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Forestry

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EXECUTIVE SUMMARY

During the last decade of the 20th century, deforestation in the tropics and forest regrowth in the temperate zone and parts of the boreal zone remained the major factors responsible for emissions and removals, respectively. However, the extent to which the carbon loss due to tropical deforestation is offset by expanding forest areas and accumulating woody biomass in the boreal and temperate zones is an area of disagreement between land observations and estimates by top-down models. Emissions from deforestation in the 1990s are estimated at 5.8 $GtCO_2$/yr (*medium agreement, medium evidence*).

Bottom-up regional studies show that forestry mitigation options have the economic potential at costs up to 100 US$/$tCO_2$-eq to contribute 1.3-4.2 $GtCO_2$-eq/yr (average 2.7 $GtCO_2$-eq/yr) in 2030. About 50% can be achieved at a cost under 20 US$/$tCO_2$-eq (around 1.6 $GtCO_2$/yr) with large differences between regions. Global top-down models predict far higher mitigation potentials of 13.8 $GtCO_2$-eq/yr in 2030 at carbon prices less than or equal to 100 US$/$tCO_2$-eq. Regional studies tend to use more detailed data and a wider range of mitigation options are reviewed, Thus, these studies may more accurately reflect regional circumstances and constraints than simpler, more aggregate global models. However, regional studies vary in model structure, coverage, analytical approach, and assumptions (including baseline assumptions). In the sectoral comparison in Section 11.3, the more conservative estimate from regional studies is used. Further research is required to narrow the gap in the potential estimates from global and regional assessments (*medium agreement, medium evidence*).

The carbon mitigation potentials from reducing deforestation, forest management, afforestation, and agro-forestry differ greatly by activity, regions, system boundaries and the time horizon over which the options are compared. In the short term, the carbon mitigation benefits of reducing deforestation are greater than the benefits of afforestation. That is because deforestation is the single most important source, with a net loss of forest area between 2000 and 2005 of 7.3 million ha/yr.

Mitigation options by the forestry sector include extending carbon retention in harvested wood products, product substitution, and producing biomass for bio-energy. This carbon is removed from the atmosphere and is available to meet society's needs for timber, fibre, and energy. Biomass from forestry can contribute 12-74 EJ/yr to energy consumption, with a mitigation potential roughly equal to 0.4-4.4 $GtCO_2$/yr depending on the assumption whether biomass replaces coal or gas in power plants (*medium agreement, medium evidence*).

In the long term, a sustainable forest management strategy aimed at maintaining or increasing forest carbon stocks, while producing an annual sustained yield of timber, fibre or energy from the forest, will generate the largest sustained mitigation benefit. Most mitigation activities require up-front investment with benefits and co-benefits typically accruing for many years to decades. The combined effects of reduced deforestation and degradation, afforestation, forest management, agro-forestry and bio-energy have the potential to increase from the present to 2030 and beyond (*medium agreement, medium evidence*).

Global change will impact carbon mitigation in the forest sector but the magnitude and direction of this impact cannot be predicted with confidence as yet. Global change may affect growth and decomposition rates, the area, type, and intensity of natural disturbances, land-use patterns, and other ecological processes (*medium agreement, medium evidence*).

Forestry can make a very significant contribution to a low-cost global mitigation portfolio that provides synergies with adaptation and sustainable development. However, this opportunity is being lost in the current institutional context and lack of political will to implement and has resulted in only a small portion of this potential being realized at present (*high agreement, much evidence*).

Globally, hundreds of millions of households depend on goods and services provided by forests. This underlines the importance of assessing forest sector activities aimed at mitigating climate change in the broader context of sustainable development and community impact. Forestry mitigation activities can be designed to be compatible with adapting to climate change, maintaining biodiversity, and promoting sustainable development. Comparing environmental and social co-benefits and costs with the carbon benefit will highlight trade-offs and synergies, and help promote sustainable development (*low agreement, medium evidence*).

Realization of the mitigation potential requires institutional capacity, investment capital, technology RD and transfer, as well as appropriate policies and incentives, and international cooperation. In many regions, their absence has been a barrier to implementation of forestry mitigation activities. Notable exceptions exist, however, such as regional successes in reducing deforestation rates and implementing large-scale afforestation programmes. Considerable progress has been made in technology development for implementation, monitoring and reporting of carbon benefits but barriers to technology transfer remain (*high agreement, much evidence*).

Forestry mitigation activities implemented under the Kyoto Protocol, including the Clean Development Mechanism (CDM), have to date been limited. Opportunities to increase activities include simplifying procedures, developing certainty over future commitments, reducing transaction costs, and building confidence and capacity among potential buyers, investors and project participants (*high agreement, medium evidence*).

While the assessment in this chapter identifies remaining uncertainties about the magnitude of mitigation benefits and costs, the technologies and knowledge required to implement mitigation activities exist today.

9.1 Introduction

In the context of global change and sustainable development, forest management activities play a key role through mitigation of climate change. However, forests are also affected by climate change and their contribution to mitigation strategies may be influenced by stresses possibly resulting from it. Socio-economically, global forests are important because many citizens depend on the goods, services, and financial values provided by forests. Within this context, mitigation options have to be sought.

The world's forests have a substantial role in the global carbon cycle. IPCC (2007a) reports the latest estimates for the terrestrial sink for the decade 1993-2003 at 3,300 $MtCO_2$/yr, ignoring emissions from land-use change (Denman *et al*., 2007, Table 7.1). The most likely estimate of these emissions for 1990s is 5,800 $MtCO_2$/yr, which is partly being sequestered on land as well (IPCC, 2007a).

The IPCC Third Assessment Report (TAR) (Kauppi *et al.,* 2001) concluded that the forest sector has a biophysical mitigation potential of 5,380 $MtCO_2$/yr on average up until 2050, whereas the SR LULUCF (IPCC, 2000a) presented a biophysical mitigation potential on all lands of 11670 $MtCO_2$/yr in 2010 (copied in IPCC, 2001, p. 110).

Forest mitigation options include reducing emissions from deforestation and forest degradation, enhancing the sequestration rate in existing and new forests, providing wood fuels as a substitute for fossil fuels, and providing wood products for more energy-intensive materials. Properly designed and implemented, forestry mitigation options will have substantial co-benefits in terms of employment and income generation opportunities, biodiversity and watershed conservation, provision of timber and fibre, as well as aesthetic and recreational services.

Many barriers have been identified that preclude the full use of this mitigation potential. This chapter examines the reasons for the discrepancy between a large theoretical potential and substantial co-benefits versus the rather low implementation rate.

Developments since TAR

Since the IPCC Third Assessment Report (TAR), new mitigation estimates have become available from local to global scale (Sathaye *et al.*, 2007) as well as major economic reviews and global assessments (Stern, 2006). There is early research into the integration of mitigation and adaptation options and the linkages to sustainable development (MEA, 2005a). There is increased attention to reducing emissions from deforestation as a low cost mitigation option, and with significant positive side-effects (Stern, 2006). There is some evidence that climate change impacts can also constrain the forest potential. There are very few multiple land-use studies that examine a wider set of forest functions and economic constraints (Brown *et al.,* 2004). Furthermore, the literature shows a large variation of mitigation estimates, partly due to the natural variability in the system, but partly also due to differences in baseline assumptions and data quality. In addition, Parties to the Convention are improving their estimates through the design of National Systems for Greenhouse Gas (GHG) Inventories.

Basic problems remain. Few major forest-based mitigation analyses have been conducted using new primary data. There is still limited insight regarding impacts on soils, lack of integrated views on the many site-specific studies, hardly any 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 balance, against which mitigation options could be examined. There is limited quantitative information on the cost-benefit ratios of mitigation interventions. Finally, there are still knowledge gaps in how forest mitigation activities may alter, for example, surface hydrology and albedo (IPCC, 2007b: Chapter 4).

This chapter: a) provides an updated estimate of the economic mitigation potential through forests; b) examines the reasons for difference between a large theoretical potential and a low rate of implementation; and c) and integrates the estimates of the economic potential with considerations to both adaptation and mitigation in the context of sustainable development.

9.2 Status of the sector and trends

9.2.1 Forest area

The global forest cover is 3952 million ha (Table 9.1), which is about 30 percent of the world's land area (FAO, 2006a). Most relevant for the carbon cycle is that between 2000 and 2005, gross deforestation continued at a rate of 12.9 million ha/yr. This is mainly as a result of converting forests to agricultural land, but also due to expansion of settlements, infrastructure, and unsustainable logging practices (FAO, 2006a; MEA, 2005b). In the 1990s, gross deforestation was slightly higher, at 13.1 million ha/yr. Due to afforestation, landscape restoration and natural expansion of forests, the most recent estimate of net loss of forest is 7.3 million ha/yr. The loss is still largest in South America, Africa and Southeast Asia (Figure 9.1). This net loss was less than that of 8.9 million ha/yr in the 1990s.

Thus, carbon stocks in forest biomass decreased in Africa, Asia, and South America, but increased in all other regions. According to FAO (2006a), globally net carbon stocks in forest biomass decreased by about 4,000 $MtCO_2$ annually between 1990 and 2005 (Table 9.1).

Table 9.1: *Estimates of forest area, net changes in forest area (negative numbers indicating decrease), carbon stock in living biomass, and growing stock in 1990, 2000, and 2005*

Region	Forest area, (mill. ha)	Annual change (mill. ha/yr)		Carbon stock in living biomass ($MtCO_2$)			Growing stock in 2005
	2005	1990-2000	2000-2005	1990	2000	2005	million m^3
Africa	63,5412	-4.4	-4.0	241,267	228,067	222,933	64,957
Asia	571,577	-0.8	1.0	150,700	130,533	119,533	47,111
Europe[a)]	1001,394	0.9	0.7	154,000	158,033	160,967	107,264
North and Central America	705,849	-0.3	-0.3	150,333	153,633	155,467	78,582
Oceania	206,254	-0.4	-0.4	42,533	41,800	41,800	7,361
South America	831,540	-3.8	-4.3	358,233	345,400	335,500	128,944
World	3,952,026	-8.9	-7.3	1,097,067	1,057,467	1,036,200	434,219

a) Including all of the Russian Federation
Source: FAO, 2006a

The area of forest plantation was about 140 million ha in 2005 and increased by 2.8 million ha/yr between 2000 and 2005, mostly in Asia (FAO, 2006a). According to the Millennium Ecosystem Assessment (2005b) scenarios, forest area in industrialized regions will increase between 2000 and 2050 by about 60 to 230 million ha. At the same time, the forest area in the developing regions will decrease by about 200 to 490 million ha. In addition to the decreasing forest area globally, forests are severely affected by disturbances such as forest fires, pests (insects and diseases) and climatic events including drought, wind, snow, ice, and floods. All of these factors have also carbon balance implications, as discussed in Sections 9.3 and 9.4. Such disturbances affect roughly 100 million ha of forests annually (FAO, 2006a). Degradation, defined as decrease of density or increase of disturbance in forest classes, affected tropical regions at a rate of 2.4 million ha/yr in the 1990s.

