forest would remain in 2050, which is 83% of the current extent, reducing carbon emissions to only 15 ± 4 GtC. Results from intermediate-case scenarios indicate that, although an expanded and enforced network of protected areas could avoid as much as one third of projected forest losses, other conservation measures are still required to maintain the functional integrity of Amazon landscapes and watersheds. Current experiments in forest conservation on private properties, markets for ecosystem services, and agro-ecological zoning must be refined and implemented to achieve comprehensive conservation. Part of the resource needed for these conservation initiatives could come in form of carbon credits resulted from the avoidance of 17 ± 4 GtC, considering a modified Kyoto protocol (Santilli *et al.*, 2005) (Figure 9.16). Notice that the difference between the two extreme-case scenarios represents an amount equivalent to eight times the carbon emission reduction to be achieved during the first compensation period of Kyoto Protocol.

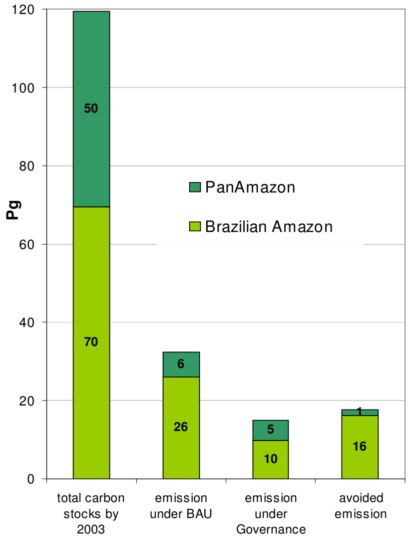


Figure 9.16 *Current carbon stocks for the Pan-Amazon and Brazilian Amazon and estimates of potential future emission from deforestation under BAU (business-as-usual) and governance scenarios. Avoided emission is the difference in values between these two extreme-case scenarios*

9.4.7.2 OECD North America

The forest resource in Canada and the USA can be characterised as respectively consisting of large areas of primary boreal forests with logging intensity concentrated in relatively small areas and large areas of secondary forests clearly in a stage of recovery from past large scale harvesting. Furthermore, the forest resource in both countries is under regular threat of forest fires, as well as an important source of raw material for industry.

Figure 9.17A (right) shows the theoretical potential of management actions aimed at modifying the net carbon balance in Canadian forests (Chen *et al.,* 2000). Of the four scenarios examined, the theoretical potential was largest in the scenario aimed at reducing regeneration delays by reforesting after natural disturbances. The estimate of the potential increase in the carbon sink was 312 $MtCO_2$/yr by 2050. The second largest estimate was obtained with annual, large-scale (125 Million ha) low-intensity (5 kg N ha^{-1}/yr) nitrogen fertilization programme with an estimated sink potential of 205 $MtCO_2$/yr. Neither of these scenarios is realistic, however, and large uncertainties are associated with these estimates. Chen's measures sum up to a theoretical potential of 570 $MtCO_2$/yr, a realistic economic potential would be around 50-70 $MtCO_2$/yr.

Other studies have explored the potential of large-scale afforestation. Mc Kenney *et al.,* (2004) project that at a carbon price of 25 \$/tCO_2, 7.5 million ha of agricultural land would become economically attractive for poplar plantations (at medium growth rates) in western and eastern Canada. Yemshanov *et al.,* (2005) confirm that, at low carbon prices, almost no land would be attractive for afforestation in Canada. These economic constraints are contributing to the declining trend in afforestation rates in Canada from about 10,000 ha y-1 in 1990 to 4,000 ha y-1 in 2002 (White and Kurz, 2005). Several research projects are currently ongoing to assess the potential of other forest management strategies aimed at reducing sources and increasing sinks, including considerations of active suppression of forest insect outbreaks.

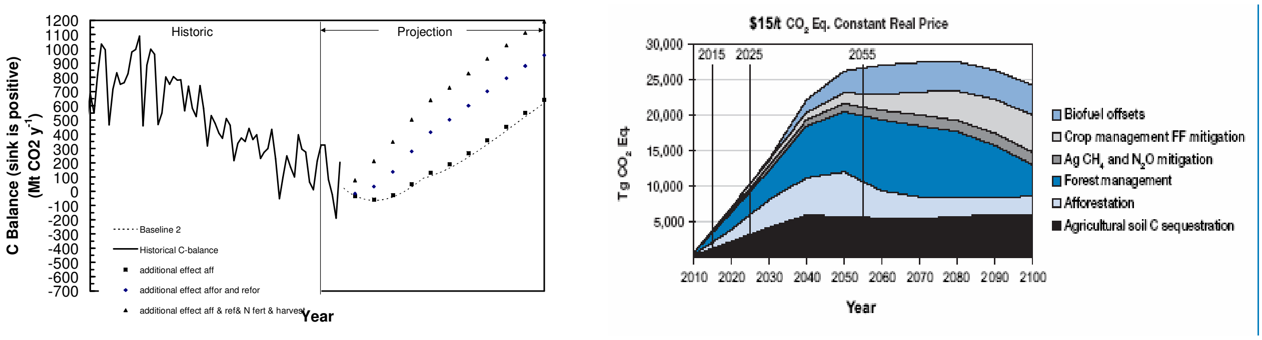


Figure 9.17A: *OECD N-America: Assessments for the economic potential in the agriculture and forestry sector in the USA (left, US-EPA 2005) and theoretical potential for the forest sector alone for Canada (right; Chen et al.)*

For the USA, the literature contains a variety of results concerning sequestration options in forestry. Several studies project the trend of the forest sector (a baseline sink in 2000 of around 750 $MtCO_2$/yr) (US EPA, 2005). Numerous studies estimate forestation, forest management, and/or biofuel potential using either econometric approaches relying on regressing historical landowner responses to price signals and government programs, or partial equilibrium models of the forest (and in some case agricultural) sector. One study (Richards and Stokes, 2004) reviewed eight roughly comparable national estimates of forest mitigation in USA and found that C prices ranging from \$1-41/tCO_2 generated 47-2,340 $MtCO_2$ per year from afforestation, 404 $MtCO_2$ from forest management, and 551-2,753 $MtCO_2$ from total forest carbon. Sohngen and Mendelsohn (2001) found that a \$13/tC price produced 265 $MtCO_2$ total carbon sequestration, and a \$27 price some 563 $MtCO_2$, annualized over a 100-year timeframe.

US-EPA published its forest and agricultural sector mitigation potential estimate based on partial equilibrium economic modelling with the FASOM GHG model (US EPA, 2005). At 15 $/tCO_2$, the mitigation potential of afforestation and forest management (annualized) would amount to 356 $MtCO_2$/y annualized over a 100-year timeframe (and also the value for 2025, as seen Figure 9.17A, left). This same central scenario would generate 749 $MtCO_2$ annualized over 120 years. These values are roughly comparable to those from Sohngen and Mendelsohn (2001) above, suggesting emerging consensus on them. At lower prices it was mainly forest management and agricultural soil C sequestration that determined the potential, at higher prices and in the long term, the potential was mainly determined by biofuels. The EPA results mentioned above are in the same range as given by Lee *et al.* (1996) at a carbon price of 15 $/tCO_2$. They present a cumulative sequestration in all forest measures of 4 GtC by 2050; this represents an annual sequestration of 293 $MtCO_2$/yr. Brown *et al.,* (2004) project for California at a price of $13.6/tCO_2$, that an annual amount of carbon that could be sequestered by afforesting grazing lands and changing forest management could be 45 $MtCO_2$/yr.

Other insights from the EPA study include that: (1) if GHG prices are expected to rise over time into the future, mitigation will start slowly as landowners wait for higher future prices; (2) the optimal portfolio mix of options varies with the carbon price, and over time; (3) mitigation is likely to be unevenly distributed among USA regions, where only a few will account for the vast majority of mitigation; (4) issues related to mitigation program design can have a major effect on the magnitude, timing and persistence of mitigation benefits, and on costs (US EPA, 2005).

9.4.7.3 Europe

The forest resources of Europe can be characterised as intensively managed, with no primary forests left any more. Most of the forests are rather young; harvesting is approximately 60% of the increment. There is a clear trend towards nature oriented forestry; possibly the current sink (of some 270 $MtCO_2$/yr) will saturate towards 2040 or later. Most of the assessments that are shown (Fig 9.17B) were projections of the forest resource as a whole. Studies that looked into additional effect of measures were done by Cannell (2003), Benitez *et al.,*(2006) and EEA (2005). Over a forest baseline sink, the studies present additional achievable sinks of 150 to 250 Mt CO_2/yr. The study by Karjalainen *et al.,* (2003) presented a projection of the full sector carbon balance (Figure 9.17B). Economic analyses were never done at a very large scale, only country studies were done, e.g. Hoen and Solberg (1994) for Norway. Issues in European forestry where options can be found are: afforestation of abandoned agricultural lands, bio energy from complementary fellings, and forest management that aims at curbing the saturation. Clearly the options should be combined to adaptation questions, and can be sought in combining carbon sequestration with nature restoration, with water retention and by providing natural pathways to connect the fragmented nature reserves. In this way, the mitigation options will contribute to sustainable development as well (see also WG II ch 'ecosystem services'). In the very long term, the goal of curbing the saturation seems feasible as most climate change impact studies predict on average enhanced forest growth in Europe (Nabuurs *et al.,* 2002, Schröter *et al.,* 2005). However, the exception is the Mediterranean, where drought and fires will most likely increase, and ecosystem services are under pressure (Schröter *et al.,* 2005).

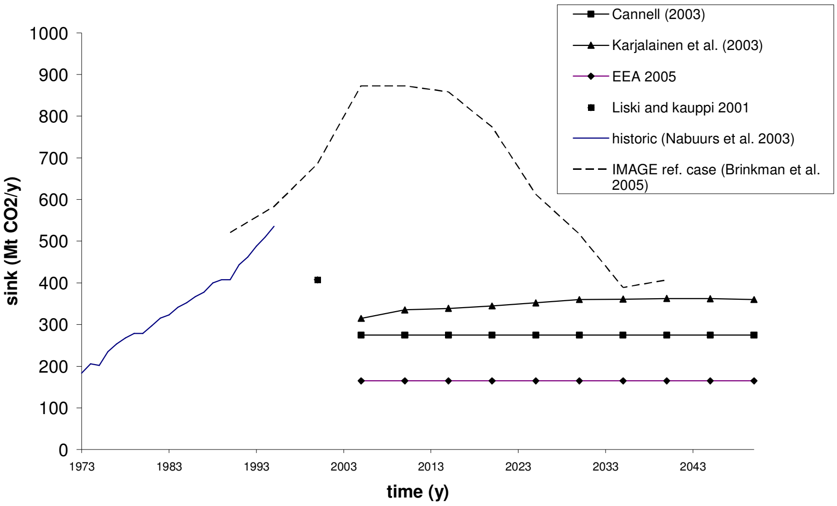


Figure 9.17B *Europe*

9.4.7.4 Countries in Transition

The forests resource in the former Soviet Union represent about 20% of the global forest resource and include a large area of primary (mostly boreal) forests. Most estimates indicate that the Russian forests are neither a large sink nor a large source. Natural disturbances (fire) play a major role in the carbon balance with emissions up to 1600 $MtCO_2$/yr (Zhang *et al.,* 2003). Large uncertainty surrounds the estimates for the current C balance, with comparisons complicated by inclusion of different sets of C pools included by different research groups (Krankina *et al.,* 1996, Shvidenko and Nilsson 2003). For the decade 1990-2000 the range of C sink values for Russia is 350-750 $MtCO_2$/yr (Nilsson *et al.*, 2000, Izrael *et al.*, 2002, Lelyakin *et al.,* 1997) with future projections ranging even further (Izrael *et al.,* 1997, Lelyakin *et al.,* 1997). Earlier estimates suggested the biological potential of forestry measures up to 880 $MtCO_2$/yr in the Former Soviet Union (Shvidenko *et al.,* 1997), while more recent estimates are an order of magnitude smaller (e.g. Izrael *et al.,* 2002, Nillson *et al.,* 2003). A recent Russian -US analysis (Sohngen *et al.,* 2005) estimated the net sink in Russia at 146-439 $MtCO_2$/yr at present. It used a deterministic land use and forestry sector model to project this baseline to be about 70 $MtCO_2$ per year in 2010, declining to a net source by 2030 as younger forests mature and are harvested, but to be a net sink over the next 100 years overall, growing at about 88 $MtCO_2$ per year. The study used both a bottom-up forest program cost estimation approach, and a top-down dynamic national/global timber model approach. It estimated the economic potential in Russia of afforestation and reforestation measures only at 73 $MtCO_2$/year on average over a 80-year period, above baseline sequestration, for a carbon price of $7-13 per ton of C, and 308-476 $MtCO_2$/year at a higher price of $100-200/tC (Sohngen *et al.,* 2005). However, large uncertainty surrounds all figures. Apart from project implementation problems, the future impact of climate change on the large areas of boreal forests is highly uncertain, and may considerably constrain the sequestration options (Figure 9.17C).