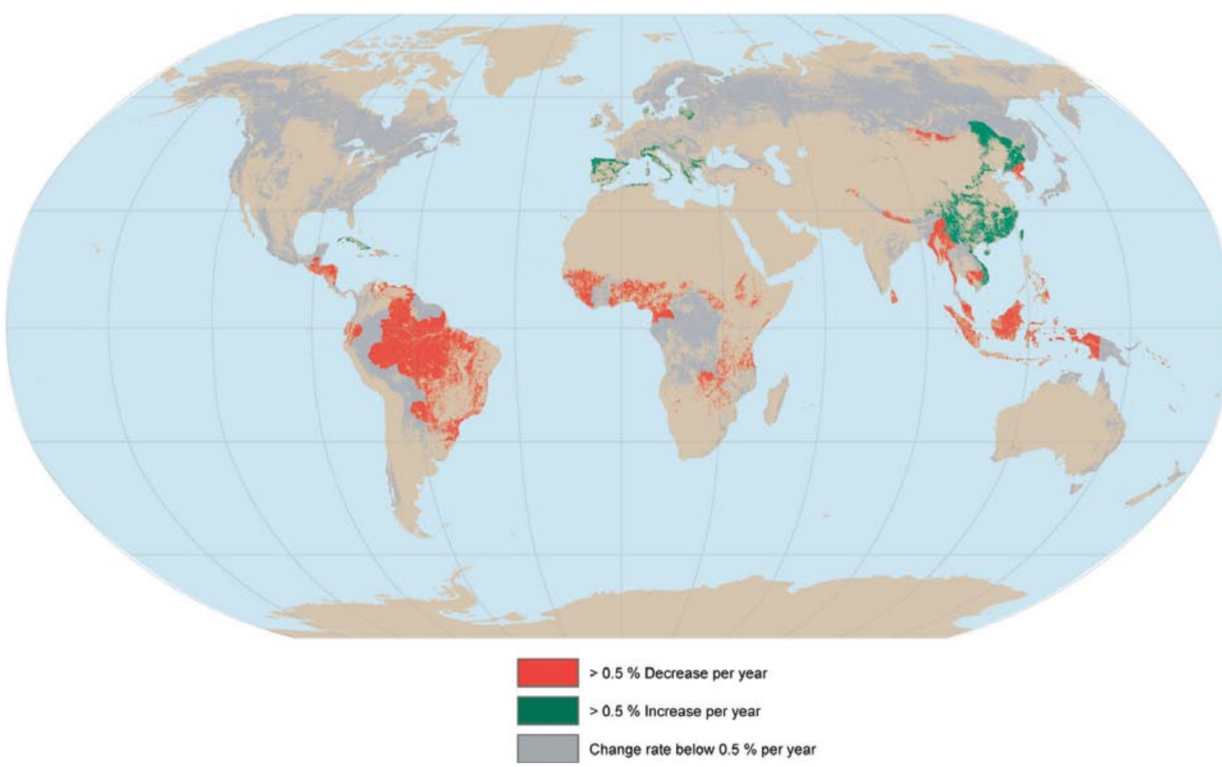

Figure 9.1: *Net change in forest area between 2000 and 2005*
Source: FAO, 2006a.

9.2.2 Forest management

Data on progress towards sustainable forest management were collected for the recent global forest resources assessment (FAO, 2006a). These data indicate globally there are many good signs and positive trends (intensive forest plantation and rising conservation efforts), but also negative trends continue (primary forests continue to become degraded or converted to agriculture in some regions). Several tools have been developed in the context of sustainable forest management, including criteria and indicators, national forest programmes, model forests and certification schemes. These tools can also support and provide sound grounds for mitigation of climate change and thus carbon sequestration.

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

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). Nevertheless, development of these markets and behaviour of forest owners may influence roundwood markets and availability of wood for conventional uses, thus potentially limiting substitution possibilities.

9.2.3 Wood supply, production and consumption of forest products

Global wood harvest is about 3 billion m^3 and has been rather stable in the last 15 years (FAO, 2006a). Undoubtedly, the amount of wood removed is higher, as illegally wood removal is not recorded. About 60% of removals are industrial roundwood; the rest is wood fuel (including fuelwood and charcoal). The most wood removal in Africa and substantial proportions in Asia and South America are non-commercial wood fuels. Recently, commercial biomass for bio-energy received a boost because of the high oil prices and the government policies initiated to promote renewable energy sources.

Although accounting for only 5% of global forest cover, forest plantations were estimated in 2000 to supply about 35% of global roundwood harvest and this percentage is expected to increase (FAO, 2006a). 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, thus contributing to climate change mitigation. With rather stable harvested volumes, the manufacture of forest products has increased as a result of improved processing efficiency. Consumption of forest products is increasing globally, particularly in Asia.

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 an extensive body of literature (Table 9.2 and IPCC, 2007a: Chapter 7 and 10).

Globally during the 1990s, deforestation in the tropics and forest regrowth in the temperate zone and parts of the boreal zone were the major factors responsible for emissions and removals, respectively (Table 9.2; Figure 9.2). However, the extent to which carbon loss due to tropical deforestation is offset by expanding forest areas and accumulating woody biomass in the boreal and temperate zones is the area of disagreement between land observations and estimates by top-down models. The top-down methods based on inversion of atmospheric transport models estimate the net terrestrial carbon sink for the 1990s, which is the balance of sinks in northern latitudes and source in tropics (Gurney *et al.,* 2002). The latest estimates are consistent with the increase found in the terrestrial carbon sink in the 1990s over the 1980s.

Denman *et al*. (2007) reports the latest estimates for gross residual terrestrial sink for the 1990s at 9,500 $MtCO_2$/yr, while their estimate for emissions from deforestation amounts to 5,800 $MtCO_2$/yr. The residual sink estimate is significantly higher than any land-based global sink estimate and in the upper range of estimates produced by inversion of atmospheric transport models (Table 9.2). It includes the sum of biases in estimates of other global fluxes (fossil fuel burning, cement production, ocean uptake, and land-use change) and the flux in terrestrial ecosystems that are not undergoing change in land use.

Improved spatial resolution allowed separate estimates of the land-atmosphere carbon flux for some continents (Table 9.2). 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

(Houghton, 2005). 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 are uncertain and hotly debated (Table 9.2; Fearnside and Laurance, 2004). Studies based on remote sensing of forest cover report lower rates than UN-ECE/FAO (2000) and lower carbon emissions carbon (Achard *et al.*, 2004).

Recent analyses highlight the important role of other carbon flows. These flows were largely overlooked by earlier research and include carbon export through river systems (Raymond and Cole, 2003), volcanic activity and other geological processes (Richey *et al.,* 2002), transfers of material in and out of products pool (Pacala *et al.,* 2001), and uptake in freshwater ecosystems (Janssens *et al.,* 2003).

Attribution of estimated carbon sink in forests to the short- and long-term 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 (Houghton, 2003b). For the USA, 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). Forest expansion and regrowth and associated carbon sinks were reported in many regions (Table 9.2; Figure 9.2). The expanding tree cover in South Western USA is attributed to the long-term effects of fire control but the gain in carbon storage was smaller than previously thought. The lack of consensus on factors that control the carbon balance is an obstacle to development of effective mitigations strategies.

Large year-to-year and decade scale variation of regional carbon sinks (Rodenbeck *et al.,* 2003) make 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. There are indications that higher temperatures in boreal regions will increase fire frequency; possible drying of the Amazon basin would increase fire frequency there as well (Cox *et al.,* 2004). Global emissions from fires in the 1997/98 El Nino year are estimated at 7,700 $MtCO_2$/yr, 90% from tropics (Werf *et al.,* 2004).

The picture emerging from Table 9.2 is complex because available estimates differ in the land-use types included and in the use of gross fluxes versus net carbon balance, among other variables. This makes it impossible to set a widely accepted baseline for the forestry sector globally. Thus, we had to rely on the baselines used in each regional study separately (Section 9.4.3.1), or used in each global study (Section 9.4.3.3). However, this approach creates large uncertainty in assessing the overall mitigation potential in the forest sector. Baseline CO_2 emissions from land-use change and forestry in 2030 are the same as or slightly lower than in 2000 (see Chapter 3, Figure 3.10).

9.4 Assessment of mitigation options

In this section, a conceptual framework for the assessment of mitigation options is introduced and specific options are briefly described. Literature results are summarized and compared for regional bottom-up approaches, global forest sector models, and global top-down integrated model approaches. The assessment is limited to CO_2 balances and economic costs of the various mitigation options. Broader issues including biodiversity, sustainable development, and interactions with adaptation strategies are discussed in subsequent sections.

9.4.1 Conceptual introduction

Terrestrial carbon dynamics are characterized by long periods of small rates of carbon uptake, interrupted by short periods of

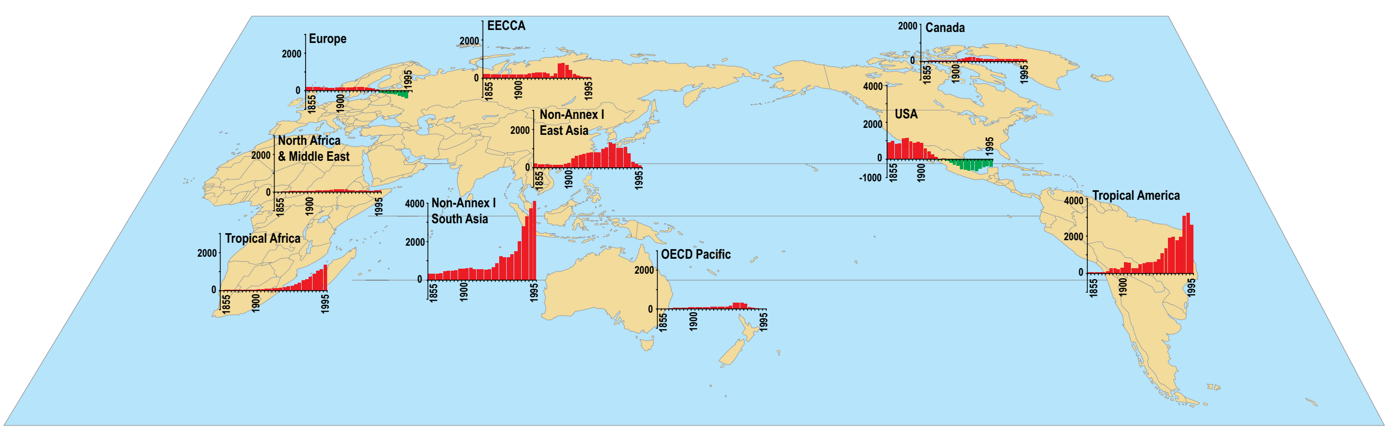

Figure 9.2: *Historical forest carbon balance ($MtCO_2$) per region, 1855-2000.*

Notes: green = sink. EECCA=Countries of Eastern Europe, the Caucasus and Central Asia. Data averaged per 5-year period, year marks starting year of period.
Source: Houghton, 2003b.

Table 9.2: *Selected estimates of carbon exchange of forests and other terrestrial vegetation with the atmosphere (in MtCO2/yr)*

Regions	Annual carbon flux based on international statistics	Annual carbon flux during 1990s	
	UN-ECE, 2000	Based on inversion of atmospheric transport models	Based on land observations
	$MtCO_2$/yr		
OECD North America		1,833 ± 2,200[9]	0 ÷ 1,100[5]
Separately: Canada USA	340 610	2,090 ± 3,337[2]	293 ± 733[1]
OECD Pacific	224		0±733[1]
Europe	316	495 ± 752[6]	0 ± 733[1] 513[11]
Countries in Transition	1,726	3,777 ± 3,447[2]	1,100 ± 2,933[9] 1,181 ÷ -1,588[7]
Separately: Russia	1,572	4,767 ± 2,933[9]	1,907± 469[8]
Northern Africa		623 ± 3,593[2]	
Sub-Saharan Africa			-576 ±235[3] -440 ± 110[4] -1,283 ± 733[1]
Caribbean, Central and South America		-2,310	-1,617 ± 972[3] -1,577 ± 733[4] -2,750 ± 1,100[1]
Separately: Brazil			± 733[12]
Developing countries of South and East Asia and Middle East		-2,493 ± 2,713[2]	-3,997 ± 1,833[1] -1,734 ± 550[3] -1,283 ± 550[4]
Separately: China		2,273 ± 2,420[2]	- 110 ± 733[1] 128 ± 95[13] 249[14]
Global total		4,767 ± 5,500[9] 2,567 ± 2,933[10] 4,913[2] 9516[17]	-7,993 ± 2,933[1] -3,300 ÷ 7,700[5] -4,000[15] -5,800 [16] -8485[18]
Annex I (excluding Russia)			1300[19]

Notes: Positive values represent carbon sink, negative values represent source. Sign ÷ indicates a range of values; sign ± indicates error term.
Because of differences in methods and scope of studies (see footnotes), values from different publications are not directly comparable. They represent a sample of reported results.
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 DeFries, 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 inter-annual 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 Ciais 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); 11Nabuurs et al., 2003 (forests only); 12 Houghton et al., 2000 (Brazilian Amazon only, losses from deforestation are offset by regrowth and carbon sink in undisturbed forests); 13 Fang et al., 2005; 14 Pan et al., 2004, 15 FAO, 2006a (global net biomass loss resulting from deforestation and regrowth); 16 Denman *et al.*,2007 (estimate of biomass loss from deforestation), 17 Denman et al.,2007 (Residual terrestrial carbon sink), 18 EDGAR database for agriculture and forestry (see Chapter 1, Figure 1.3a/b (Olivier et al., 2005)). These include emissions from bog fires and delayed emissions from soils after land- use change, 19 (Olivier et al., 2005).

rapid and large carbon releases during disturbances or harvest. Depending on the stage of stand[1] development, individual stands are either carbon sources or carbon sinks (1m^3 of wood stores ~ 0.92 tCO_2)[2]. For most immature and mature stages of stand development, stands are carbon sinks. At very old ages, ecosystem carbon will either decrease or continue to increase

1 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 comprising many stands.
2 Assuming a specific wood density of 0.5g dry matter/cm3 and a carbon content of 0.5g C/g dry matter.

slowly with accumulations mostly in dead organic matter and soil carbon pools. In the years following major disturbances, the losses from decay of residual dead organic matter exceed the carbon uptake by regrowth. While individual stands in a forest may be either sources or sinks, the forest carbon balance 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.

The design of a forest sector mitigation portfolio should consider the trade-offs between increasing forest ecosystem carbon stocks and increasing the sustainable rate of harvest and transfer of carbon to meet human needs (Figure 9.3). The selection of forest sector mitigation strategies should minimize net GHG emissions throughout the forest sector and other sectors affected by these mitigation activities. For example, stopping all forest harvest would increase forest carbon stocks, but would reduce the amount of timber and fibre available to meet societal needs. Other energy-intensive materials, such as concrete, aluminium, steel, and plastics, would be required to replace wood products, resulting in higher GHG emissions (Gustavsson *et al.,* 2006). Afforestation may affect the net GHG balance in other sectors, if for example, forest expansion reduces agricultural land area and leads to farming practices with higher emissions (e.g., more fertilizer use), conversion of land for cropland expansion elsewhere, or increased imports of agricultural products (McCarl and Schneider, 2001). The choice of system boundaries and time horizons affects the ranking of mitigation activities (Figure 9.3).

Forest mitigation strategies should be assessed within the framework of sustainable forest management, and with consideration of the climate impacts of changes to other processes such as albedo and the hydrological cycle (Marland *et al.*, 2003). At present, however, few studies provide such comprehensive assessment.

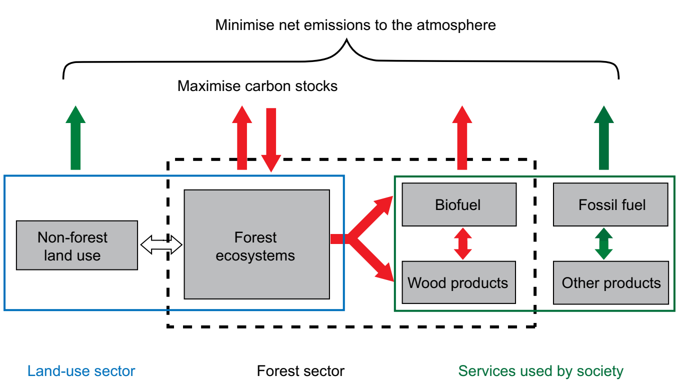

Figure 9.3: *Forest sector mitigation strategies need to be assessed with regard to their impacts on carbon storage in forest ecosystems on sustainable harvest rates and on net GHG emissions across all sectors.*

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

- maintaining or increasing the forest area through reduction of deforestation and degradation and through afforestation/reforestation;
- maintaining or increasing the stand-level carbon density (tonnes of carbon per ha) through the reduction of forest degradation and through planting, site preparation, tree improvement, fertilization, uneven-aged stand management, or other appropriate silviculture techniques;
- maintaining or increasing the landscape-level carbon density using forest conservation, longer forest rotations, fire management, and protection against insects;
- increasing off-site carbon stocks in wood products and enhancing product and fuel 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.

Each mitigation activity has a characteristic time sequence of actions, carbon benefits and costs (Figure 9.4). Relative to a baseline, the largest short-term gains are always achieved through mitigation activities aimed at emission avoidance (e.g., reduced deforestation or degradation, fire protection, and slash burning). But once an emission has been avoided, carbon stocks on that forest will merely be maintained or increased slightly. In contrast, the benefits from afforestation accumulate over years to decades but require up-front action and expenses. Most forest management activities aimed at enhancing sinks require up-front investments. The duration and magnitude of their carbon benefits differ by region, type of action and initial condition of the forest. In the long term, sustainable forest management strategy aimed at maintaining or increasing forest carbon stocks, while producing an annual yield of timber, fibre, or energy from the forest, will generate the largest sustained mitigation benefit.

Reduction in fossil fuel use in forest management activities, forest nursery operations, transportation and industrial production provides additional opportunities similar to those in other sectors, but are not discussed here (e.g., see Chapter 5, Transportation). 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.

9.4.2 Description of mitigation measures

Each of the mitigation activities is briefly described. The development of a portfolio of forest mitigation activities requires

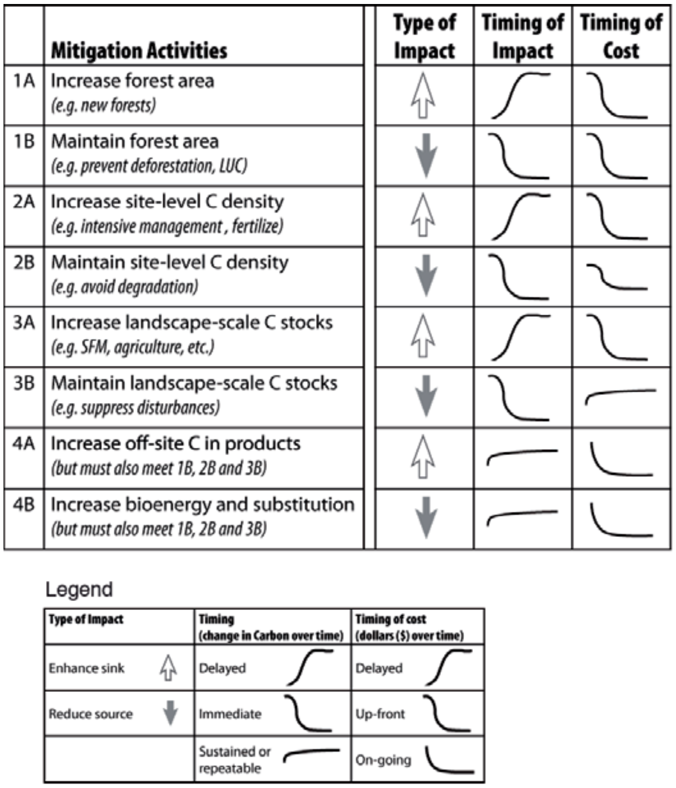

Figure 9.4: *Generalized summary of forest sector options and type and timing of effects on carbon stocks and the timing of costs* [3]

an understanding of the magnitude and temporal dynamics of the carbon benefits and the associated costs.

9.4.2.1 Maintaining or increasing forest area: reducing deforestation and degradation

Deforestation - human-induced conversion of forest to non-forest land uses - is typically associated with large immediate reductions in forest carbon stock, through land clearing. Forest degradation - reduction in forest biomass through non-sustainable harvest or land-use practices - can also result in substantial reductions of forest carbon stocks from selective logging, fire and other anthropogenic disturbances, and fuelwood collection (Asner *et al.*, 2005).

In some circumstances, deforestation and degradation can be delayed or reduced through complete protection of forests (Soares-Filho *et al.*, 2006), sustainable forest management policies and practices, or by providing economic returns from non-timber forest products and forest uses not involving tree removal (e.g., tourism). Protecting forest from all harvest typically results in maintained or increased forest carbon stocks, but also reduces the wood and land supply to meet other societal needs.

Reduced deforestation and degradation is the forest mitigation option with the largest and most immediate carbon stock impact in the short term per ha and per year globally (see Section 9.2 and global mitigation assessments below), because large carbon stocks (about 350-900 tCO_2/ha) are not emitted when deforestation is prevented. The mitigation costs of reduced deforestation depend on the cause of deforestation (timber or fuelwood extraction, conversion to agriculture, settlement, or infrastructure), the associated returns from the non-forest land use, the returns from potential alternative forest uses, and on any compensation paid to the individual or institutional landowner to change land-use practices. These costs vary by country and region (Sathaye *et al.*, 2007), 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 distinguished by how long the non-forest condition has prevailed. For the remainder of this chapter, afforestation is used to imply either afforestation or reforestation. To date, carbon sequestration has rarely been the primary driver of afforestation, but future changes in carbon valuation could result in large increases in the rates of afforestation (US EPA, 2005).

Afforestation typically leads to increases in biomass and dead organic matter carbon pools, and to a lesser extent, in soil carbon pools, whose small, slow increases are often hard to detect within the uncertainty ranges (Paul *et al.,* 2003). Biomass clearing and site preparation prior to afforestation may lead to short-term carbon losses on that site. On sites with low initial soil carbon stocks (e.g., after prolonged cultivation), afforestation can yield considerable soil carbon accumulation rates (e.g., Post and Kwon (2000) report rates of 1 to 1.5 t CO_2/yr). Conversely, on sites with high initial soil carbon stocks, (e.g., some grassland ecosystems) soil carbon stocks can decline following afforestation (e.g., Tate *et al.* (2005) report that in the whole of New Zealand soil carbon losses amount up to 2.2 MtCO_2/yr after afforestation). Once harvesting of afforested land commences, forest biomass carbon is transferred into wood products that store carbon for years to many decades. Accumulation of carbon in biomass after afforestation varies greatly by tree species and site, and ranges globally between 1 and 35 t CO_2/ha.yr (Richards and Stokes, 2004).

Afforestation costs vary by land type and region and are affected by the costs of available land, site preparation, and labour. The cost of forest mitigation projects rises significantly

3 We thank Mike Apps for a draft of this figure.

when opportunity costs of land are taken into account (VanKooten *et al.*, 2004). 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 non-carbon benefits of afforestation, such as reduction in erosion or non-consumptive use of forests, however, can more than off-set afforestation cost (Richards and Stokes, 2004).

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

Forest management activities to increase stand-level forest carbon stocks include harvest systems that maintain partial forest cover, minimize losses of dead organic matter (including slash) or soil carbon by reducing soil erosion, and by avoiding slash burning and other high-emission activities. Planting after harvest or natural disturbances accelerates tree growth and reduces carbon losses relative to natural regeneration. Economic considerations are typically the main constraint, because retaining additional carbon on site delays revenues from harvest. The potential benefits of carbon sequestration can be diminished where increased use of fertilizer causes greater N_2O emissions. Drainage of forest soils, and specifically of peatlands, may lead to substantial carbon loss due to enhanced respiration (Ikkonen *et al.,* 2001). Moderate drainage, however, can lead to increased peat carbon accumulation (Minkkinen *et al.,* 2002).

Landscape-level carbon stock changes are the sum of stand-level changes, and the impacts of forest management on carbon stocks ultimately need to be evaluated at landscape level. Increasing harvest rotation lengths will increase some carbon pools (e.g., tree boles) and decrease others (e.g., harvested wood products (Kurz *et al.*, 1998).

9.4.2.4 Increasing off-site carbon stocks in wood products and enhancing product and fuel substitution

Wood products derived from sustainably managed forests address the issue of saturation of forest carbon stocks. The annual harvest can be set equal to or below the annual forest increment, thus allowing forest carbon stocks to be maintained or to increase while providing an annual carbon flow to meet society's needs of fibre, timber and energy. The duration of carbon storage in wood products ranges from days (biofuels) to centuries (e.g., houses and furniture). Large accumulations of wood products have occurred in landfills (Micales and Skog, 1997). When used to displace fossil fuels, woodfuels can provide sustained carbon benefits, and constitute a large mitigation option (see Box 9.2).