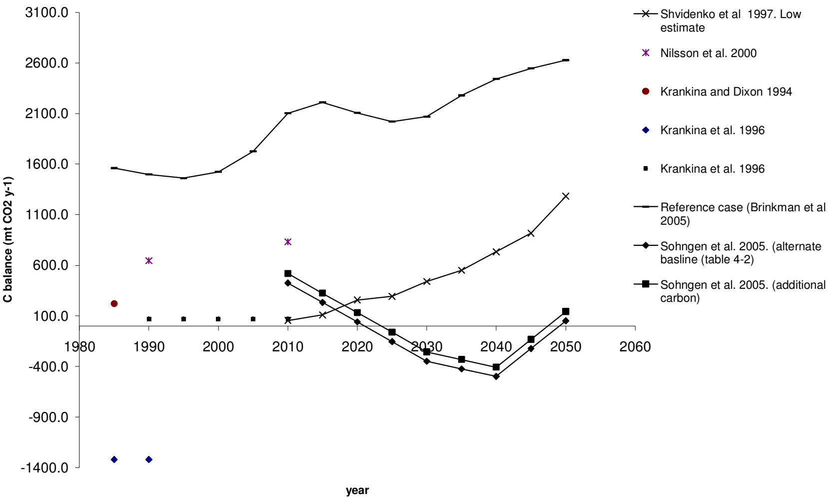


***Figure 9.17C** Countries in transition*

9.4.7.5 OECD Pacific

Kirschbaum (2000) estimated that new plantations in Australia could sequester between 2 and 25 $MtCO_2$ per year over the first commitment period. The actual quantity depends on both the area of eligible plantations that will be established from 1999 onwards and whether plantations will be allowed to grow to the end of the commitment period or will be in short-rotation stands that may be harvested before 2012. The highest estimate requires the establishment of new plantations at the Australian Government's target rate of 100,000 ha per year. Kirschbaum and Cowie (2004) estimate that carbon stock changes in Australian post-1990 plantations will remain between 7 and 15 $MtCO_2$/yr from 2005 until beyond 2040 assuming future expansion of the plantation estate by 80,000 ha/yr.

New Zealand reached a peak in new planting of around 98,000ha in the 1994 and estimates of stock changes were largely dependent on afforestation rates (MfE, 2002). If new planting was maintained at 40,000 ha/yr it was estimated that the stock increase in Kyoto forests (117 $MtCO_2$) would offset all increases in NZ emissions since 1990. The total stock increase in all forests would offset all emissions increases until 2020.

However, the current new planting rate has plummeted to 6,000ha (lowest rate since 1960) and conversion of 7,000 ha of plantations to pastures has led to net deforestation in the year to March 2005 (MAF, 2006). As a result, the total removal units anticipated to be available (from Kyoto forests) during the first commitment period has dropped from an estimate of 105 $MtCO_2$e in 2003, 95 $MtCO_2$e in 2004, to 71 $MtCO_2$e in 2005 (MfE, 2005). This leads to uncertainty over the selection of an appropriate baseline.

Trotter *et al.,* (2005) estimate NZ has approximately 1.45 Million ha of marginal pastoral land suitable for afforestation, including production forestry and reversion of native scrub species. Average sequestration rates on this land have been estimated at 2.1 tC/ha per year for some native species and around 8 tC/ha per year for pine. Hence if all the area was established, total sequestration at these rates could range from 10 to 42 $MtCO_2$/yr. This would lead to a removal of approximately 44 to 170 $MtCO_2$ by 2010. Trotter *et al.,* (2005) estimate that ‘carbon farming’ with native species is an economically attractive option at 10 Euro/tCO_2.

Japan is covered with semi natural and natural forests to a large extent. Issues in Japanese forestry where options can be found are in bio energy from complementary fellings, and forest management that aims at curbing the saturation. Clearly the options should be combined to adaptation questions, and can be sought in combining carbon sequestration with nature restoration, with water retention and by reducing soil erosion. From the assessments the sequestration potential can be estimated in the range of 35 to 70 $MtCO_2$/yr (Alexandrov *et al.*, 1999, Matsumoto *et al.,* 2002, Fang *et al.,* 2005, Government of Japan, 1997).

9.4.7.6 Centrally planned Asia

East Asia to a large extent formed by China, Korea and Mongolia, has a range of forest covers from a relatively small area of moist tropical forest to large extents of temperate forest and steppe like shrublands. Country assessments for the forest sector all project a sink ranging from 75 to 400 $MtCO_2$/yr, however the additionality of these figures is unclear (Zhang and Xu, 2003). In addition, Kohn *et al.,* (2003) project a significant sink potential at 1400 $MtCO_2$/yr. Given the large areas, the fast economic development (and thus demand for wood products) we estimate the additional potential in the region at 150 to 400 Mt CO_2/yr. Issues in forestry with which the carbon sequestration goal can be combined sustainably are reduction of degradation of tropical and dry woodlands, stopping desertification of the steppes (see ch 8), afforestations, and bioenergy from complementary fellings.

9.4.7.7 Global totals

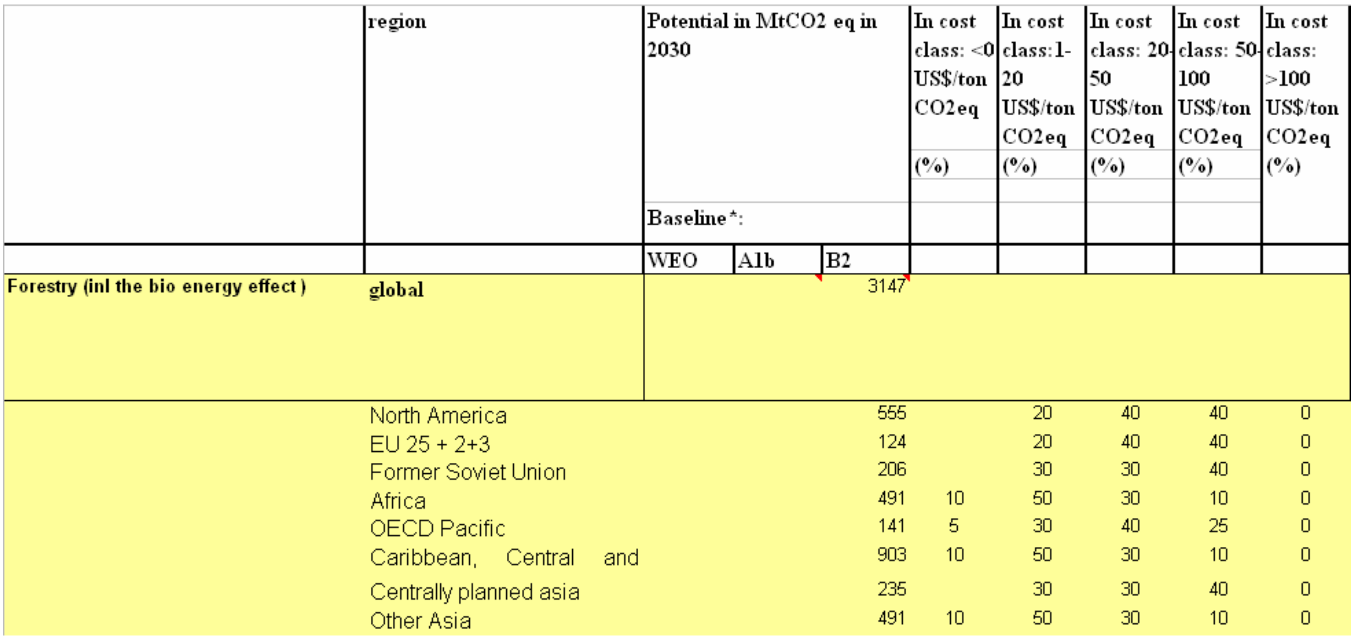
Summing the regional results is critical as leakage effects between regions have not been taken into account in the studies (Table 9.9). Still, if we sum and average the low and high estimate (including the bio energy potential), we arrive at a mitigation potential (all prices) of 4130 $MtCO_2$/yr in 2040 (Figure 9.18). Given a gradual implementation of activities, we interpolate this (Figure 9.19) to a potential of 3150 $MtCO_2$/yr in 2030 (medium confidence). This is the number provided in the top of Table 9.10. 900 $MtCO_2$/yr of this potential can be achieved in C&S America. About 50% of this can be achieved at costs under 20 US$/$tCO_2$ (= 1550 $MtCO_2$/yr). This sink enhancement/emission avoidance will be located in the tropics for 65% (high confidence), be found mainly in above ground biomass, and for 10% achieved through bio energy (medium confidence). In the short term, this potential is much smaller, with 1180 $MtCO_2$/yr in 2010 (high confidence)

Uncertainty from this estimate arises from the variety of studies used, the different assumptions, from the different measures taken into account, and from the lack of taking into account possible leakage between continents.

Table 9.9: *Summation of regional results as presented in section 9.4.7. Note that these figures are surrounded by large uncertainty. Differences in studies, assumptions, and price scenarios make a simple summation almost impossible. These are best estimates for the medium long term period where these values may be reached around 2040 in the medium price scenario of around 20US\$/tonne CO_2. If measures are effective, then the higher ranges apply beyond 2050*

	Economic potential of annual Sequestration and or avoiding deforestation around 2040 ($MtCO_2$/yr) **low**	Economic potential of annual Sequestration and or avoiding deforestation around 2040 ($MtCO_2$/yr) **high**	Bioenergy (avoided emissions average) ($MtCO_2$/ yr)
North America	400	820	470
EU 25 + 2+3	90	180	170
Former Soviet Union	150	300	400
Africa	300	875	370
OECD Pacific	85	255	100
Caribbean, Central and South America	500	1750	750
Centrally planned Asia	150	400	200
Other Asia	300	875	300
Total	**1975**	**5455**	**2760**

Table 9.10: *Regional economic mitigation potentials in forestry as assessed from bottom up studies broken down by cost classes*



	region	Potential in MtCO2 eq in 2030 Baseline*:			In cost class: <0 US$/ton CO2eq (%)	In cost class:1-20 US$/ton CO2eq (%)	In cost class: 20-50 US$/ton CO2eq (%)	In cost class: 50-100 US$/ton CO2eq (%)	In cost class: >100 US$/ton CO2eq (%)
		WEO	A1b	B2					
Forestry (inl the bio energy effect)	**global**			3147					
	North America			555		20	40	40	0
	EU 25 + 2+3			124		20	40	40	0
	Former Soviet Union			206		30	30	40	0
	Africa			491	10	50	30	10	0
	OECD Pacific			141	5	30	40	25	0
	Caribbean, Central and			903	10	50	30	10	0
	Centrally planned asia			235		30	30	40	0
	Other Asia			491	10	50	30	10	0