Wood products can displace more fossil-fuel intensive construction materials such as concrete, steel, aluminium, and plastics, which can result in significant emission reductions (Petersen and Solberg, 2002). Research from Sweden and Finland suggests that constructing apartment buildings with wooden frames instead of concrete frames reduces lifecycle net carbon emissions by 110 to 470 kg CO_2 per square metre of floor area (Gustavsson and Sathre, 2006). The mitigation benefit is greater if wood is first used to replace concrete building material and then after disposal, as biofuel.

9.4.3 Global assessments

For quantification of the economic potential of future mitigation by forests, three approaches are presented in current literature. These are: a) regional bottom-up assessments per country or continent; b) global forest sector models; and c) global multi-sectoral models. An overview of studies for these approaches is presented in Section 9.4.3. The final integrated global conclusion and regional comparison is given in Section 9.4.4. Supply of forest biomass for bio-energy is given in Box 9.2 and incorporated in Section 11.3.1.4, within the energy sector's mitigation potential. For comments on the baselines, see Section 9.3.

9.4.3.1 Regional bottom-up assessments

Regional assessments comprise a variety of model results. On the one hand, these assessments are able to take into account the detailed regional specific constraints (in terms of ecological constraints, but also in terms of land owner behaviour and institutional frame).On the other hand, they also vary in assumptions, type of potential addressed, options taken into account, econometrics applied (if any), and the adoption of baselines. Thus, these assessments may have strengths, but when comparing and summing up, they have weaknesses as well. Some of these assessments, by taking into account institutional barriers, are close to a market potential.

Tropics

The available studies about mitigation options differ widely in basic assumptions regarding carbon accounting, costs, land areas, baselines, and other major parameters. The type of mitigation options considered and the time frame of the study affect the total mitigation potential estimated for the tropics. A thorough comparative analysis is, therefore, very difficult. More detailed estimates of economic or market potential for mitigation options by region or country 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-Ponce *et al. (*2007) and Waterloo *et al.* (2003), highlighting the large potential by avoiding deforestation and enhancing afforestation and reforestation, including bio-energy.

Reducing deforestation

Assumptions of future deforestation rates are key factors in estimates of GHG emissions from forest lands and of mitigation benefits, and vary significantly across studies. In all the studies, however, future deforestation is estimated to remain high in the tropics in the short and medium term. Sathaye *et al.* (2007) estimate that deforestation rates continue in all regions, particularly at high rates in Africa and South America, for a total of just under 600 million ha lost cumulatively by 2050. Using a spatial-explicit model coupled with demographic and economic databases, Soares-Filo *et al.* (2006) predict that, under a business-as-usual scenario, by 2050, projected deforestation trends will eliminate 40% of the current 540 million ha of Amazon forests, releasing approximately 117,000 ± 30,000 $MtCO_2$ of carbon to the atmosphere (Box 9.1).

Reducing deforestation is, thus, a high-priority mitigation option within tropical regions. In addition to the significant carbon gains, substantive environmental and other benefits could be obtained from this option. Successfully implementing mitigation activities to counteract the accelerated loss of tropical forests requires understanding the causes for deforestation, which are multiple and locally based; few generalizations are possible (Chomitz *et al.,* 2006).

Recent studies have been conducted at the national, regional, and global scale to estimate the mitigation potential (areas, carbon benefits and costs) of reducing tropical deforestation. In a short-term context (2008-2012), Jung (2005) estimates that 93% of the total mitigation potential in the tropics corresponds to avoided deforestation. For the Amazon basin, Soares- Filo *et al.* (2006) estimate that by 2050 the cumulative avoided deforestation potential for this region reaches 62,000 $MtCO_2$ under a "governance" scenario (see Box 9.1).

Looking at the long-term, (Sohngen and Sedjo, 2006) estimate that for 27.2 US$/tCO2, deforestation could potentially be virtually eliminated. Over 50 years, this could mean a net cumulative gain of 278,000 $MtCO_2$ relative to the baseline and 422 million additional hectares in forests. For lower prices of 1.36 US$/$tCO_2$, only about 18,000 $MtCO_2$ additional could be sequestered over 50 years. The largest gains in carbon would occur in Southeast Asia, which gains nearly 109,000 $MtCO_2$ for 27.2 US$/$tCO_2$, followed by South America, Africa, and Central America, which would gain 80,000, 70,000, and 22,000 $MtCO_2$ for 27.2 US$/$tCO_2$, respectively (Figure 9.5).

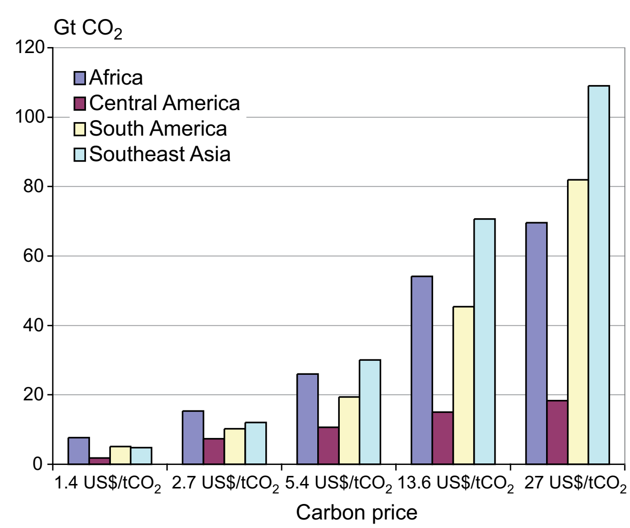

Figure 9.5: *Cumulative carbon gained through avoided deforestation by 2055 over the reference case, by tropical regions under various carbon price scenarios*
Source: Sohngen and Sedjo, 2006.

In a study of eight tropical countries covering half of the total forested area, Grieg-Gran (2004) present a best estimate of total costs of avoided deforestation in the form of the net present value of returns from land uses that are prevented, at 5 billion US$ per year. These figures represent costs of 483 US$ to 1050 US$/ha.

Afforestation and reforestation

The assumed land availability for afforestation options depends on the price of carbon and how that competes with existing or other land-use financial returns, barriers to changing land uses, land tenure patterns and legal status, commodity price support, and other social and policy factors.

Cost estimates for carbon sequestration projects for different regions compiled by Cacho *et al.*, (2003) and by Richards and Stokes (2004) show a wide range. The cost is in the range of 0.5 US$ to 7 US$/$tCO_2$ for forestry projects in developing countries, compared to 1.4 US$ to 22 US$/$tCO_2$ for forestry projects in industrialized countries. In the short-term (2008-2012), an estimate of economic potential area available for afforestation/ reforestation under the Clean Development Mechanism (CDM) is estimated to be 5.3 million ha in Africa, Asia and Latin America together, with Asia accounting for 4.4 million ha (Waterloo *et al.,* 2003).

Summing the measures, the cumulative carbon mitigation benefits (Figure 9.6) by 2050 for a scenario of 2.7 US$/$tCO_2$ + 5% annual carbon price increment for one model are estimated to be 91,400 $MtCO_2$; 59% of it coming from avoided deforestation. These estimates increase for a higher price scenario of 5.4 US$/$tCO_2$ + 3%/yr annual carbon price into 104,800 $MtCO_2$), where 69% of total mitigation comes from avoiding deforestation (Sathaye *et al.,* 2007). During the period 2000-2050, avoided deforestation in South America and Asia dominate by accounting for 49% and 21%, respectively, of the total mitigation potential. When afforestation is considered, Asia dominates. The mitigation potential of the continents Asia, Africa and Latin America dominates the global total mitigation potential for the period up to 2050 and 2100, respectively (Figure 9.6).

In conclusion, the studies report a large variety for mitigation potential in the tropics. All studies indicate that this part of the world has the largest mitigation potential in the forestry sector. For the tropics, the mitigation estimates for lower price ranges (<20 US$/$tCO_2$) are around 1100 $MtCO_2$/yr in 2040, about

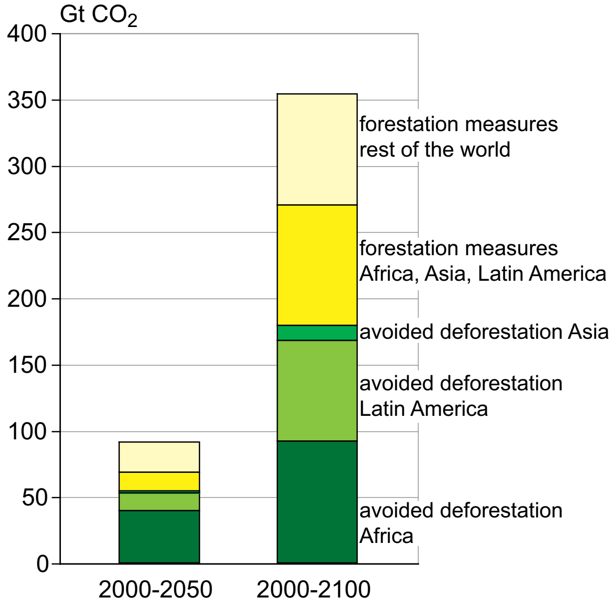

Figure 9.6: *Cumulative mitigation potential (2000-2050 and 2000-2100) according to mitigation options under the 2.7 US$/tCO2 +5%/yr annual carbon price increment*

Source: Sathaye et al., 2007.

half of this potential is located in Central and South America (Sathaye et al., 2007; Soares Filho et al., 2006; Sohngen and Sedjo, 2006). For each of the regions Africa and Southeast Asia, this mitigation potential is estimated at 300 $MtCO_2$/yr in 2040. In the high range of price scenarios (< 100 US$/$tCO_2$), the mitigation estimates are in the range of 3000 to 4000$MtCO_2$/yr in 2040. In the summary overviews in Section 9.4.4, an average estimate of 3500 is used, with the same division over regions: 875, 1750 and 875 for Africa, Latin and South America, and Southeast Asia, respectively. The global economic potential for the tropics ranges from 1100 to 3500 $MtCO_2$/yr in 2040 (Table 9.6).

OECD North America

Figure 9.8 shows the technical potential of management actions aimed at modifying the net carbon balance in Canadian forests (Chen *et al.,* 2000). Of the four scenarios examined, the potential was largest in the scenario aimed at reducing regeneration delays by reforesting after natural disturbances. The second largest estimate was obtained with annual, large-scale (125 million ha) low-intensity (5 kg N/ha/yr) nitrogen fertilization programmes. Neither of these scenarios is realistic,

Box 9.1 Deforestation scenarios for the Amazon Basin

An empirically based, policy-sensitive simulation model of deforestation for the Pan-Amazon basin has been developed (Soares-Filho *et al.*, 2006) (Figure 9.7). 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 117,000 $MtCO_2$ cumulatively by 2050. 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 or only 17% deforested, reducing cumulative carbon emissions by 2050 to only 55,000 $MtCO_2$. 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 financial resources needed for these conservation initiatives could come in the form of carbon credits resulting from the avoidance of 62,000 $MtCO_2$ emissions over 50 years.

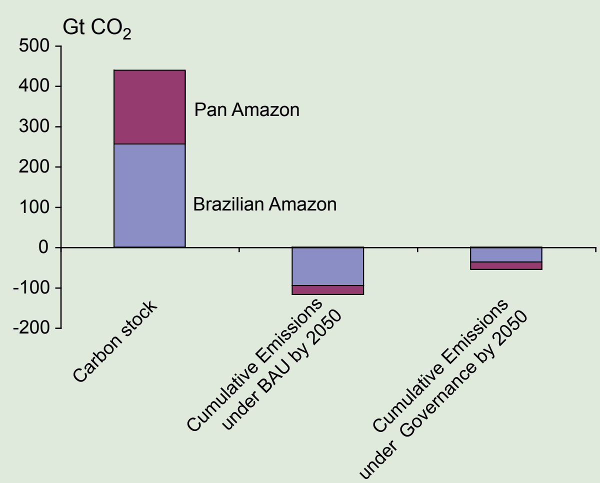

Figure 9.7: *Current carbon stocks for the Pan-Amazon and Brazilian Amazon (left bar) and estimates of cumulative future emission by 2050 from deforestation under BAU (business-as-usual) and governance scenarios.*

Note: The difference between the two scenarios represents an amount equivalent to eight times the carbon emission reduction to be achieved during the first commitment period of the Kyoto Protocol.