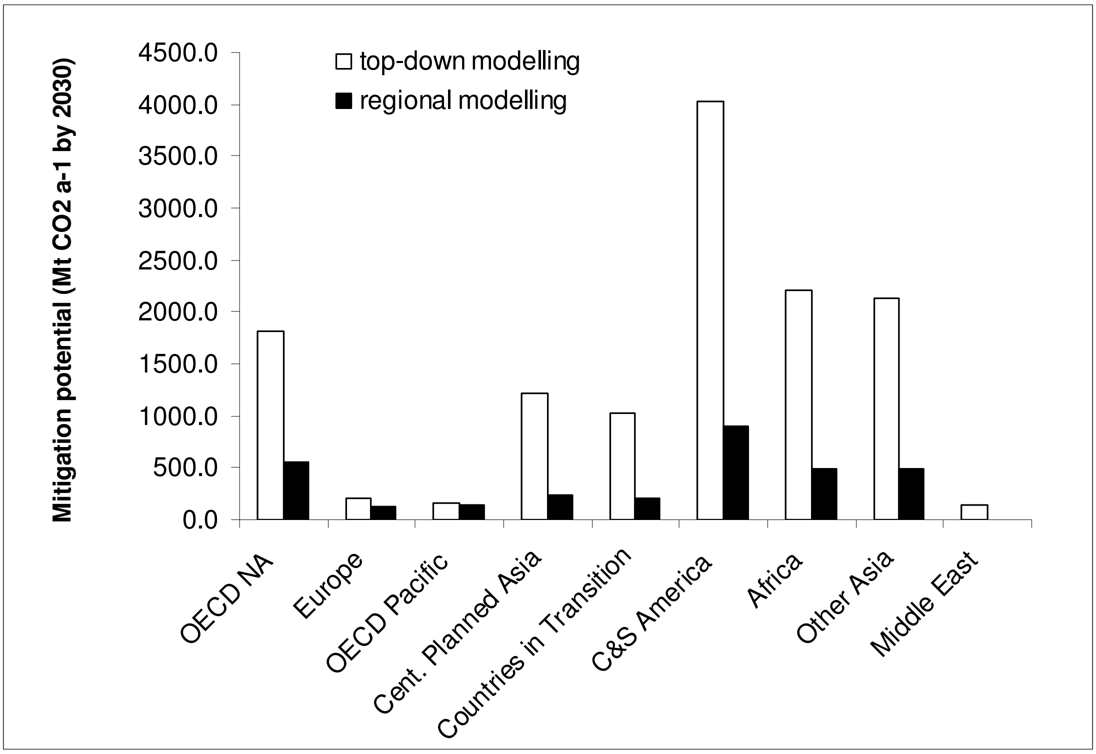


***Figure 9.18**: Comparison of outcomes of economic mitigation potential in the forestry sector (all prices) as based on top-down global models (§9.4.5.), versus the regional modelling results (§9.4.7.)*

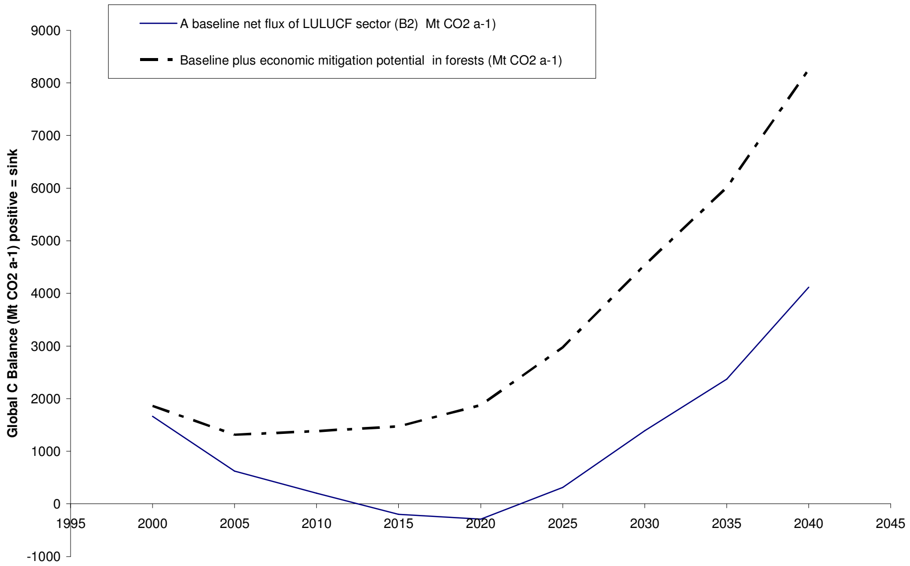


***Figure 9.19:** The wedge: A hypothetical projection of the baseline of the global LULUCF sector (B2) and the economic potential of curbing of this baseline by additional measures in the forestry sector alone at a carbon price of around 20US$/tCO$_2$. Note that large uncertainty surrounds both the baseline, as well as the effect of the measures. Naturally, choosing another baseline would have an impact on the size of the curbing as well, however, literature does not allow such a dynamic approach*

9.5 Interactions with adaptation and vulnerability

Much of the mitigation potential as given in this chapter might be counteracted by adverse effects of climate change on forest ecosystems (WG II, Ch 4). Thus it is important to explore options to adapt to new climate circumstances at an early stage. There are significant opportunities for mitigating and for adapting to climate change, while enhancing the conservation of biodiversity (CDB, 2003) and getting other environmental as well as socio-economic benefits. However, mitigation and adaptation have been considered separately in the global negotiations as well as in the literature. In the Third Assessment Report of IPCC mitigation was addressed in the Working Group III and impact and adaptation was considered in Working Group II while the potential synergy and trade-off issues were not addressed. This section explores the synergy between mitigation and adaptation by considering the forest sector, which on the one hand is projected to be adversely impacted under the projected climate change scenarios and on the other provides opportunity to mitigate climate change (Ravindranath and Sathaye, 2002). The potential and need for incorporating adaptation strategies and practices in mitigation projects is presented with a few examples.

9.5.1 Climate Impacts and Adaptation

In addition to natural factors, forest ecosystems have long been subjected to many human induced pressures such as land-use change, over-harvesting, over-grazing by livestock, fire and introduction of new species. Climate change constitutes an additional pressure that could change or endanger these ecosystems. Chapters 4 and 5 of Working Group II of AR4 have highlighted the potential impacts of climate change on forest ecosystems. The future synergistic impacts of direct human-induced stresses and climate change will induce significant biodiversity loss. It is also virtually certain to drive the migration and dieback of tree species, resulting in changes in the geographic distribution of forest types, new combinations of species within forests, and changes to forest productivity. Modelling studies show potential significant disruption of ecosystems under climate change. Climate change can affect the species distribution and productivity of forest ecosystems, impacting on forestry operations (IPCC 2002) and thus on mitigate capacity of forests. Given the possibly adverse impacts of projected climate change, adaptation to climate impacts in the forest sector is critical, (IPCC, 2001d).

9.5.2 Mitigation and Adaptation Synergies

The mitigation and adaptation trade-offs and synergies in the forestry sector are dealt with in detail in Chapter 18 of Working Group II of AR4. Table 9.11 shows a qualitative assessment of these trade-offs and synergies for selected mitigation options. UNFCCC and the Kyoto Protocol have led to several response strategies to address climate change. Some examples relevant to the forest sector are; the Global Environmental Facility (GEF), Clean Development Mechanism (CDM), Activities under Article 3.3 namely, afforestation, reforestation and deforestation and under Article 3.4 such as forest, cropland, and grassland management, and the Adaptation Fund. Many of them aim at implementation of either mitigation or adaptation technologies or policies. New mechanisms to address mitigation and adaptation may emerge in the future. Thus, it is necessary to promote synergy in planning and implementation of mitigation and adaptation projects to derive maximum benefit to the global environment as well as local communities or economies. Further, climate change adaptation activities can promote conservation and sustainable use of biodiversity, and in turn conserve or enhance the carbon stocks in forest ecosystems (CBD, 2003).

Table 9.11: *Synergy or tradeoff between climate mitigation activities and adaptation potential*

Activities, practices and management systems	*Carbon sequestration or emission reduction potential*	*Biodiversity conservation*	*Reduction of vulnerability*
Reducing deforestation	+++	+++	+++
Afforestation & Reforestation	+++	+/ -	++
Forest Management	++	++	++
Product substitution (including bioenergy)	+++	- -	--
Agro-forestry	++	++	+++
Urban forestry	++	+	++

Notes: + Low Positive Impact; ++ Medium Positive Impact; +++ High Positive Impact; *- Low negative impact, -- Medium negative impact; +/- Positive/negative impact*

Incorporating Adaptation in Mitigation Projects

The ecological impacts of climate change mitigation options such as afforestation are a key uncertainty with respect to their impacts on biodiversity and ecosystem functioning (Chapter 4, Working Group II, AR4). Forest sector mitigation projects, including forest conservation, afforestation/reforestation, bioenergy and others, are already being implemented or are in the planning stage. Thus, there is a need to explore adaptation opportunities in these projects. Adaptation and mitigation linkages and vulnerability of mitigation options to climate change is presented in Table 9.12.

i) *Forest conservation*: Forest conservation aimed at halting or reducing deforestation, is one of the most important mitigation options (Section 9.4). Forests or plantations consisting of multiple species are also an attractive adaptation option as they are more resilient or less vulnerable due to different climate tolerance of different species, different migration abilities and effectiveness of invading species (IPCC, 2001b). Forest conservation is also a critical strategy to promote sustainable development due to its importance for biodiversity conservation, watershed protection and promotion of livelihoods of forest dependent communities (IPCC, 2002). A primary management adaptation is to reduce as many ancillary stresses on the forest resource as possible. Maintaining widely dispersed and viable populations of individual species minimizes the probability that localized catastrophic events will cause extinction (Chapter 4, Working Group II, AR4).

Formation of Protected area or nature reserves is an example of mitigation as well as adaptation. Regrowth of trees due to effective protection will lead to carbon sequestration. Formation and management of protected areas also leads to conservation of biodiversity, in turn reducing the vulnerability to climate change. One of the additional adaptation strategies to be incorporated while forming a protected area is to create ecological corridors to create opportunities for migration of flora and fauna, which facilitates adaptation to changing climate.

ii) Afforestation and reforestation: Afforestation and reforestation are the dominant mitigation efforts, currently being pursued in the global negotiations. They are included under Article 3.3 as well as Article 12 (CDM) of the Kyoto Protocol. Afforestation and reforestation activities proposed as mitigation activities also provide opportunity for adaptation.

Several adaptation strategies or practices can be used in the forest sector, including changes in land use choice (Kabat *et al.,* 2005), management intensity, hardwood/softwood species mix, timber growth and harvesting patterns within and between regions, rotation periods, salvaging dead timber, shifting to species more productive under the new climatic conditions, landscape planning to minimize fire and insect damage and provide connectivity, and adjusting to altered wood size and quality (Alig *et al.*, 2002; Spittlehouse and Stewart, 2003).

iii) Biomass energy plantations: Bioenergy requires sustainable production of biomass feedstock. Normally bioenergy plantations are likely to be intensively managed to produce biomass for energy. To ensure sustainable supply of biomass feedstock and to reduce vulnerability to climate change it is necessary to adopt the practices mentioned above for afforestation and reforestation projects such as, rotation periods, salvaging dead timber, shifting to species more productive under the new climatic conditions, mixed species forestry, short rotation species and fire protection measures.

iv) Agro-forestry: Agro-forestry provides an example of a set of innovative practices that are designed to enhance productivity in a way that often contributes to climate change mitigation through enhanced carbon sequestration, and that can also strengthen the systems ability to cope with adverse impacts of changing climate conditions. Agro-forestry management systems offer important opportunities creating synergies between actions undertaken for mitigation and activities undertaken for adaptation (Verchot et al, 2006). The area suitable for agro-forestry is estimated to be 585-1215 Mha with a technical mitigation potential of 1.1-2.2 Pg C in terrestrial ecosystems over the next 50 years (Albrecht and Kandji, 2003). Agroforestry can also have an indirect effect on C sequestration when it helps decrease pressure on natural forests. Another indirect avenue of C sequestration is through the use of agroforestry technologies for soil conservation, which could enhance C storage in trees and soils. Agroforestry systems with perennial crops may be important carbon sinks, while intensively managed agroforestry systems with annual crops are more similar to conventional agriculture (Montagnini and Nair, 2004).

v) Urban forestry: This involves formation of parks, planting trees along the alleys, and growing trees within residential compounds. It is necessary to adopt multi-species and multi-purpose approach in urban forestry to reduce vulnerability of tree species to climate change.

Adaptation practices could be incorporated synergistically in most mitigation projects in the forest sector. However, it is important to note that the mitigation strategies such as afforestation and reforestation could also have adverse implications for water yields in arid and semi-arid regions (UK FRP, 2005) and biodiversity (Caparros and Jacquemont, 2003), particularly due to over planting of fast growing exotic species. Table 9.12 shows a qualitative ranking of forest activities in terms of their mitigation and adaptation potential.