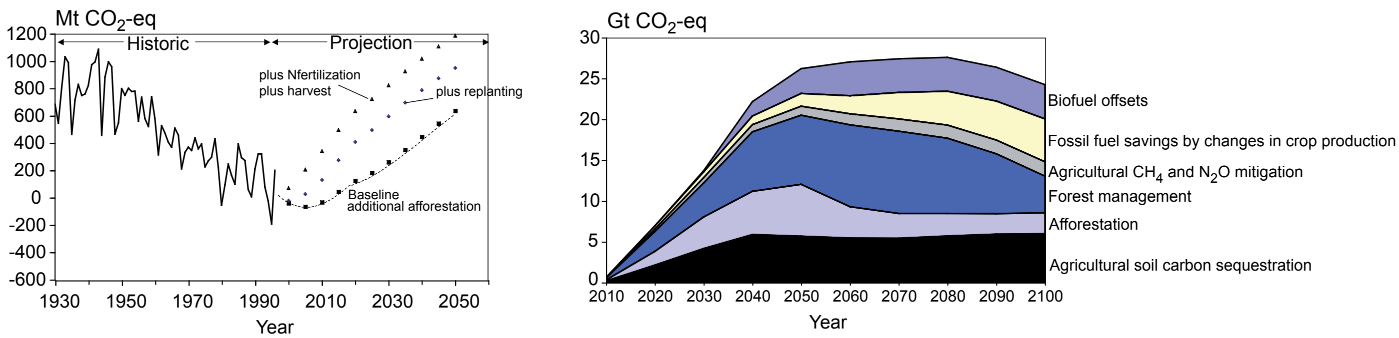

Figure 9.8: *OECD North America: technical potential for the forest sector alone for Canada (left, sink is positive) and the economic potential (at 15 US\$/tCO$_2$eq in constant real prices) in the agriculture and forestry sector in the USA (right) Left: Chen et al., 2000; right: US-EPA, 2005*

however, but can be seen as indications of the type of measures and impact on carbon balance (as described by Chen *et al., 2000*). Chen's measures sum up to a technical potential of 570 $MtCO_2$/yr. Based on the assumption that the economic potential is about 10% of technical potential (see Section 9.4.3.3. for carbon prices 20 US\$/tCO_2), the economic potential can be "guesstimated" at around 50-70 $MtCO_2$/yr (Table 9.6).

Other studies have explored the potential of large-scale afforestation in Canada. Mc Kenney *et al.* (2004) project that at a carbon price of 25 US\$/tCO_2, 7.5 million ha of agricultural land would become economically attractive for poplar plantations. Economic constraints are contributing to the declining trend in afforestation rates in Canada from about 10,000 ha/yr in 1990 to 4,000 ha/yr in 2002 (White and Kurz, 2005).

For the USA, Richards and Stokes (2004) reviewed eight national estimates of forest mitigation and found that carbon prices ranging from 1 to 41 US\$/tCO_2 generated an economic mitigation potential of 47-2,340 $MtCO_2$/yr from afforestation, 404 $MtCO_2$ from forest management, and 551-2,753 $MtCO_2$/yr from total forest carbon. Sohngen and Mendelsohn (2003) found that a carbon programme with prices rising from 2 US\$/tCO_2 to 51 US\$/tCO_2 during this century could induce sequestration of 122 to 306 $MtCO_2$/yr total carbon sequestration, annualized over a 100-year time frame.

US EPA (2005) present that, at 15 US\$/tCO_2, the mitigation potential of afforestation and forest management (annualized) would amount to 356 $MtCO_2$/yr over a 100-year time frame. At 30 US\$/tCO_2, this analysis would generate 749 $MtCO_2$ annualized over 100 years. At higher prices and in the long term, the potential was mainly determined by biofuels. With the mitigation potential given above for Canada, the OECD North America sums to a range of 400 to 820 $MtCO_2$/yr in 2040 (Table 9.6).

Europe

Most assessments shown (Figure 9.9) are of the carbon balance of the forest sector of Europe's managed forest as a whole[4]. Additional effects of measures were studied by Cannell (2003), Benitez-Ponce *et al.* (2007), EEA (2005), and Eggers *et al.* (2007). Karjalainen *et al,* (2003) present a projection of the full sector carbon balance (Figure 9.9). Eggers *et al.* (2007) presents the European forest sector carbon sink under two global SRES scenarios, and a maximum difference between scenarios of 197 $MtCO_2$/yr in 2040. Therefore, an additionally achievable sink of 90 to 180 $MtCO_2$/yr was estimated (Table 9.6). Economic analyses were not only done; country studies were done, for example, Hoen and Solberg (1994) for Norway. New European scale economic analyses may be available from the INSEA[5] project, MEACAP project[6], and Carbo Europe [7].

Issues in European forestry where mitigation options can be found include: afforestation of abandoned agricultural

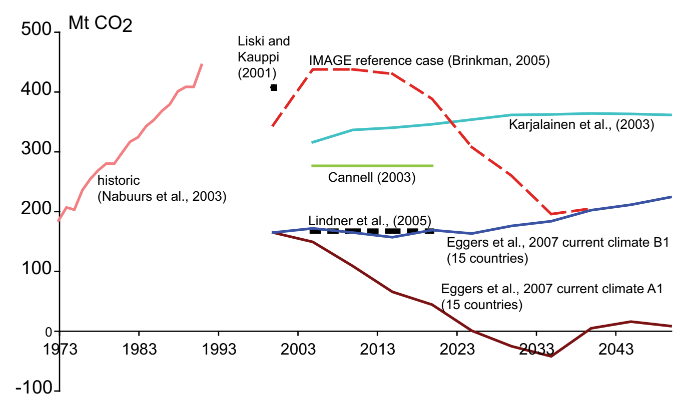

Figure 9.9: *European forest sector carbon sink projections for which various assumptions on implementation rate of measures were made*
Note: positive = sink.

4 Europe here excludes the European part of Russia.
5 www.iiasa.ac.at/Research/FOR/INSEA/index.html?sb=19
6 www.ieep.eu/projectMiniSites/meacap/index.php
7 www.carboeurope.org/

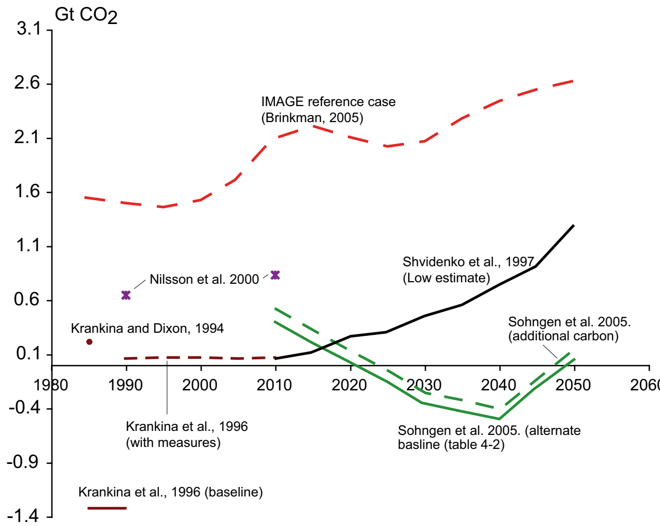

Figure 9.10: *Russian Federation forest sector carbon sink projections, with assumptions regarding implementation rates differing in the various studies*
Note: positive = sink.

lands; bio-energy from complementary fellings; and forest management practices to address carbon saturation in older forests. Furthermore, management of small now under-managed woodlands represent a potential (Viner *et al.,* 2006) and also in combination with adaptation measures in connecting the fragmented nature reserves (Schröter *et al.,* 2005).

Russian Federation

The forests of the Russian Federation include large areas 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 1,600 $MtCO_2$/yr (Zhang *et al.,* 2003). Large uncertainty surrounds the estimates for the current carbon balance ((Shvidenko and Nilsson *et al.,* 2003). For the decade 1990-2000, the range of carbon sink values for Russia is 350-750 $MtCO_2$/yr (Nilsson *et al.*, 2003; Izrael *et al.*, 2002). A recent analysis estimated the net sink in Russia at 146-439 $MtCO_2$/yr at present (Sohngen *et al.,* 2005). They projected this baseline to be about 257 $MtCO_2$ per year in 2010, declining to a net source by 2030 as younger forests mature and are harvested. They estimated the economic potential in Russia of afforestation and reforestation at 73-124 $MtCO_2$/yr on average over an 80-year period, for a carbon price of 1.9-3.55 US$/$tCO_2$, and 308-476 $MtCO_2$/yr at prices of more than 27 US$/$tCO_2$ (Figure 9.10). Based on these estimates, the estimated economic mitigation potential would be between 150 and 300 $MtCO_2$/yr in the year 2040 (Table 9.6).

OECD Pacific

Richards and Brack (2004) used estimates of establishment rates for hardwood (short and long rotation) and softwood plantations to model a carbon account for Australia's post-1990 plantation estate. The annual sequestration rate in forests and wood products together is estimated to reach 20 $MtCO_2$/yr in 2020.

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

However, the current new planting rate has declined to 6,000 ha and conversion of 7,000 ha of plantations to pasture has led to net deforestation in the year to March 2005 (MAF, 2006). As a result, the total removal units anticipated to be available during the first commitment period dropped to 56 $MtCO_2$ in 2005 (MfE, 2005). Trotter *et al.* (2005) estimate New Zealand has approximately 1.45 million ha of marginal pastoral land suitable for afforestation. If all of this area was established, total sequestration could range from 10 to 42 $MtCO_2$/yr. This would lead to a removal of approximately 44 to 170 $MtCO_2$ cumulative by 2010 at 13 US$/$tCO_2$.

In Japan, 67% of the land is covered with forests including semi-natural broad-leaved forests and planted coniferous forests mostly. The sequestration potential is estimated in the range of 35 to 70 $MtCO_2$/yr (Matsumoto *et al.*, 2002; Fang *et al.*, 2005), and planted forests account for more than 60% of the carbon sequestration. These assessments show that there is little potential for afforestation and reforestation, while forest management and practices for planted forests including thinning and regeneration are necessary to maintain carbon sequestration and to curb saturation. In addition, there seems to be large potential for bio-energy as a mitigation option.

These three countries for the region lead to an estimate of potential in the range of 85 to 255 $MtCO_2$/yr in 2040 (Table 9.6).

Non-annex I East 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 shrubland. Country assessments for the forest sector all project a sink ranging from 75 to 400 $MtCO_2$/yr (Zhang and Xu, 2003). Given the large areas and the fast economic development (and thus demand for wood products resulting in increased planting), the additional potential in the region would be in the high range of the country assessments at 150 to 400 $MtCO_2$/yr (Table 9.6). Issues in forestry with which the carbon sequestration goal can be combined sustainably are: reducing degradation of tropical and dry woodlands; halting desertification of the steppes (see Chapter 8); afforestation; and bio-energy from complementary fellings.

9.4.3.2 *Global Forest sectoral modelling*

Currently, no integrated assessment (Section 9.4.3.3) and climate stabilization economic models (Section 3.3.5) have fully integrated a land use sector with other sectors in the models. Researchers have taken several approaches, however, to account for carbon sequestration in integrated assessment models, either by iterating with the land sector models (e.g., Sohngen and Mendelsohn, 2003), or implementing mitigation response curves generated by the sectoral model (Jakeman and Fisher, 2006). The sectoral model results described here use exogenous carbon price paths to simulate effects of different climate policies and assumptions. The starting point and rate of increase are determined by factors such as the aggressiveness of the abatement policy, abatement option and cost assumptions, and the social discount rate (Sohngen and Sedjo, 2006).