Table 9.12: *Adaptation and Mitigation Matrix*

Option	**Vulnerability**	**Implications for GHG emissions due to adaptation**
A. Increasing or maintaining the forest area		
Reducing deforestation and forest degradation	Carbon stocks in forest pools is vulnerable to Climate Change impacts (i.e. "forest dieback") Vulnerability to CC can be reduced by introducing adaptation management practices in the forest sector (i.e. Fire management)	No or marginal implications for GHG emissions It may be implications on GHG, due to for example increase in fires emissions
Afforestation / Reforestation	Carbon stocks are vulnerable to Climate Change (i.e. increase of fires, storms, increase of temperature vs. increse respiration from soils)	Yes, some practices like need irrigation or preventing fire management need may lead to increase in emissions form certain pools of Carbon
B. Changing forest management: Increasing of carbon density at plot and landscape level		
Forest management in plantations	Carbon stocks are vulnerable to Climate Change	Marginal implications on GHGs
Forest management in native forest	Carbon stocks are vulnerable to Climate Change	No or marginal
C. Substitution of energy intensive materials		
Increasing substitution fossil energy intensive products by wood products	Stocks in products not vulnerable to Climate Change	No implications in GHGs emissions
D. Bioenergy		
Bioenergy production from forestry	Plantations from where bioenergy comes from are vulnerable, but the activity of substitution is not.	No implications

9.5.3 Mitigation in adaptation strategies and projects

There is little information on how mitigation practices can be incorporated into adaptation projects. Some examples of adaptation options and practices, which also contribute to mitigation are as follows (Ravindranath, 2006):

- Adaptation activities such as mangrove forests and coastal plantations, apart form reducing vulnerability of coastal settlements to extreme climatic events, sequester carbon. Similarly shelterbelts aimed at reducing impacts of desertification and droughts also sequester carbon.
- *Soil and water conservation* and e*nhancing soil organic matter*through contour bunding, organic manuring, green manuring crops etc. not only reduces the vulnerability to drought and moisture stress but also increases the carbon sequestration rates of tree as well as grass species.

- *Urban park and tree planting in residential compounds;* promotes adaptation to heat stress in urban areas by reducing air conditioning needs, also leads to carbon sequestration in trees and soil.
- *Agroforestry;* options may provide opportunity for mitigation along with promotion of adaptation (Verchot *et al.*, 2006). Agroforestry is a means for diversifying production systems and increasing the adaptive capacity of smallholder farming systems. Tree-based systems have some obvious advantages for maintaining production during wetter and drier years, apart from sequestering carbon.

9.5.3.1 Adaptation and mitigation synergy and sustainable development

The need for integration of mitigation and adaptation strategies to promote sustainable development is presented in Chapter 18 of Working Group II. The analysis has shown the complementarity or synergy between many of the adaptation options and mitigation (Dang et al, 2003). Promotion of synergy between mitigation and adaptation will also advance sustainable development, since mitigation activities could contribute to reducing the vulnerability of natural ecosystems and socio-economic systems (Ravindranath, 2006). Currently, there are very few ongoing studies trying to understand the interaction between mitigation, adaptation and sustainable development (Wilbanks, 2003, Government of Australia, 2001 and Dang et al, 2003). Quantification of synergy is necessary to convince the investors or policy makers (Dang et al, 2003).

Box 9.4: Early Lessons Learned from the BioCarbon Fund

The BioCarbon Fund (BioCF), a private/public partnership managed by the World Bank, purchases emission reductions from LULUCF projects. It aims at demonstrating that LULUCF can simultaneously provide cost-effective emission reductions, improve livelihoods of local communities, and yield other environmental benefits like biodiversity conservation or desertification prevention.

Operational since May 2004, and with a capital of US$53.8 million, the BioCF is currently preparing CDM and JI documentation for twenty-three projects with a wide geographic and activity range (www.biocarbonfund.org). As of June, 2006, it has signed three emission reductions purchase agreements for a total of 1.3 $MtCO_2e$ until 2017, in projects that are expected to generate about 5 $MtCO_2e$ over the next 20 years. Also, three of its afforestation/reforestation projects have seen their baseline and monitoring methodologies approved by the CDM Executive Board. Early findings are that:

The supply of LULUCF projects grossly exceeds demand. Despite a willingness to pay of around $4/$tCO_2e$ and even though the interest of the BioCF was mostly limited to A/R activities, the BioCF has received about 150 project ideas in 30 months, representing over 500 $MtCO_2e$ of sequestration potential. Roughly 20% of these ideas were deemed viable, though not all can be supported at current level of capitalization.

Even in this price range, carbon finance can have significant impacts on the financials of the project: carbon revenues represent between 30% and 60% of the nominal investment cost of selected projects.

By paying “on delivery”, the BioCF provides incentives to make new activities sustainable. However, bridge financing is often necessary to finance investment costs.

The BioCF typically purchases carbon in projects over 10 years or more, but it privileges tCERs over lCERs in that tCERs give more flexibility and security to the parties to the contract. Flexibility in the sense that the parties commit for no more than 5 years at a time. Security in the sense that the buyer does not expect the seller to perform for more than 5 years, and the seller is able to resell the tons to another buyer in case the original buyer does not renew its purchase beyond 5 years.

The projects supported consist of several activities within a landscape - watershed management, erosion control, soil fertility improvements, food and fodder tress and natural habitat restoration - rather than simply forest plantations.

The projects supported yield various development benefits including employment, alternative income generation, empowerment of women, etc.

Simple but reliable monitoring techniques with conservative assumptions often prove preferable to solutions that are more accurate but much more expensive (Pearson *et al.*, 2005). Remaining uncertainties in measurements can be addressed contractually by selling less than the quantity expected to be sequestered.

As of June 2006, the BioCarbon Fund remains the only significant buyer of LULUCF credits designed to provide compliance under the Kyoto Protocol. Delayed adoption of regulations governing LULUCF projects, lingering uneasiness about LULUCF projects, and the decision by the EU not to accept LULUCF CDM credits under the EU ETS appear to be the key reasons for this slow start.

Mitigation activities should not increase the vulnerability of forest ecosystems and plantation forestry. Further, it is necessary to explore the possibility of incorporating adaptation practices into mitigation projects to reduce vulnerability. Mitigation, through Kyoto Protocol activities under Article 3.3, 3.4 and 12, provides an opportunity to incorporate adaptation practices. Thus guidelines may be necessary for promoting synergy in mitigation as well as adaptation programmes and projects of the existing UNFCCC and Kyoto Protocol mechanisms as well as emerging mechanisms. Integrating adaptation practices in such mitigation projects would maximize the utility of the investment flow and contribute to enhancing the institutional capacity to cope with risks associated with climate change (Dang et.al. 2003).

9.6 Effectiveness of and experience with policies affecting net emissions in the forestry sector

This section examines the barriers, opportunities and implementation issues associated with policies affecting mitigation in the forestry sector. Non-climate policies, i.e. forest sector policies that affect net greenhouse gas emissions from forests, but that are not designed primarily to achieve climate objectives, as well as policies primarily designed to reduce net forest emissions are considered. Both non climate policies as well as policies that are primarily designed to reduce net emissions from the forest sector are examined. Many factors will influence the efficacy of forest policies in achieving intended impacts on forest land-use, including land tenure, institutional and regulatory capacity of governments, the financial competitiveness of forestry as a land use, and a society’s cultural relationship to forests. Some of these factors typically differ between industrialized and developing countries. For example, in comparison to developing countries, industrialized countries tend to have relatively small amounts of unallocated public lands, and relatively strong institutional and regulatory capacities. Where appropriate, the following discussion separately examines policy options and effectiveness in industrialized and developing countries. Because integrated and non-climate policies are designed primarily to achieve objectives other than net emissions reductions, evaluations of their effectiveness focus primarily on indicators, such as maintenance of forest cover, that provide only partial insight into their potential to mitigate climate change. Under conditions with high potential for leakage, for example, such indicators may overestimate the potential for carbon benefits. (Section 9.6.3).

9.6.1 Policies aimed at reducing deforestation

Deforestation in developing countries, the largest source of emissions from the forestry sector, has remained at high levels since 1990 (FAO 2005). There are substantial barriers to enacting effective policies to reduce forest loss. Profitability incentives often run counter to forest conservation and sustainable forest management (Tacconi *et al.,* 2003). There are many direct and indirect drivers of deforestation outside of the forest sector, especially agricultural policies and markets (Angelsen & Kaimowitz 1999; Wunder 2004). Limited regulatory and institutional capacity and insufficient resources constrain the ability of many governments to implement forest policies on the ground (Tacconi *et al.,* 2003).

In the face of these challenges, national forest policies designed to slow deforestation on public lands in developing countries have had mixed success:

- In countries where institutional and regulatory capacities are insufficient, new clearing by commercial and small-scale agriculturalists responding to market signals continues to be a dominant driver of deforestation (Wunder 2004).
- A number of national initiatives are underway to combat illegal logging (e.g., Consulate General of Brazil, 2005; Sizer, 2005). While these have increased the number of charges and convictions, it is too early to assess their impact on forest degradation and deforestation.
- Legally protecting forests by designating protected areas, indigenous reserves, non-timber forest reserves and community reserves has proven an effective way to maintain forest cover in some countries, while in others, a lack of resources and personnel result in the conversion of legally protected forests to other land uses (Kainer *et al.*, 2003; Mertens *et al.*, 2004).

China (Cohen *et al.*, 2002), the Phillipines and Thailand (Granger, 1997) have significantly reduced their deforestation rates in response to experiencing severe environmental and public health consequences of forest loss and degradation. These examples indicate that strong and motivated government institutions and public support are key factors in implementing effective forest policies.

Options for maintaining forests on private lands in developing countries are generally more limited than on public lands, as governments typically have less regulatory control. An important exception is private landholdings in the Brazilian Amazon, where the government requires that landowners maintain 80% of the property under forest cover. Although this regulation has had limited effectiveness in the past (Alves *et al.,* 1999), recent experience with a licensing and monitoring system in the state of Mato Grosso has shown that a commitment to enforcement can significantly reduce deforestation rates (Fearnside 2003). Market access may also prove to be an effective incentive for landholders to meet forest conservation requirements on their lands.

A recently developed approach is for governments to provide environmental service payments to private forest owners in developing countries, thereby providing a direct financial incentive for the retention of forest cover. A successful example is Costa Rica's payment system for forest environmental services, which uses carbon and watershed protection financing to reimburse landowners for reforestation, sustainable forest management and forest protection (Chomitz *et al.,* 1998). Relatively high transaction costs and insecure land and resource tenure have thus far limited applications of this approach in other countries (Grieg-Gran, 2004), but significant potential may exist for developing payment schemes for restoration and retention of forest cover to provide climate mitigation (see below) and watershed protection services (Winrock International, 2004).

In addition to national-level policies, numerous international policy initiatives to support countries in their efforts to reduce deforestation have also been attempted.

- Forest policy processes, such as the UN Forum on Forests (UNFF, 2006), the Tropical Forest Action Plan, and the International Tropical Timber Organization (ITTO, 2006) have provided support to national forest planning efforts (Mankin, 1998) but have yet had demonstrable impacts on reducing deforestation (Speth, 2002). .
- The World Bank has modified its lending policies to reduce the risk of direct negative impacts to forests, but they do not appear to have measurably slowed deforestation (WBOED, 2000).
- The World Bank and G-8, have also recently initiated the Forest Law Enforcement and Governance (FLEG) process among producer and consumer nations to combat illegal logging in Asia and Africa (World Bank, 2005). It is too early to assess the effectiveness of these initiatives on conserving forests stocks.
- Independent performance evaluations of the Global Environmental Facility have concluded that while the project portfolio has likely made significant contributions to biodiversity conservation (including forests), assessing measurable impacts has been limited by the lack of an effective monitoring program (Dublin and Volante, 2004).

Taken together, non-climate policies have had minimal impact on slowing tropical deforestation, the single largest contribution of land-use change to global carbon emissions. Nevertheless, there are promising examples where countries with adequate resources and political will have been able to slow deforestation, raising the possibility that with sufficient institutional capacity, political will and sustained financial resources, it may possible to scale up these efforts. One potential source of additional financing for reducing deforestation in developing countries is through well-constructed carbon markets or other environmental service payment schemes (Winrock 2004, Santilli *et al.*, 2005; Section 9.4).

Under the UNFCCC and Kyoto Protocol, no climate policies currently exist to reduce emissions from deforestation or forest degradation in developing countries. The decision to exclude avoided deforestation projects from the Clean Development Mechanism in the Kyoto Protocol's first commitment period was in part based on methodological concerns, particularly over whether leakage could be sufficient controlled or quantified to allow for robust carbon crediting (Skutch *et al.,* 2006). In December 2005, COP-11 established a two-year process to review relevant scientific, technical and methodological issues and consider possible policy approaches and positive incentives for reducing emissions from deforestation in developing countries (UNFCCC 2005).

Recent literature suggests a broad range of possible architectures by which future climate policies might be designed to effectively reduce emissions from tropical deforestation and forest degradation (Santilli *et al.,*2005, Moutinho & Schwartzman 2005, Schlamadinger *et al.,*2005, Frieberg *et al.,*2006, Skutch *et al.,*2006). For example, Santilli *et al.*(2005), propose that non-Annex I countries might, on a voluntary basis, elect to reduce their national emissions from deforestation, with emissions reductions then credited and sold to governments or international carbon investors at the end of a commitment period, contingent upon agreement to stabilize, or further reduce, deforestation rates in the subsequent commitment periods. With effective monitoring, such a national-level approach might substantially address the problem of leakage noted above, as reductions in emissions in one area could be balanced against any emissions increases in other areas.