Since TAR, several new global assessments of forest mitigation potential have been produced. These include Benitez-Ponce *et al,* (2004; 2007), Waterloo *et al.* (2003) with a constraints study, Sathaye *et al.* (2007), Strengers *et al.* (2007) Vuuren *et al.* (2007), and Riahi *et al.* (2006). Global estimates are provided that are consistent in methodology across countries and regions, and in terms of measures included. Furthermore, they provide a picture in which the forestry sector is one option that is part of a multi sectoral climate policy and its measures. Thus, these assessments provide insight into whether land-based mitigation is a cost-efficient measure in comparison to other mitigation efforts. Some of these models use a grid-based global land-use model and provide insight into where these models allocate the required afforestation (Figure 9.11).

The IMAGE model (Strengers *et al.*, 2007) allocates bio-energy plantations and carbon plantations mostly in the fringes of the large forest biomes, and in Eastern Europe. The Waterloo study only looked at tropical countries, but found by far the largest potential in China and Brazil. Several models report at the regional level, and project strong avoided deforestation in Africa, the Amazon, and to a lesser extent in Southeast Asia (where land opportunity costs in the timber market are relatively high). Benitez-Ponce (2004) maps geographic distribution of afforestation, adjusted by country risk estimates, under a 50

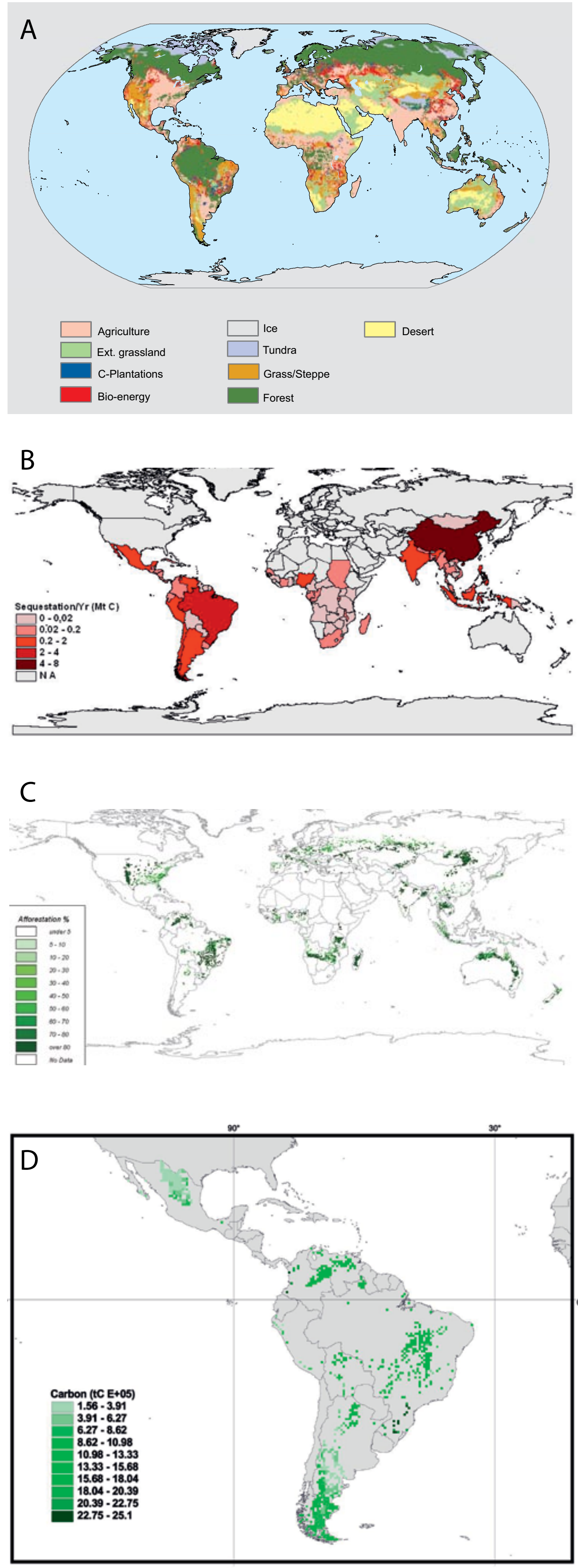

Figure 9.11: *Comparison of allocation of global afforestation in various studies*
(A) Location of bio-energy and carbon plantations
(B) Additional sequestration from afforestation per tropical country per year in the period 2008-2012 (MtC/yr),
(C) Percentage of a grid cell afforested
(D) Cumulative carbon sequestration through afforestation between 2000 and 2012 in Central and South America).

Source: (A) Strengers et al., 2007; (B) Waterloo et al., 2003; (C) Strengers et al., 2007; (D) Benitez-Ponce et al., 2007.

US$/t carbon price. Afforestation activity is clustered in bands in South-Eastern USA, Southeast Brazil and Northern South America, West Africa, north of Botswana and East Africa, the steppe zone grasslands from Ukraine through European Russia, North- Eastern China, and parts of India, Southeast Asia, and Northern Australia. Hence, forest mitigation is likely to be patchy, but predictable using an overlay of land characteristics, land rental rates, and opportunity costs, risks, and infrastructure capacity.

Several models produced roughly comparable assessments for a set of constant and rising carbon price scenarios in the EMF 21 modelling exercise, from 1.4 US$/t$CO_2$ in 2010 and, rising by 5% per year to 2100, to a 27 US$ constant CO_2 price, to 20 US$/t$CO_2$ rising by 1.4 US$/yr though 2050 then capped. This exercise allowed more direct comparison of modelling 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) models have different drivers of land use change (e.g., population and GDP growth for IMAGE, versus land rental rates and timber market demand for GTM).

Global models provide broad trends, but less detail than national or project analyses. Generally global models do not address implementation issues such as transaction costs (likely to vary across activities, regions), barriers, and mitigation programme rules, which tend to drive mitigation potential downward toward true market potential. Political and financial risks in implementing afforestation and reforestation by country were considered by Benitez-Ponce *et al.* (2007), for example, who found that the sequestration reduced by 59% once the risks were incorporated.

In the last few years, more insight has been gained into carbon supply curves. At a price of 5 US$/t$CO_2$, Sathaye *et al.* (2007) project a cumulative carbon gain of 10,400 MtCO_2 by 2050 (Figure 9.12b). The mitigation results from a combination of avoided deforestation (68%) and afforestation (32%). These results are typical in their very high fraction of mitigation from reduced deforestation. Sohngen and Sedjo (2006) estimate some 80% of carbon benefits in some scenarios from land-use change (e.g., reduced deforestation and afforestation/reforestation) versus some 20% from forest management.

Benitez-Ponce *et al.* (2007) project that at a price of 13.6 US$/t$CO_2$, the annual sequestration from afforestation and reforestation for the first 20 years amounts to on average 510 MtCO_2/yr (Figure 9.12a). For the first 40 years, the average annual sequestration is 805 MtCO_2/yr. The single price of 13.6 US$/t$CO_2$ used by Benitez-Ponce *et al.* (2005) should make afforestation an attractive land-use option in many countries. It covers the range of median values for sequestration costs that Richards and Stokes (2004) give of 1 US$ to 12 US$/t$CO_2$, although VanKooten *et al.* (2004) present marginal cost results rising far higher. Sathaye *et al.* (2007) project the economic potential cumulative carbon gains from afforestation and avoided deforestation together (see also tropics, Section 9.4.3.1.). In the moderate carbon price scenarios, the cumulative carbon gains by 2050 add up to 91,400 to 104,800 MtCO_2.

The anticipated carbon price path over time has important implications for forest abatement potential and timing. Rising carbon prices provide an incentive for delaying forest abatement actions to later decades, when it is more profitable (Sohngen and Sedjo, 2006). Carbon price expectations influence forest investment decisions and are, therefore, an important consideration for estimating mitigation potential. Contrary, high constant carbon prices generate significant early mitigation, but the quantity may vary over time. Mitigation strategies need to take into account this temporal dimension if they seek to meet specific mitigation goals at given dates in the future (US EPA, 2005).

Some patterns emerge from the range of estimates reviewed in order to assess the ratio between economic potential and technical potential (Sathaye *et al.*, 2007; Lewandrowski *et al.*, 2004; US EPA, 2005; Richards and Stokes, 2004). The technical potential estimates are generally significantly larger than the economic potential. These studies are difficult to compare, since each estimate uses different assumptions by different analysts. Economic models used for these analyses can generate mitigation potential estimates in competition to other forestry or agricultural sector mitigation options. Generally, they do not specify or account for specific policies and measures and market penetration rates, so few market potential estimates are generated. Many studies do not clearly state which potentials are estimated.

The range of economic potential as a percentage of technical potential is 2% to 100% (the latter against all costs). At carbon prices less than 7 US$/t$CO_2$, the highest estimate of economic potential is 16% of the technical potential. At carbon prices from 27 US$/t$CO_2$ to 50 US$/t$CO_2$, the range of economic potential is estimated to be 58% or higher of the technical potential, a much higher fraction as carbon prices rise. Table 9.3 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, 2006; and GCOMAP (Sathaye *et al.*, 2007), one recent detailed spatially resolved analysis of afforestation (Benitez-Ponce *et al.*, 2007), and one integrated assessment model with detail for the forest sector (IMAGE 2.2, Vuuren *et al.*, 2007). 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-Ponce *et al.,* 2007). All but the Benitez-Ponce *et al.* study have been compared by the modelling teams in the EMF 21 modelling exercise (see Sections 3.2.2.3 and 3.3.5) as well.

These global models (Table 9.3) present a large potential for climate mitigation through forestry activities. The global annual

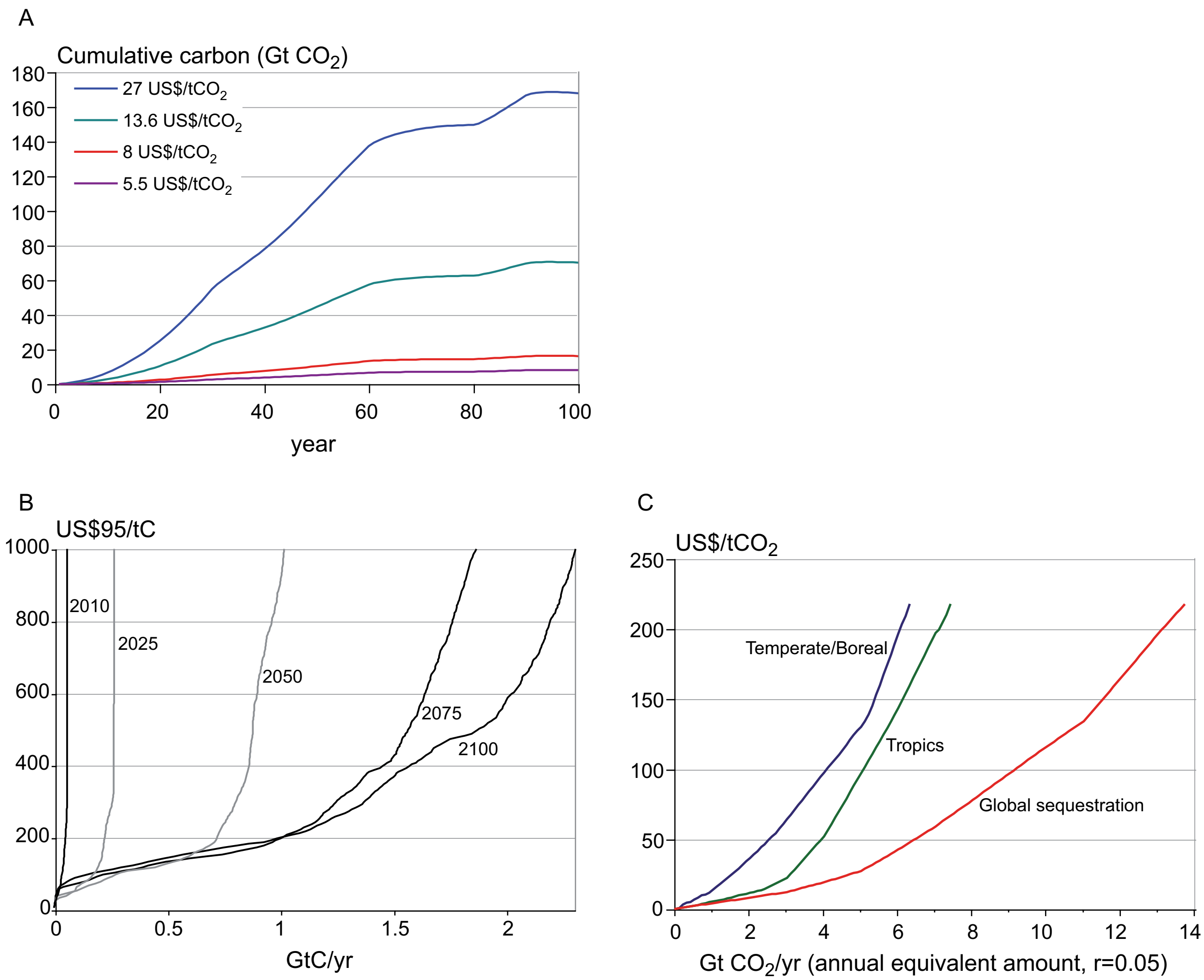

Figure 9.12: *Comparison of carbon supply curves globally from various studies*

*(*A) Cumulative carbon supply curves: afforestation and reforestation by year and price scenario. At a price of 100 US$/tC after 70 years, some 40 Gt carbon will have been supplied cumulatively from afforestation.

(B) Annual cost-supply curves for abandoned agricultural land in the B2 scenario. For example, at a price of 100 US$/tC, in 2075, some 250 Mt carbon will have been supplied annually from afforestation and reducing deforestation.

(C) Annual marginal cost curves for carbon sequestration in forests: estimates for boreal, temperate, and tropical regions. For example, at a price of 100 US$/tC, some 1400 Mt carbon will have been supplied annually from afforestation and reducing deforestation in 2100.

Sources: (A) Benitez-Ponce et al., 2005; (B) Strengers et al., 2007; (C) Sohngen and Sedjo, 2006.

potential in 2030 is estimated at 13,775 $MtCO_2$/yr (at carbon prices less than or equal to 100 US$/$tCO_2$), 36% (~5000 $MtCO_2$/yr) of which can be achieved under a price of 20 US$/$tCO_2$. Reduced deforestation in Central and South America is the most important measure in a single region with 1,845 $MtCO_2$/yr. The total for the region is the largest for Central and South America with an estimated total potential of 3,100 $MtCO_2$/yr. Regions with a second largest potential, each around 2000 $MtCO_2$, are Africa, Centrally Planned Asia, other Asia, and USA. These results project significantly higher mitigation than the regional largely bottom-up results. This is somewhat surprising, and likely, the result of the modelling structure, assumptions, and which activities are included. Additional research is required to resolve the various estimates to date using different modelling approaches of the potential magnitude of forestry mitigation of climate change.

Table 9.3: *Potential of mitigation measures of global forestry activities. Global model results indicate annual amount sequestered or emissions avoided, above business as usual, in 2030 for carbon prices 100 US$/t$CO_2$ and less.*

Region	Activity	Potential at costs equal or less than 100 US$/t$CO_2$, in Mt$CO_2$/yr in 2030 [1)]	Fraction in cost class: 1-20 US$/t$CO_2$	Fraction in cost class: 20-50 US$/t$CO_2$
USA	Afforestation	445	0.3	0.3
	Reduced deforestation	10	0.2	0.3
	Forest management	1,590	0.26	0.32
	TOTAL	2,045	0.26	0.31
Europe	Afforestation	115	0.31	0.24
	Reduced deforestation	10	0.17	0.27
	Forest management	170	0.3	0.19
	TOTAL	295	0.3	0.21
OECD Pacific	Afforestation	115	0.24	0.37
	Reduced deforestation	30	0.48	0.25
	Forest management	110	0.2	0.35
	TOTAL	255	0.25	0.34
Non-annex I East Asia	Afforestation	605	0.26	0.26
	Reduced deforestation	110	0.35	0.29
	Forest management	1,200	0.25	0.28
	TOTAL	1,915	0.26	0.27
Countries in transition	Afforestation	545	0.35	0.3
	Reduced deforestation	85	0.37	0.22
	Forest management	1,055	0.32	0.27
	TOTAL	1,685	0.33	0.28
Central and South America	Afforestation	750	0.39	0.33
	Reduced deforestation	1,845	0.47	0.37
	Forest management	550	0.43	0.35
	TOTAL	3,145	0.44	0.36
Africa	Afforestation	665	0.7	0.16
	Reduced deforestation	1,160	0.7	0.19
	Forest management	100	0.65	0.19
	TOTAL	1,925	0.7	0.18
Other Asia	Afforestation	745	0.39	0.31
	Reduced deforestation	670	0.52	0.23
	Forest management	960	0.54	0.19
	TOTAL	2,375	0.49	0.24
Middle East	Afforestation	60	0.5	0.26
	Reduced deforestation	30	0.78	0.11
	Forest management	45	0.5	0.25
	TOTAL	135	0.57	0.22
TOTAL	Afforestation	4,045	0.4	0.28
	Reduced deforestation	3,950	0.54	0.28
	Forest management	5,780	0.34	0.28
	TOTAL	13,775	0.42	0.28

1) Results average activity estimates reported from three global forest sector models including GTM (Sohngen and Sedjo, 2006), GCOMAP (Sathaye et al., 2007), and IIASA-DIMA (Benitez-Ponce et al., 2007). For each model, output for different price scenarios has been published. The original authors were asked to provide data on carbon supply under various carbon prices. These were summed and resulted in the total carbon supply as given middle column above. Because carbon supply under various price scenarios was requested, fractionation was possible as well.

Two right columns represent the proportion available in the given cost class. None of the models reported mitigation available at negative costs. The column for the carbon supply fraction at costs between 50 and 100 US$/t$CO_2$ can easily be derived as 1- sum of the two right hand columns.

9.4.3.3 *Global forest mitigation in climate stabilization analysis*

Evaluating the cost-competitiveness of forestry mitigation versus other sector options in achieving climate mitigation goals requires different modelling capabilities. Global integrated assessment and climate economic models are top-down models, generally capable of dynamically representing feedbacks in the economy across sectors and regions and reallocations of inputs, as well as interactions between economic and atmospheric-ocean-terrestrial systems. These models can be used to evaluate long-term climate stabilization scenarios, like achieving a stabilization target of 450 or 650 CO_2-eq by 2100 (see Section 3.3.5). In this framework, the competitive mitigation role of forest abatement options, such as afforestation, can be estimated as part of a dynamic portfolio of the least-cost combination of mitigation options from across all sectors of the economy, including energy, transportation, and agriculture.

To date, researchers have used various approaches to represent terrestrial carbon sequestration in integrated assessment models. These approaches include iterating with the land-sector models (e.g., Sohngen and Mendelsohn, 2003), and implementing mitigation response curves generated by a sectoral model (Jakeman and Fisher, 2006). At present, all integrated assessment models include afforestation strategies, but only some consider avoided deforestation, and none explicitly model forest management mitigation options (e.g., harvest timing: Rose *et al.*, 2007). However, the top-down mitigation estimates account for economic feedbacks, as well as for some biophysical feedbacks such as climate and CO_2 fertilization effects on forest growth.

Table 9.4: *Global forest cost-effective mitigation potential in 2030 from climate stabilization scenarios, or 450-650 CO_2-eq atmospheric concentration targets, produced by top-down global integrated assessment models. Forest options are in competition with other sectoral options to generate least-cost mitigation portfolios for achieving long-run stabilization.*

Carbon price in scenario (US$/t$CO_2$-eq)	Mitigation potential in 2030	
	MtCO_2-eq/yr	Number of scenario results
0 - 20	40 - 970	4
20 - 50	604 - 790	3
50 - 100	nd	0
>100	851	1

Notes: Jakeman and Fisher (2006) estimated 2030 forest mitigation of 3,059 MtCO_2, well above other estimates, but not included due to an inconsistency inflating their forest mitigation estimates for the early 21st century.
nd = no data.
Source: Section 3.3.5; data from Rose et al., 2007.

The few estimates of global competitive mitigation potential of forestry in climate stabilization in 2030 are given in Table 9.4. Some estimates represent carbon plantation gains only, while others represent net forest carbon stock changes that include plantations as well as deforestation carbon loses induced by bio-energy crops. On-going top-down land-use modelling developments should produce more refined characterization of forestry abatement alternatives and cost-effective mitigation potential in the near future. The results in Table 9.4 suggest a reasonable central estimate of about 700 million tonne CO_2 in 2030 from forestry in competition with other sectors for achieving stabilization, significantly less than the regional bottom-up or global sector top-down estimates in this chapter summarized in Table 9.7.

Box 9.2: Commercial biomass for bio-energy from forests

Current use of biomass from fuelwood and forest residues reaches 33 EJ (see Section 4.3.3). Three main categories of forest residues may be used for energy purposes: primary residues (available from additional stemwood fellings or as residues (branches) from thinning salvage after natural disturbances or final fellings); secondary residues (available from processing forest products) and tertiary residues (available after end use). Various studies have assessed the future potential supply of forest biomass (Yamamoto et al., 2001; Smeets and Faaij, 2007; Fischer and Schrattenholzer, 2001). Furthermore, some global biomass potential studies include forest residues aggregated with crop residue and waste (Sørensen, 1999). At a regional or national scale, studies are more detailed and often include economic considerations (Koopman, 2005; Bhattacharya et al., 2005; Lindner et al., 2005; Cuiping et al., 2004). Typical values of residue recoverability are between 25 and 50 % of the logging residues and between 33 and 80% of processing residues. Lower values are often assumed for developing regions (Yamamoto et al., 2001; Smeets and Faaij, 2007). At a global level, scenario studies on the future energy mixture (IPCC, 2000c; Sørensen, 1999; OECD, 2006) have included residues from the forestry sector in their energy supply (market potential).

The technical potential of primary biomass sources given by the different global studies is aggregated by region in Table Box 9.2. From this table, it 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. It is outside the scope of this chapter to examine all pros and cons of increased production required for biomass for bio-energy (see Section 11.9).

Box 9.2 continued

Table 9.5. *The technical potential of primary biomass for bio-energy from the forest sector at a regional level (in EJ/yr), for the period 2020-2050. The economic potential under 20 US$/t$CO_2$ is assumed to be in the range of 10-20% of these numbers.*

Regions	EJ/yr	
	LOW	HIGH
OECD		
OECD North America	3	11
OECD Europe	1	4
Japan + Australia + New Zealand	1	3
Economies in Transition		
Central and Eastern Europe, the Caucasus and Central Asia	2	10
Non-OECD		
Latin America	1	21
Africa	1	10
Non-Annex I East Asia	1	5
Non-Annex I Other Asia	1	8
Middle East	1	2
World low and high estimates	*12*	*74*
World (based on global studies) assumed economic potential	**14**	**65**

Notes: Conversion factors used: 0.58 tonne dry matter/m^3, a heating value of 15 GJ/tonne air dry matter, and a percentage of 49% carbon of dry matter. For example, 14 EJ (left column) is roughly comparable to 700 million tonnes of dry matter, which is (if assumed this has to come from additional stemwood fellings) comparable to roughly 1.5 billion m^3 of roundwood, half of current global harvesting of wood.
Sources: Fischer and Schrattenholzer, 2001; Ericsson and Nilsson, 2006; Yoshioka et al., 2006; Yamamoto, 2001; Williams, 1995; Walsh et al., 1999; Smeets

In general, the delivery or production costs of forestry residues are expected to be at a level of 1.0 to 7.7 US$/GJ. Smeets and Faaij (2007) concluded that at a global level, the economic potential of all types of biomass residues is 14 EJ/yr: at the very lower level of estimates in the table. This and the notion that the summation of the column of lower ranges of dry matter supply equals 700 million tonnes (which is assumed stemwood) is half of current global stemwood harvesting) was the reason to estimate the economic potential at 10-20% of above given numbers.