9.6.2 Policies aimed to promote afforestation and reforestation

Non-climate forest policies have a long history of the successful creation of plantation forests on both public and private lands in developing and developed countries. If governments have strong regulatory and institutional capacities, they may successfully control land use on public lands, and state agencies can reforest these lands directly. In cases where such capacities are more limited, governments may enter into joint management agreements with communities, so that both parties share the costs and benefits of plantation establishment (Williams, 2002). Incentives for plantation establishment may take the form of afforestation grants, investment in transportation and roads, energy subsidies, tax exemptions for forestry investments, and tariffs against competing imports (Cossalter and Pye-Smith, 2003). In contrast to the conservation of existing forests, the underlying financial incentives to establish plantations may be positive. However, the creation of virtually all significant plantation estates has relied upon government support, at least in the initial stages. This is due, in part, to the illiquidity of the investment, the high cost of capital establishment and long waiting period for financial return. Government support for plantation establishment on private lands may take the form of afforestation grants, investment in transportation and roads, energy subsidies, tax exemptions for forestry investments, and tariffs against competing imports (Cossalter and Pye-Smith, 2003).

9.6.3 Policies to improve forest management

Non-climate forest policies may impact both the sequestration and storage of carbon in managed forests (Richards *et al.*, in press). Industrialized countries generally have sufficient resources to implement policy changes in public forests. Opportunities for However, the fact that these forests are already managed to relatively high standards may limit possibilities for increasing sequestration through changed management practices include (e.g., by changing species mix, lengthening rotations, reducing harvest damage and or accelerating replanting rates) will be. However, there may be possibilities to reduce harvest rates to increase carbon storage (e.g., by reducing harvest rates and/or harvest damage).

Governments typically have less authority to regulate land use on private lands, and so have relied upon providing incentives to maintain forest cover, or to improve management. These incentives can take the form of tax credits, subsidies, cost sharing, contracts, technical assistance, and environmental service payments. In the United States, for example, several government programs promote the establishment, retention, and improved management of forest cover on private lands, often of marginal agricultural quality (Box 9.5; Gaddis *et al.*, 1995).

The lack of robust institutional and regulatory frameworks, trained personnel and secure land tenure has constrained the effectiveness of forest management in many developing countries (Tacconi *et al.,* 2003, Box 9.6). Africa, for example, had c. 649 million forested hectares as of 2000 (FAO, 2002a). Of this, only 5.5 million ha (0.8%) had long-term management plans, and only 0.9 million ha (0.1%) were certified to sound forestry standards. Thus far, efforts to improve logging practices in developing countries have met with limited success. For example, reduced-impact logging (RIL) techniques would increase carbon storage over traditional logging, but have not been widely adopted by logging companies, even when they lead to cost savings (Holmes *et al.*, 2002). Nevertheless, there are several examples where large investments in building technical and institutional capacity have dramatically improved forestry practices (Dourojeanni, 1999, Rainforest Alliance 2005).

Policies aimed at liberalizing trade in forest products have mixed impacts on forest management practices. Although trade liberalization in forest products can enhance competition and can make improved forest management practices more economically attractive in mature markets (Clarke, 2000), in the relatively immature markets of many developing countries, liberalization may act to magnify the effects of policy and market failures (Sizer *et al.*, 1999).

9.6.3.1 Mitigating the impacts of natural disturbances:

The FAO's recent forest assessment conservatively estimates that insects, disease and fire annually impact 3.2% of the forests in reporting countries (FAO 2005). Policies that successfully increase the protection of forests against natural disturbance agents may substantially reduce net emissions from forest lands (Richards *et al.*, in press). In industrialized countries, a history of fire suppression and a lack of thinning treatments have created high fuel loads in many public forests, such that when fires do occur, they release large quantities of carbon (Goldammer 2001, Schelhaas *et al.,* 2003).

Some public agencies are attempting to restore historic fire regimes in an effort to reduce damage to forests from catastrophic fires and avoid excessive suppression costs (Mutch *et al.,* 1993). A major technical obstacle is designing careful management interventions to reduce fuel loading and to restore landscape heterogeneity to forest structure (USDA Forest Service 2000). Scaling up their application to large forested areas, such as in the western US, northern Canada or Russia, could lead to large gains in the conservation of existing carbon stocks (Sizer *et al.,* 2005), Forest fire prevention and suppression capacities are rudimentary in many developing countries, but trial projects show that with sufficient resources and training, significant reductions in forest fires can be achieved (ITTO 1999; Nepstad *et al.,* 2002).

9.6.3.2 Voluntary forest certification:

Voluntary certification to sustainable forestry standards aims to improve forest management by providing incentives such as increased market access or price premiums to certified producers who meet these standards (Upton & Bass 1996). Various certification schemes have collectively certified hundreds of millions of hectares in the last decade and certification can result in measurable improvements in management practices (Dahl 2001; Gullison, 2003). However, voluntary certification efforts to date continue to be challenged in engaging and improving the management practices of forest managers operating at low standards (Atyi & Simula, 2002), where the potential for improvement and net emissions reductions are greatest. One possible approach to overcoming current barriers in areas with weak forest management practices is an include stepwise or phased approaches to certification.

9.6.4 Policies to increase substitution of forest-derived biofuels for fossil fuels and biomass for energy-intensive materials

Countries may promote the use of bioenergy for many non-climate reasons, including increasing energy security, improving air quality, and promoting rural development (Parris, 2004) and have developed a variety of approaches to support the development and maintenance of biomass industries. Brazil, for example, has a long history of encouraging plantation establishment for the production of industrial charcoal by offering a combination of tax exemption for plantation lands, tax exemption for income originating from plantation companies, and deductibility of funds used to establish plantations (Couto and Betters, 1995). The United States provides a range of incentives for ethanol production, including exclusion from excise taxes, mandating clean air performance requirements that created markets for ethanol, and tax incentives and accelerated depreciation schedules for electricity generating equipment that burn biomass (USDOE, 2005).

Building codes and other government policies that can, where appropriate, promote the substitution of use of sustainably harvested forest products wood for more energy-intensive construction materials (USEPA 2006, USGBC 2006) may have substantial potential to reduce net emissions (Trusty and Meil, 2001, Lippke *et al.,* 2004, Murphy 2004). Private companies (e.g., BSR 2006) and individuals may also modify their procurement to prefer or require certified wood from well-managed forests on environmental grounds. Such efforts might be expanded once the climate mitigation benefits of sustainably harvested wood products are more fully recognized.

9.6.5 Strengthening the role of forest policies in mitigating climate change

Policies have generally been most successful in changing forestry activities where either they provide or are consistent with underlying provide profitability incentives, or where there is sufficient political will, financial resources and regulatory capacity for effective implementation. Available evidence suggests that policies that seek to alter forestry activities where these conditions do not apply have had limited effectiveness. Additional factors that influence the potential for non-climate polices to reduce net emissions from the forest sector include their ability to (1) provide relatively large net reductions per unit area (2) be potentially applicable at a large geographic scale and (3) have relatively low leakage (Niesten *et al.*, 2002).

By these criteria, promising approaches across both industrialized and developing countries include policies that combat the loss of public forests to natural disturbance agents, and environmental service payments that provide an incentive for the retention of forest cover. In both cases there are good examples where they have been successfully implemented at small scales, and the impediments to increasing scale are relatively well understood. There is also a successful history of policies to create new forests, and these have led to the large onsite reductions in net emissions. Care must be taken however to make sure that at plantation creation, there is no displacement of economic or subsistence activities that will lead to forest clearing elsewhere. Policies to increase the substitution of fossil fuels with bioenergy have also had a large positive impact on net emissions. If feedstock is forestry waste, then there is little potential leakage. If new plantations are created for biofuel, then care must be taken to reduce leakage.

Because forestry policies tend not to have climate mitigation as core objective, leakage and other factors that may limit net reductions are generally not considered. This may change as countries begin to integrate climate mitigation objectives more fully into national forestry policies. Countries where such integration is taking place include Costa Rica, the Dominican Republic and Peru (Rosenbaum *et al.*, 2004).

Box 9.5: Non-climate forest policies as an element of carbon management in the United States

Many programs in the United States support the establishment, retention, and improved management of forest cover on private lands, which comprise approximately 60 % of the land base, 70% in the contiguous 48 states. These are administered primarily through the US Department of Agriculture (USDA) and entail contracts and subsidies to private landowners to improve or change land use management practices. The USDA also provides technical information, research services, cost sharing and other financial incentives to improve land management practices, including foresting marginal agricultural lands, and improving the management of existing of forests. Examples include the Conservation Reserve Program; the Forestry Incentives Program; Partners for Wildlife; Conservation Reserve Enhancement Program; and the Forest Legacy Program (Gaddis *et al.,*1995, Richards *et al.,*in press). For example, in the twenty year period between 1974 – 1994, the Forestry Incentives Program spent US $200 million to fund 3.32 million acres of tree planting, 1.45 million acres of stand improvement, and 0.27 million acres of site preparation for natural regeneration (Gaddis *et al.,* 1995).

Richards *et al.,* (in press) review the range of existing agricultural and forestry programs and policies in the United States and conclude that they can help form part of the framework of a national carbon management strategy. They suggest that substantial gains in carbon sequestration and storage could be achieved by increasing the resources and scope of these programs and through new results-based programs, which would reward landowners based on the actual carbon they sequester or store.

Box 9.6 Non-climate forest policies as an element of carbon management in Africa, with a case study of Sudan

Forest and land use policies across African countries have historically passed through two types of governance: Under *traditional systems controlled by families, traditional leaders and communities*, decisions regarding land allocation, redistribution and protection were the responsibility of traditional leaders. Land and resources were under relatively sustainable management. Most communities were either nomadic or agro-pastoralist who developed systems to cope with vulnerable conditions. The customary management system continued regulations and customary laws used as instruments for implementation of land and resource management systems. Agriculture was typically limited to shifting cultivation, with forest and range resources managed for multiple benefits.

Under strong central government systems, land-use policies are sectorally focused, with traditional strong governance in the agricultural sector. Agriculture expansion policies typically dominate land use at the expense of forestry and rangeland management. This has greatly influenced present day forest and range policies and practices and resulted in vast land degradation (IUCN 2002, 2004).The adoption of centralized land management policies and legislation system has often brought previously community-oriented land management systems into national frameworks, largely without the consent and involvement of local communities. Central control is reflected in large protected areas, with entry of local communities prevented.

Presently, contradiction and conflicts in land-use practices between sectors and communities is a common feature that negatively impacts the sustainability of forest management. Many conflicts have resulted in subsequent negotiations demanding decentralization and equity in resource distribution. The results may lead to changes in land tenure systems in which communities and official organizations will increasingly agree to collaboration and joint management regimes. Many countries have positively changed attitudes to decentralization as a result of greater involvement of civil societies. In some countries, parastatal institutions have been established to formulate and implement policies and legislations that coordinate between sectors and to encourage community participation in land and resource management.

Land tenure categories characteristically include *private holdings* (5–25 % of national area), *communal land* (usually very small percent) and *state lands* (the majority of the land under government control). Each faces many problems generated by conflicting rights of use and legislation that give greater government control on types of resource use even under conditions of private ownership. Land control system and land allocation policy adopted by central governments often have negative impacts on land and tree tenure. Local communities are not encouraged to plant, conserve and manage trees on land perceived as government. Even large-scale farmers who are allocated large areas for cultivation, abandon the land and leave it as bare when it is becoming non-productive. The land is government owned and the farmers use it on lease system. Forest lands reserved and registered under community ownership are communally managed on the basis of stakeholder system and shared benefits.

Many case studies in Sudan indicate acceptance of integrated forest management based on collaborative management in which communities have access rights to forest lands and are involved in management. An example is the rehabilitation of the Elrawashda Natural Forest Reserve in Eastern Sudan. Here, an FAO project (FAO/SUD/FDES) from its start in 1980 clearly defined the objectives of rehabilitation of the forest involving the local villagers. During the rehabilitation process, the villagers have access to agricultural land, grazing land and water points in an agroforestry system involving agricultural crops and tree seed cultivation on the same land. Forest seedlings survival counts indicated very high rates of first-year survival.

During (1994-1999) the project developed a contract-based collaborative system with the local villagers for the use of the forest land property. The contract clearly defines acceptable criteria for land cultivation by the local people and for renewal of forest crop. Each individual farmer is granted a piece of land inside the forest such that 75% of it is used for agricultural crop cultivation and on the 25% the farmer raises forest crop and obliged to protect the young seedlings. The annually planted area, the stocking density and the increasing number of farmers willing to participate in the system during 1994-1998 was indicative of the success of the collaborative system.

9.6.6 Greenhouse Gas Mitigation Project-based experience since 2000

Due to uncertainty over regulation, few forestry mitigation projects have been undertaken since 2000. Clean Development Mechanism (CDM) afforestation and reforestation (A/R) was not operational before September 2004, when the first call for methodologies was issued by the CDM Executive Board. Projects in Annex I countries are subject to fewer limitations. In principle, all land-use related activities are eligible for crediting, starting from 2008. Furthermore, the credits generated do not expire, because host country governments will remain responsible for the maintenance of the carbon stocks once built up on their territories.

9.6.6.1 Social Issues

Literature stresses the importance of social issues for LULUCF projects. While on the one hand, LULUCF activities have the potential to improve local livelihoods, most of all in developing countries, risks and benefits are seen to be unevenly spread between different project types. Under this aspect, there is a noticeable preference for agro-forestry projects (Smith and Scherr 2003). Among the most important risks there is land use competition, ownership concentration, and resource access by indigenous populations (Orlando *et al.,* 2002). Under CDM A/R, an analysis of socio-economic impacts is required, and an impact assessment is due, if one of the project participants or the host country party considers these impacts significant (UNFCCC, 2003). Several sets of criteria have been proposed to assess these impacts. LULUCF projects are seen to vastly improve local livelihoods, reasons being that they potentially imply large areas under competing land uses and largely adopt traditional techniques (Robledo and Blaser 2001). Ten different areas of concern are identified: "(1) identification of social groups and social system; (2) land tenure and land-use rights; (3) perception of affected social groups; (4) credibility; (5) participation; (6) social acceptance; (7) communication; (8) local capacity building; (9) equity; and (10) livelihood improvement." (Madlenera *et al.,* 2003).

9.6.6.2 Environmental issues

For climate projects, the atmospheric benefit is the market indicator for one single environmental service (Smith and Scherr 2002), which is checked when assessing project additionality. Nevertheless, LULUCF implies a series of environmental externalities. Indicators for these are the project's impact on water resources, soils (beyond carbon content), biodiversity and environmental education (May *et al.,* 2004). Biodiversity conservation is among the targets defined in Art. 2 of the ultimate objective of the UNFCCC ("allowing ecosystems to adapt naturally to climate change") (Ott *et al.,* 2004), and there is an indirect reference to it in Art. 2.1 (ii) of the Kyoto Protocol (Smith and Scherr 2002). As for social issues, the CDM A/R modalities and procedures require an environmental impact analysis and an assessment if one of the project participants or the host country party deems this appropriate (UNFCCC, 2003).

9.6.6.3 Methodology development since the Third Assessment Report

Out of the methodologies to be submitted for the first ten CDM A/R projects, only one was approved in 2005. Among those, there are seven forest restoration activities, most of which include commercial harvesting. The remaining three are agro-forestry or silvo-pastoril activities. Their size varies between 523 and 19,000 ha. All except for two were started between the years 2000 and 2005. Lifetimes range between 20 and 60 years, the expected lifetime CERs are summing up to 18 Mt temporary CO_2 equivalents (see below under "Permanence"). Size and CER value do not necessarily correlate, as the latter depend on growth conditions, tree species and management practices.

9.6.6.4 Leakage

Leakage is the term used for measurable external GHG effects attributable to a determined climate change mitigation activity outside the boundaries of the mitigating entity (e.g., a nation, or a mitigation project). There is no indication that leakage effects are necessarily higher in either GHG emission reduction or removal, and they occur in other sectors as well, but they can be significant in LULUCF mitigation (Chomitz 2002). Some authors distinguish between primary and secondary effects. A primary effect is defined as resulting from agents that perform land use activities reflected in the baseline. Populations previously active on the project area may shift their activities to other areas, referred to as activity shifting. Also logging companies shift operations or buy timber from outside the area to compensate for reduced supply of a commodity like timber (outsourcing the activity). Secondary leakage activities are not linked to project participants or previous actors on the area. They are often termed market effects, where a project increases (as in the case of A/R) or decreases (deforestation avoidance, FM) wood supply. Also super-acceptance, i.e. an influx of population, can constitute secondary leakag e (Aukland et al., 2003). The order of magnitude and even the direction (negative vs. positive) of leakage, however, depends on the actual project design or national program (Schwarze et al., 2003). More recently, economic appraisal of leakage argues that leakage is economic in nature, and thus all essentially market leakage (US EPA, 2005).

There is an extensive body of literature discussing leakage, but a small set estimating market leakage in the context of LULUCF (Sohngen and Brown, 2004, Vohringer *et al.,* 2004) (Table 9.13). If forestation, forest management or avoided deforestation is undertaken as an individual mitigation activity, then significant to very large leakage is likely and GHG accounting would need to reflect it (US EPA, 2005). Quantitative estimates of leakage suggest that leakage varies by mitigation activity and region, reflecting wood product market responses across regions (e.g., afforestation leakage in the USA varies from 18-42% (Murray et al, 2004). Avoided deforestation leakage is on the order of 50% but can range higher (Sohngen and Brown, 2004). Nevertheless, as under CDM A/R only emissions and not stock changes outside the project area are being accounted for, market leakage is hardly an issue in the first commitment period. Project emissions unrelated to stock change, like from the use of fossil fuels and fertilizer, are internally compensated by deducting them from the tCERs or lCERs produced.

Table 9.13: *Forestry mitigation activity leakage estimates by activity and region from this issue, compared to other literature. Source: Editorial: Special Issue on Estimation of Baselines and Leakage in Carbon Mitigation Forestry Projects, Jayant A.Sathaye and Kenneth Andrasko*

Activity	**Region**	**Leakage Estimation Method**	**Estimated Leakage Rate (% of C mitigation)**	**Source**
Afforestation: Tropical Region Estimates				
Afforestation of degraded lands	Kolar district, Karnataka, India hypothetical project	Household wood demand survey	0.02	Ravindranath, Murthy, Sudha et al, this issue
Plantations, forest conservation, agroforestry of degraded lands	Magat watershed, Philippines hypothetical project	Historical rates of technology adoption	19 – 41	Authors estimates based on Lasco *et al.*, this issue
Afforestation on small landowner parcels	Scolel Té project, Chiapas, Mexico	Household wood demand survey	0 (some positive leakage)	De Jong *et al.*, this issue
Afforestation degraded uplands	Betalghat hypothetical project, Uttaranchal, India	Household wood demand survey	10 from fuelwood, fodder	Hooda *et al.*, this issue
Afforestation, farm forestry	Bazpur hypothetical project, Uttaranchal, India	Household wood demand survey	20 from fuelwood, poles	Hooda *et al.*, this issue
Afforestation: Global and Temperate Region Estimates				
Afforestation (plantation establishment)	Global	PEM	0.4-15.6	Sedjo and Sohngen, 2000
Afforestation	USA wide	PEM	18-42	Murray *et al.*, 2004
Afforestation only	USA wide	PEM	24	US EPA, 2005
Afforestation and	USA wide	PEM	-2.8 *	US EPA, 2005

forest management jointly				
Avoided Deforestation: Tropical Region Estimates				
Avoided deforestation	Bolivia, Noel Kempff project and national	PEM	5-42 undiscounted 2-38 discounted	Sohngen and Brown, 2004
Avoided Deforestation and Biofuels: Temperate Region Estimates				
Avoided deforestation	Northeast USA	PEM	41-43	US EPA, 2005
Avoided deforestation	Rest of USA	PEM	0-92	US EPA, 2005
Avoided deforestation	Pacific NW USA	PEM	8-16	US EPA, 2005
Avoided deforestation (reduced timber sales)	Pacific NW USA	Econometric model	43 West region 58 continental US 84 US and Canada	Wear and Murray, 2004
Biofuel production (short rotation)	USA		0.2	US EPA, 2005

* Negative leakage rate means positive leakage; NA means not available; PEM means partial equilibrium model

However, if forestation and forest management are undertaken (and paid for in some GHG mitigation program) jointly, then leakage in USA drops to zero or positive leakage occurs, since activity that would be leaked to forest management is also included in program payments and GHG accounting (US EPA. 2005). Thus comprehensive mitigation that includes the entire forest sector of a country or region may have minimal leakage. Leakage appears to have a time dimension as well, due to the dynamics of the forest C cycle and management (e.g., timing of harvest, planting and regrowth, or protection). Analysis in the USA indicates that national afforestation in response to a C price of \$15/tCO_2 would have 39% leakage in the first two decades, but decline to 24% leakage over 5-10 decades, due to forest management dynamics (US EPA. 2005). Leakage also occurs internationally, as say reduced timber harvest in one country is offset by increased harvest in another country.

9.6.6.5 Permanence

The necessity to adapt accounting to the generic problem of non-permanence of carbon removal from the atmosphere arises wherever the host country of an activity cannot be held liable for a loss in carbon stocks on its territory. This is the case for CDM LULUCF activities in non-Annex I countries.

The “ton-year” approach, as discussed in the LULUCF SR, was intended to create a direct comparison between LULUCF mitigation activities and other GHG emission avoidance. Though several approaches were presented, they ultimately failed to convince decision makers, because they all depended on an arbitrarily chosen time horizon. In 2000, the Colombian delegation first presented a proposal to create expiring CERs (UNFCCC, 2000). Its basic idea is that the validity of CERs from

LULUCF CDM directly relates to the time of existence of the relating stocks. Most projects developed before 2003 departed from CO_2 removals to be accounted as permanent credits. The European Union Emissions Trading Scheme for its pre-Kyoto period 2005-2007 refrains from converting any forest-related credits into European Allowance Units; be they from JI or CDM (EU, 2003).

Decision 19/CP.9 (UNFCCC, 2003) created two types of CERs to reflect the potential non-permanence of carbon sequestration in A/R projects. These are temporary CERs (tCERs) and long-term CERs (lCERs). Both credit types have in common that their validity is limited and notified on the actual certificate. After the end of their validity, they have to be replaced. During the commitment period in which they were certified, the buyer does not hold any liability. While tCERs expire after five years, lCERs expire at the end of the last full crediting period covered by the project crediting period. Replacement of tCERs can be done by any type of permanent emission allowance. Also, newly certified tCERs are accepted as a replacement for used tCERs. A/R projects need to be verified first at a point in time at the discretion of the project participants, and exactly every five years thereafter. If a negative stock variation is assessed by the verifier between two verification dates, the respective part of lCERs stemming from the project will be cancelled and have to be replaced in the subsequent commitment period (Table 9.14). In spite of their longer validity, lCERs show several drawbacks, compared to tCERs (Dutschke, 2005). The tCER/lCER value critically depends on the market participants' expectations on future commitment periods. Assuming constant carbon prices, it is estimated to range between 14 and 35 percent the one of "normal" CERs during the first commitment period (Figure 9.20).

Table 9.14: *Characteristics of lCER's and tÇER's*

	tCER	lCER
Discount for project emissions and negative leakage	Only for emissions since the last verification	During the whole (remaining) crediting period
Duration of validity	Five years after last verification during the crediting period	Only until the end of the last entire commitment period during the crediting period
Validity for compliance	Renewed tCER can be used during the commitment period it was certified	As lCERs are not renewed. they can only be used for compliance in one commitment period

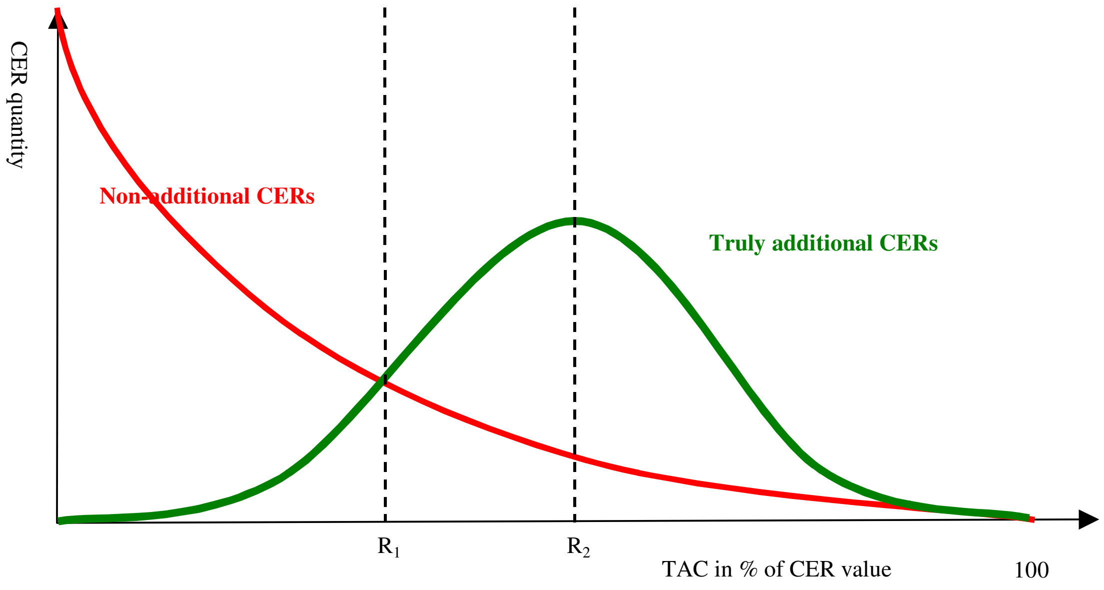


***Figure 9.20:** Trade-off between control-related Transaction costs (TAC) and Certified emission reduction (CER) output*

9.6.6.6 Project quality standardization

Temporary crediting leads to recurrent investor liability. Hence, the investment decision depends on project quality investors uninvolved in the project activity are unable assess. The Climate, Community & Biodiversity Alliance, an international consortium of enterprises, environmental NGOs and research institutions, has developed a triple project design standards for climate-relevant project activities, which is geared towards becoming a benchmark for forest-climate activities inside and outside the Kyoto Protocol. It is directed to project participants, investors and governments. The first edition of the proposed standard was published in May 2005 (CCBA, 2005). During the development phase, the standard was field-tested on a dozen of project sites.

9.6.6.7 Additionality and baselines

Additionality is a central concern in any compliance mechanism, and LULUCF is no exception. The Consolidated Additionality Tool constitutes guidance by the CDM Executive Board to project developers. Specific for A/R, the A/R Additionality Tool tests area eligibility along the forest definitions provided under the relevant Decision 11/CP.7, in order to avoid the implementation on areas that previous to the project start were forests in 1990 or after. There are differences in baseline-setting between industrial and A/R projects. Industrial mitigation projects continue to provide the same product or service with lower emissions in production or use. The analogy in the land-use sector would be forest management. Most A/R activities however, are constituted by a switch from other land uses to forestry (to the exception of agro-forestry or silvo-pastoral systems). In case the area was under productive use before, the activity usually causes a combination of opportunity costs of disruption of the previous activity and activity leakage in varying degrees.

9.7 Forests and Sustainable Development

Sustainable forest management of both natural and planted forests is essential to achieving sustainable development and is a means to reduce poverty, reduce deforestation, halt the loss of forest biodiversity, and reduce land and resource degradation. At the same time, forests can play a role to achieve the ultimate objective of the United Nations Framework Convention on Climate Change of stabilisation of greenhouse gas concentrations in the atmosphere (Article 2), as recalled by the UN Millenium Declaration, while promoting sustainable development (SD) (Article 2 of the Kyoto Protocol). Thus, forests have to be seen in the framework of the multiple dimensions of SD, if the positive co-benefits from forestry mitigation activities want to be maximized. Important environmental, social and economic ancillary benefits can be gained by considering forestry mitigation options as an element of the broad land management plans.

9.7.1 Conceptual aspects

LULUCF policies and measures undertaken to reduce GHG emissions may have significant positive or negative impacts on environmental and sustainable development objectives that are a central focus of other multilateral environmental agreements (MEAs), including UN Convention on Biological Diversity (CBD), UN Convention to Combat Desertification (CCD), and Ramsar Convention on Wetlands (IPCC, 2000). Article 2.1(a,b) provides that Parties might consider potential impacts of mitigation options and whether and how to establish some common approaches to promoting the SD contributions of LULUCF measures. In addition, a broad range of issues relating to forest conservation and sustainable forest management are one of the focus of recent dialogues under the Intergovernmental Forum on Forests (UNFF), and SFM is promoted by international organisations as the International Tropical Timber Organisation (ITTO).

Recent studies highlighted that strategic thinking about the transition to a sustainable future is particularly important for land (Swanson *et al.*, 2004). In general, in many countries a full variety of separate sets of social, economic and environmental indicators are used, making it difficult to allow for an adequate monitoring and analysis of trade-offs between these interlinked dimensions. Still, SD strategies remain many times in the periphery of government decision-making processes; and lack co-ordination between sub-national and local institutions; and economic instruments are often under-utilised.

To manage forest ecosystems in a sustainable way implies knowledge of their main functions, and the effects of human practices. In recent years the scientific literature shows an increasing attempt to understand integrated and long-term effects of current practices of forest management on SD, but often considering environmental or socio-economic effects in isolation, or without sufficient understanding of the potential long term impacts of these practices on SD. Environmental payment schemes for forest services (i.e. recognizing carbon value) may be foreseen as part of forest management implementation, providing new incentives to change to more sustainable decision patterns..

Important environmental, social and economic ancillary benefits can be gained by considering forestry mitigation options as an element of the broad land management plans, pursuing SD paths, involving local stakeholders and developing adequate policy frameworks.

9.7.2 Ancillary effects of GHG mitigation policies

Climate mitigation policies may have benefits that go beyond global climate protection and actually accrue at the local level (Dudek *et al.*, 2002). Since ancillary benefits tend to be local, rather than global (OECD, 2002), identifying and accounting for them can reduce or partially compensate the costs of the mitigation measures. However, it should always be kept in mind that forests fulfill many important environmental functions and services that can be enhanced or negatively disturbed by human activities and management decisions. On the other hand, also negative effects can be triggered by some mitigation options under certain circumstances (i.e. short monoculture rotations for bioenergy can lead to losses on Biodiversity, particularly in the tropics). Table 9.15 presents positive as well negative impacts of mitigation options on sustainable development.

Table 9.15: *Sustainable Development Implications of Forestry Mitigation*

Activity category	**Sustainable development Implications**		
	Social	**Economic**	**Environmental**
A. Increasing or maintaining the forest area			
Reducing deforestation and forest degradation	Promote livelihood [1]	Provide sustained income for poor communities, but possible problems if competing with non local forest industry	Biodiversity conservation Water shield protection Soil protection Amenity values (Nature reserves, etc.)
Afforestation / Reforestation	Promote livelihood Slow down the population migration to other areas. Displacement of people may occur if the former activity is stopped, and optional activities not provided	Creation of employment (when not a more intense land use is replaced) Increase/decrease of the income of local communities Provision of forest products (i.e. fuel wood, fibre, construction materials) and other services	Potential negative impacts on Biodiversity conservation (i.e. mono-specific plantations replacing diverse shrub lands) Water shield protection Soil protection
B. Changing forest management			
Forest management in plantations	Promote livelihood May compete with other potential land uses (i.e. agriculture)	Creation of employment Increase of the income of local communities Provision of forest products (i.e. fuel wood, fibre, construction materials) and other services	Negative impacts on Biodiversity and water shield protection may result in negative impacts under certain management
Forest management in native forest	Promote livelihood May compete with other potential land uses (i.e. agriculture)	Creation of employment Increase of the income of local communities Provision of some forest products (i.e. fuel wood, fibre, construction materials) and other services	Negative impacts on Biodiversity Water shield protection may result affected under certain management
C. Substitution of energy intensive materials			
Increasing substitution of fossil energy intensive products by wood products	Minimal impacts expected	Increased local income employment Potential diversification of local economies Provision of renewable, and independent energy source	Positive or negative impacts possible, but likely to be less negative impacts than in the case of bioenergy
D. Bioenergy			
Bioenergy production from forestry	Minimal impacts expected Forest owners may benefit Potential competition with the agricultural sector (food production, etc.)	Increased local income employment, but possibly higher raw material prices for forest industry Potential diversification of local economies Provision of renewable, and independent energy source	Positive if production of fuelwood is done in a sustainable way

9.7.2.1 Reducing deforestation and forest degradation:

Stopping or slowing deforestation and forest degradation (loss of C density) and sustainable management of native forests may significantly contribute to avoid emissions, conserve water resources and prevent flooding, reduce run-off, control erosion, reduce siltation of rivers, and protect fisheries and investments in hydroelectric power facilities; and at the same time preserve biodiversity (Parrotta, 2002).

9.7.2.2 Afforestation / Reforestation

Planted Forests. Plantations provide an option to enhance terrestrial sinks and mitigate climate change. Effects of plantations on SD of rural societies have been diverse, depending on the site and management regime. Plantations may have either significant positive and /or negative effects (i.e. environmental and social effects). They can positively contribute, for example, to employment, economic growth, exports, renewable energy supply and poverty alleviation. But in some instances, plantation may also lead to negative social impacts such as loss of grazing land and source of livelihoods.

Large investments have been made in commercial plantations on degraded land in Asia (Sayer *et al.*, 2004), these initiatives are often politically driven and aspire to achieve both economic and environmental benefits, but often lack of clarity about the objectives and lack of consultation with stakeholders (i.e state of land tenure and use rights) may result in failure to achieve the pursued results. Spek (2006) also notes that weaknesses in the risk assessment system when having to decide in investing in pulp mills and plantations, allow poor practice to go undetected. As a result, highly unsustainable pulp producers can often obtain funding, even though the existence of safeguards should make this impossible. Better integration between social goals and afforestation activities seems to be necessary (Farley *et al.*, 2004) As demand increases for lands to install plantations, more comprehensive, multidimensional environmental assessment and planning will be required to manage land in a sustainable way.

Agroforestry can produce a wide range of economic, social and environmental benefits; probably wider than in case of large-scale afforestation. Agroforestry systems could be an interesting opportunity for conventional livestock production with low financial returns and negative environmental effects (e.g. overgrazing and soil degradation). For many livestock farmers, which may face financial barriers to develop this type of combined systems (i.e. silvopastoral systems); payment for environmental services could contribute to the feasibility of these initiatives (Gobbi, 2003). Shadow of trees and shelter may have also beneficial effects on livestock production and income, as reported by Bentancourt *et al.,* (2003). Little evidence of local extinctions and invasions of species, risking biodiversity, has been found when practicing agroforestry (Clavijo *et al.*, 2005).

9.7.3 Implications of mitigation options water, biodiversity and soil

Land degradation, access to water and food and human health remained at the centre of global attention under the debate on the World Summit on Sustainable Development (WSSD). The focus on five key thematic areas was proposed (Water, Energy, Health, Agriculture, and Biodiversiy - WEHAB), driving the attention to the fact that managing the natural resources like forest in a sustainable and integrated manner is essential for SD. In this regard, to reverse the current trend in forest degradation as soon as possible, it is necessary to implement strategies which should include targets adopted at the national and, where appropriate, regional levels to protect ecosystems and to achieve integrated management of land, water and living resources associated to forest areas, while strengthening regional, national and local capacities.

Water cycle: Afforestation may result in better balance in the regional water cycle balance by, reducing flooding, and control groundwater recharge and watersheds protection. However, massive afforestation may have strong yet not completely quantified effects on the hydrological cycle, i.e.: conversion of native grasslands in the Southern Hemisphere (Nosetto *et al.*, 2005). Plantations on grasslands may reduce water flow into other ecosystems and rivers and affect aquifers layer and recharge (Gyenge *et al.*, 2003) and lead to substantial losses in stream flow (Jackson et al, 2005). In addition, some possible changes in soil properties are largely driven by changes in hydrology.

Soils: Compared to other ecosystems, plantations have increased nutrient demands that affect soil fertility and soil properties, for example leading to higher erodibility of the uncovered mineral soil surface (*Eucalyptus grandis* plantations, Perez-Bidegain *et al.*, 2001; conifer plantations in New Zealand, Powell, 2001 and Condron, 2002), podzolization of the soil that negatively affects SOC (Carrasco-Letellier *et al.*, 2004); and biological properties changes (Sicardi *et al.,* 2004). Regarding chemical properties, increased Na concentrations, exchangeable sodium percentage and soil acidity, and decreased base saturation have been detected in many situations. (Jackson, R.B. *et al.*, 2005). In general, afforestation of low soil C croplands may present considerable opportunities for C sequestration in soil, while afforestation of grazing land can result in relatively smaller increases or decreases in soil C (Paul *et al.,*2003 Guo and Gifford, 2002). Some possible changes in the above mentioned soil properties are largely driven by changes in hydrology.

Biodiversity: Usually plantations have lower biodiversity compared to previous land use (Wagner 2006), with the exception of degraded lands. Plantations can negatively affect biodiversity if they replace biologically rich native grassland or wetland habitats (Bregje *et al.*, 2003). Being scale, species, management, age, and rotation period relevant for biodiversity (Quine and Humphrey, 2005). Plantations may act as corridors, source, or barriers for different species (Rusch *et al.*, 2004), and a tool for landscape restoration (Parrota, 2005).

The literature seems to suggest that plantations require careful assessment of the potential impacts on soils, hydrological cycle and biodiversity, and that negative impacts could be controlled or minimised if adequate landscape planning and basin management and good practices are introduced. There is a need for further work to quantify the key ecosystems processes that change with afforestation (Ross et al, 2002). Carbon sequestration strategies with afforestation of non forest lands should consider their full environmental consequences. The ultimate balance of co-benefits and co-costs depends on the specific conditions and previous and future soil management. To compare the value of ecosystem services gained or lost with the value of carbon sequestration is one way to understand actual trade-offs and ensure sustainable management of land (Jackson et al; 2005).

9.8 Technology RD, deployment, diffusion and transfer

Technology research, development and transfer have a potential to promote forestry mitigation options through sustainable forest management, plantations, substitution of wood products and bioenergy. There are broad levels and categories of technologies for promoting mitigation options from the national level to the forest stand level, and from forest practice approaches to socio-economic approaches (IPCC, 2000).

9.8.1 Technology RD in the Forest Sector

Regarding technology for harvesting and procurement, mechanized forest machines such as harvesters, processors and forwarders which have been developed in Northern Europe and North America, have been coming into increasing use around the world for the past several decades. Mechanization in forestry seems to be effective for promoting mitigation options (Karjalainen and Asikainen 1996). However, harvesting and procurement systems vary due to terrain, type of forest, infrastructure and transport regulations (Andersson *et al.,* 2002), and appropriate systems also vary by regions and countries. Low-impact logging is considered in some cases such as tropical forests (Pinard 1996, Enters *et al.,* 2002). Therefore, technologies on forest machines and harvesting systems for promoting mitigation options should be developed that are suitable for the specific conditions in countries and regions.

As the area of planted forests including plantations of fast growing species for carbon sequestration increases, forest practices including thinning will become more important for both productivity and the environment. Thinning is also promoted to prevent forest fires and insect disease in the United States (LeVan-Green 2003). However, single-tree felling and handling of small-diameter trees at thinning are labor-intensive operations which result in higher costs (Andersson *et al.,* 2002). The development of suitable low-cost technologies will be necessary for promoting thinning. Moreover, technology will have to be developed for making effective use of small wood, including thinned timber, in forest products and markets. Thinning and tree pruning for fuelwood and fodder are regularly conducted in many developing countries as part of local integrated forest management strategies. Although natural dynamics are part of the forest ecosystem, the suppression of forest fires and prevention of insect and pest disease are important for mitigation. Fire and insect/pest management have been researched for a long time (Amiro *et al.,* 2002), but further progress will have to be made to enhance mitigation options.

Substitution of energy-intensive materials by forest products reduces fossil fuel consumption. There is a wide array of technologies for using the energy of biomass derived from forests, including direct combustion, gasification, pyrolysis, and fermentation (See Chapter 4, and also Kitani and Hall, 1989). To conserve forest resources, it is necessary to expand the recycling of wood waste material. Technology for manufacturing waste-derived board has almost been established, but further R&D will be necessary to re-use waste sawn timber or to recycle it as lumber. While these technologies often need large infrastructure and incentives in industrialized countries, practical devices such as new generations of efficient wood-burning cooking stoves (Aggarwal and Chandel, 2004; Masera *et al.,* 2005) have proved effective in developing countries as a means to reduce the use of wood fuels derived from forests at the same time providing tangible SD benefits for local people such as reduction in indoor air pollution levels.

Technological research and development for proper estimation of cabon stocks and fluxes is fundamental not only for monitoring and managing land use, land-use change and forestry including deforestation, reforestation and forest management, but also for predicting the impact of climate change and evaluating policies for mitigating climate change. Practical methods for estimating carbon stocks and fluxes based on forest inventories and remote sensing have been recommended in the Good Practice Guidance for LULUCF (IPCC, 2004). At the same time, large-scale estimations of the carbon flux in the forest sector have been carried out with carbon flux models such as the CBM-CFS2 (Kurz and Apps, 1999), CO2FIX V.2 model (Masera et al, 2003), EFISCEN (Nabuurs *et al.,* 2002, Karjalainen et al, 2002), FullCAM (Richards and Evans, 2004), and GORCAM (Schlamadinger and Marland 1996). High-resolution satellite images have become available, so new research on remote sensing has begun on using satellite radar and LIDAR (light detection and ranging) for estimating forest biomass (Lefsky *et al.*, 2002, Hirata *et al.*, 2003).

Socio-economic approaches are also important for making decisions and polices for mitigation. A cost analysis of mitigation options showed that the costs of substitution of biomass were lowest (van Kooten *et al.*, 2004), and a combination of ecological and economic models could estimate the potential effects of climate change on the global forest sector (Perez-Garcia *et al.*, 2002). Integrated multiscale sustainability assessments have proved very helpful to understand the synergies and trade-offs between the social, economic and environmental dimensions of forestry mitigation options (Spilsbury, 2005).

New technologies including the remote sensing, carbon flux models and socio-economic methods described above will facilitate the implementation of mitigation options. Furthermore, the integration of scientific knowledge, practical techniques, socio-economic and political approaches will become increasingly significant for mitigation technologies in the forest sector,

9.8.2 Technology Deployment, Diffusion and Transfer

The deployment, diffusion and transfer of technologies such as improved forest management systems, forest practices and processing technologies including bioenergy, are key to improving the economic and social viability of the different mitigation options.

For technology deployment, diffusion and transfer, governments could play a critical role in: a) providing targeted financial and technical support through multilateral agencies (such as GEF, World Bank, FAO, UNDP, UNEP), CGIAR institutions (such as CIFOR, ICRAF) and ODA, in developing and enforcing the regulations to implement mitigation options, b) promoting the participation of communities, institutions and NGOs in forestry projects, and c) creating conditions to enable the participation of industry and farmers with adequate guidelines to ensure forest management and practices as mitigation options (IPCC, 2000). In addition, the role of private sector funding of projects needs to be promoted under the new initiatives, including the proposed flexible mechanisms under the Kyoto Protocol. GEF could fund projects that actively promote technology transfer and capacity building in addition to the mitigation aspects.

Appropriately designed forestry mitigation and adaptation projects will also contribute to other environmental benefits such as biodiversity conservation and watershed protection, and provide socio-economic benefits to urban and rural populations through access to forest products and the creation of jobs, especially in rural areas. Ultimately, this will help to promote sustainable development (Section 9.7).

9.9 Long-term Outlook

Projections of forest mitigation are usually reported as a net sum of emissions from deforestation versus sinks from afforestation and build up of growing stock in existing forests. Recent estimates project baseline annual global net forest carbon emissions of approximately 1100 to 2200 $MtCO_2$/yr in 2050 and a wide range from a sink of 2200 $MtCO_2$/yr to a source of 700 $MtCO_2$/yr in 2100, well within the broad SRES ranges that result from the various SRES storylines. However, Leemans *et al.,* (2002) showed that uncertainties in the carbon cycle, the uncertain impacts of climatic change and its many dynamic feedbacks can cause large variation in future carbon balance projections. Other scenarios suggest that net deforestation pressure will slow over time as population growth slows and crop and livestock productivity increase; and, despite continued projected loss of forest area, carbon uptake from afforestation and reforestation could result in net sequestration (Chapter 3).

By 2030 the economic potential of a combination of measures in afforestation, avoided deforestation, forest management, agroforestry, and bioenergy, could yield on average an additional sink of around 3150 $MtCO_2$/yr (medium confidence). Top-down global models generally give higher global economic potentials with an average of 12800 $MtCO_2$/yr in 2030. Mitigation measures are able to avoid the biosphere going into a net source globally (Fig Exe sum 1). The market potential is probably a small fraction of these numbers as is reflected by current slow processes of implementation of forestry measures under the Kyoto Protocol (medium confidence).

The longer-term prospects (beyond 2030) of mitigation within the forestry sector will be influenced by the interrelationship of a complex set of environmental, socio-economic and political factors. The history of land-use and forest management processes that have taken place in the last century, particularly within the temperate and boreal regions, as well as on the recent patterns of land-use will have a critical effect on the mitigation potential. Also, the impacts of climate change on forests will be a major source of uncertainty regarding future projections. Other issues that will have an effect on the long-term mitigation potential include future sectoral changes within forestry, changes in other economic sectors, as well as political and social change, and the particular development paths that take place within industrialized and developing countries beyond the first half of the XXI century.

Specific factors and trends that will have a major impact on the mitigation potential of forestry worldwide include:

- Increase in the management of forests for recreational/nature uses with emphasis on the provision of environmental services, particularly within industrialized countries.
- Increase in the area of forest plantations, particularly among developing countries. This rate will probably peak in the first half of the century and tend to slow down afterwards because as the most productive and economically interesting sites are been used.
- More emphasis in the use of forest residues and forest plantations –including multi-purpose plantations- for the production of bioenergy. As the price for fossil fuels increase, the use of forests for bioenergy will be more competitive increasing its role in the overall mitigation from the forest sector.
- A reduction in deforestation rates. While long-term predictions are highly uncertain, current deforestation rates will be difficult to be maintained in the long-term if no else due to the exhaustion of the more accessible forest areas. Environmental and other concerns will also make it difficult to continue the clearing of large areas as it is done currently. This means, among other things, less potential for avoided deforestation projects.
- Abandoned or degraded areas may also increase substantially during this century giving place to forest re-growth and thus an increase in carbon sequestration through forest restoration projects.
- The economic mitigation potential will depend on incentives and the relative prices of other options.
- The actual mitigation potential will depend ultimately on solving structural problems linked to the sustainable management of forests, such as securing land tenure and indigenous people´s rights on their land, reducing poverty levels in rural areas and the rural-urban divide, disincentivating short-term behavior of economic actors, and others.

Forestry mitigation projections are expected to be regionally unique, while still linked across time and space by changes in global physical and economic forces. Overall, it is expected that the large boreal primary forests will continue to fluctuate around zero, maybe with some enhancement of growth due to climate change, counteracted by loss of soil organic matter, and maybe counteracted by increased fires (see below). The temperate forests in USA, Europe, China and Oceania, will probably continue the vegetation rebound, and thus fill up the sink, possibly also enhanced by enhanced growth due to climate change. In the tropical regions, the human induced land-use changes will continue to drive the dynamics for decades. In the meantime, the (enhanced growth of) large areas of primary forests, secondary regrowth, and increasing plantation areas will increase the sink eventually. Depending on the region, the sources will revert to sinks, but this will be in the very long term (beyond 2040). Sohngen and Sedjo, (forthcoming) for example, estimate that by the end of the century, approximately 65-70% of the global sequestration will be taken up by the tropics. In the medium to long term as well, commercial bioenergy is expected to become more and more important.

A major source of uncertainty on long-term mitigation is the potential impact of climate change on forests. Findings from the WGII assessment report (Chapter 4 and Chapter 5) suggest a whole range of changes with negative and some positive consequences. Specifically, observed climate change impacts may be more rapid than previously projected by ecological models. Changes in mean and variability of temperature and precipitation will lead to more frequent and severe fire events and insect damage. Climate change will trigger increased mortality at the boundaries of adaptation ranges eliminating forest species. On the positive side, carbon capture in ecosystems will tend to increase due to the effect of CO_2 fertilization on Net Primary Productivity, however this effect is expected to be lower than previously expected when the additional factors such as N availability are taken into account. Moderate climate change is expected to increase timber production. The induced changes can result in highly variable, region-specific economic, social and environmental transformations such as relocation of production and processing, change in employment and income.

It should be stressed that in the long-term, carbon will only be one of the goals that drive land-use decisions. Within each region, local solutions have to be found that optimize all goals and aim at integrated and sustainable land use. Developing the optimum regional strategies for climate change mitigation involving forests will require complex analyses of the trade-offs (synergies and competition) in land-use between forestry and other land uses, the trade-offs between forest conservation (carbon storage) and harvesting forests to provide society with carbon-containing fiber, timber and bioenergy resources, and the trade-offs among utilization strategies of harvested wood products aimed at maximizing storage in long-lived products, recycling, and use for bioenergy.

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