The CO_2 mitigation potential can only be calculated if the actual use and the amount of use of forestry biomass supply are known. This depends on the balance of supply and demand (see bio-energy in Section 11.3.1.4.). However, to give an indication of the order of magnitude of the figures the CO_2-eq emissions avoided have been calculated from the numbers in Table 9.5 using the assumption that biomass replaces either coal (high range) or gas (low range). Based on these calculations[8], the CO_2-eq emissions avoided range from 420 to 4,400 MtCO_2/yr for 2030. This is about 5 to 25% of the total CO_2-eq emissions that originate from electricity production in 2030, as reported in the World Energy Outlook (OECD, 2006).

9.4.4 Global summation and comparison

An overview of estimates derived in the regional bottom-up estimates as given in Section 9.4.3.1 are presented in Table 9.6. Based on indications in literature and carbon supply curves, the fraction of the mitigation potential in the cost class < 20 US$/t$CO_2$ was estimated.

Assuming a linear implementation rate of the measures, the values in Table 9.4 were adjusted to 2030 values (the values required in the cross sector summation in Chapter 11, Table 11.3). The 2030 values are presented in Table 9.7 against the values derived from global forest sector models, and from global integrated models for three world regions. The mitigation effect of biomass for bio-energy (see text, Box 9.2) was excluded.

The range of estimates in the literature and presented in Table 9.7 help in understanding the uncertainty surrounding forestry mitigation potential. Bottom-up estimates of mitigation generally include numerous activities in one or more regions

8 Assuming that it is used in a biomass combustion plant of 30% conversion efficiency and replaces a coal combustion plant with an efficiency of 48% (see IEA 2002) and a coal CO_2 content of 95 kgCO_2/GJ for the high range or a gas IGCC with an efficiency of 49% and a gas CO_2 content of 57 kgCO_2/GJ.

Table 9.6: *Summation of regional results (excluding bio-energy) as presented in Section 9.4.3.1 for 2040. Fraction by cost class is derived from Section 9.4.3.1.*

	Economic potential in 2040 ($MtCO_2$/yr) low	Economic potential in 2040 ($MtCO_2$/yr) high	Fraction of total (technical) potential in cost class <20 US$/$tCO_2$
North America	400	820	0.2
Europe	90	180	0.2
Russian Federation	150	300	0.3
Africa	300	875	0.6
OECD Pacific	85	255	0.35
Caribbean, Central and South America	500	1750	0.6
Non Annex I East Asia	150	400	0.3
Non Annex I South Asia	300	875	0.6
Total	**1,975**	**5,455**	

Note: These figures are surrounded by uncertainty. Differences in studies, assumptions, baselines, and price scenarios make a simple summation difficult.

Table 9.7: *Comparison of estimates of economic mitigation potential by major world region and methodology excluding biomass for bio-energy in $MtCO_2$/yr in 2030, at carbon prices less or equal to 100 US$/$tCO_2$. Fraction by cost class is given in Tables 9.3 and 9.6.*

	Regional bottom-up estimate			Global forest sector models	Global integrated assessment models
	Mean	Low	High		
OECD	700	420	980	2,730	
Economies in transition	150	90	210	3,600	
Non-OECD	1,900	760	3,040	7,445	
Global	**2,750**[a]	**1,270**	**4,230**	**13,775**	**700**

[a] Excluding bio-energy (see Box 9.2). Including the emission reduction effect of the economic potential of biomass for bio-energy would yield a total mean emission reduction potential (based on bottom up) of 3140 $MtCO_2$/yr in 2030.

represented in detail. Top-down global modelling of sectors and of long-term climate stabilization scenario pathways generally includes fewer, simplified forest options, but allows competition across all sectors of the economy to generate a portfolio of least-cost mitigation strategies. Comparison of top-down and bottom-up modelling estimates (Figure 9.13) is difficult at present. This stems from differences in how the two approaches represent mitigation options and costs, market dynamics, and the effects of market prices on model and sectoral inputs and outputs such as labour, capital, and land. One important reason that bottom-up results yield a lower potential consistently for every region (Figure 9.13) is that this type of study takes into account (to some degree) barriers to implementation. The bottom-up estimate has, therefore, characteristics of a market potential study, but the degree is unknown.

The uncertainty and differences behind the studies referred to, and the lack of baselines are reasons to be rather conservative with the final estimate for the forestry mitigation potential. Therefore, mostly the bottom-up estimates are used in the final estimate. This stands apart from any preference for a certain type of study. Thus synthesizing the literature, we estimate that forestry mitigation options have the economic potential (at carbon prices up to 100 US$/$tCO_2$) to contribute between 1270 and 4230 $MtCO_2$/yr in 2030 (medium confidence, medium agreement). About 50% of the medium estimate can be achieved at a cost under 20 US$/$tCO_2$ (= 1550 $MtCO_2$/yr: see Figure 9.14). The combined effects of reduced deforestation and degradation, afforestation, forest management, agro-forestry and bio-energy have the potential to increase gradually from the present to 2030 and beyond. For comparison with other sectors in Chapter 11, Table 11.2, data on cost categories <0 US$/$tCO_2$ and 20-50 US$100/$tCO_2$ have been derived from Tables 9.3 and 9.6, using cost information derived from regional bottom-up studies and global top- down modelling. The cost classes assessed should be seen as rough cost-class indications, as the information in the literature varies a lot. These analyses assume gradual implementation of mitigation activities starting at present.

This sink enhancement/emission avoidance will be located for 65% in the tropics (high confidence, high agreement; Figure 9.14); be found mainly in above-ground biomass; and for 10% achieved through bio- energy (medium confidence, medium agreement). In the short term, this potential is much smaller, with 1180 $MtCO_2$/yr in 2010 (high confidence, medium agreement). Uncertainty from this estimate arises from the variety of studies

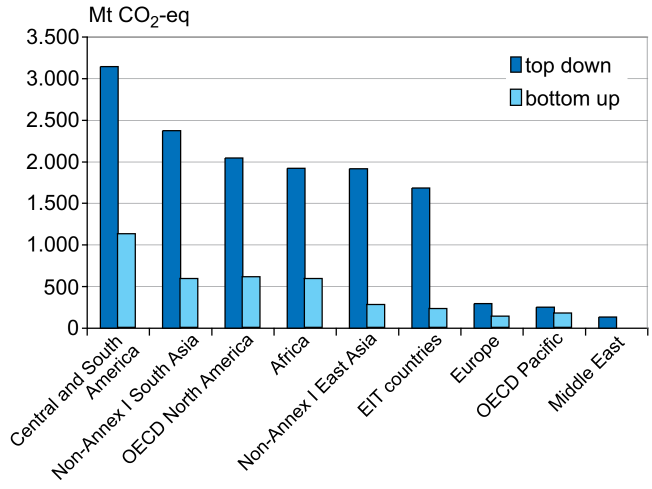

Figure 9.13: *Comparison of estimates of economic mitigation potential in the forestry sector (up to 100 US$/tCO$_2$ in 2030) as based on global forest sector models (top-down) versus regional modelling results (bottom-up).*

Note: Excluding bio-energy; data from Table 9.3 and Table 9.6.

used, the different assumptions, the different measures taken into account, and not taking into account possible leakage between continents.

These final results allow comparison with earlier IPCC estimates for forestry mitigation potential (Figure 9.15). The estimates for Second Assessment Report (SAR), Third Assessment Report (TAR) and Special Report have to be seen as estimates for a technical potential, and are comparable to our Fourth Assessment Report (AR4) estimates for a carbon dioxide price < 100 US$/tCO$_2$ (as displayed). As the bars in this figure are lined by the year to which they apply, one would expect an increasing trend towards the right-hand columns. This is not the

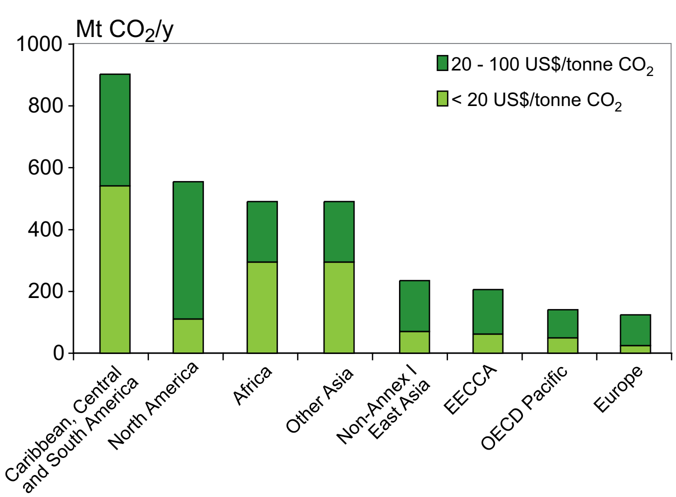

Figure 9.14: *Annual economic mitigation potential in the forestry sector by world region and cost class in 2030.*

Note: EECCA=Countries of Eastern Europe, the Caucasus and Central Asia.

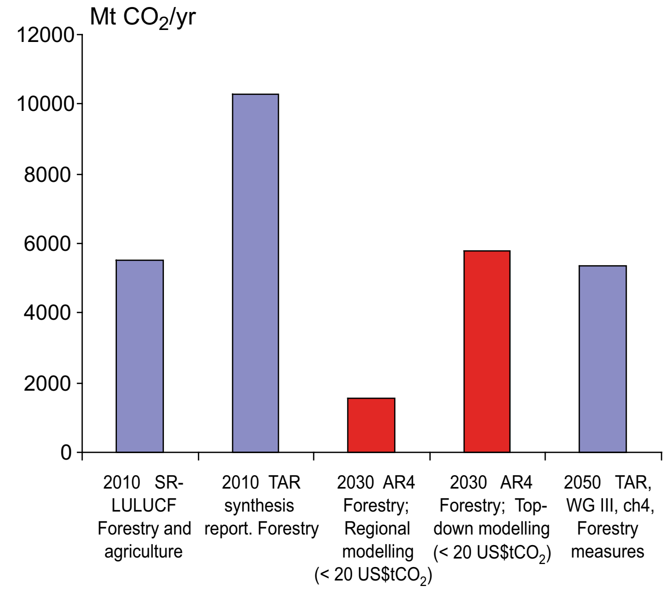

Figure 9.15: *Comparison of estimates of mitigation potential in previous IPCC reports (blue) and the current report (in red).*

Note the difference in years to which the estimate applies, in applied costs, and between forest sector only versus whole LULUCF estimates.

case. Instead a large variety is displayed. There is a trend visible through the consecutive IPCC reports, and not so much through the years to which the estimate applies. When ignoring the TAR synthesis, we start with the highest estimate in SAR (just over 8000 MtCO$_2$/yr), then follows SR LULUCF with 5500 MtCO$_2$, and TAR with 5300. Finally, the present report follows with a conservative estimate of 3140 (including bio-energy).

9.5 Interactions with adaptation and vulnerability

Some of the mitigation potential as given in this chapter might be counteracted by adverse effects of climate change on forest ecosystems (Fischlin *et al*., 2007). Further, mitigation-driven actions in forestry could have positive adaptive consequences (e.g., erosion protection) or negative adaptation consequences (e.g., increase in pest and fires). Similarly, adaptation actions could have positive or negative consequences on mitigation. To avoid trade-offs, it is important to explore options to adapt to new climate circumstances at an early stage through anticipatory adaptation (Robledo *et al.,* 2005). The limits to adaptation stem in part from the way that societies exacerbate rather than ameliorate vulnerability to climate fluctuations (Orlove, 2005) that can also affect mitigation potentials. There are significant opportunities for mitigation and for adapting to climate change, while enhancing the conservation of biodiversity, and achieving 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 until very recently. Now, the two concepts are seen to be linked, however to achieve synergies may be a challenge (Tol, 2006). In the IPCC Third Assessment Report, potential synergy and trade-off issues were not addressed. This section explores the synergy between mitigation and adaptation in the forest sector (Ravindranath and Sathaye, 2002). The potential and need for incorporating adaptation strategies and practices in mitigation projects is illustrated with a few examples.

9.5.1 Climate impacts on carbon sink 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, overgrazing by livestock, fire, and introduction of new species. Climate change constitutes an additional pressure that could change or endanger these ecosystems. The IPCC Fourth Assessment report (Fischlin *et al*., 2007 and Easterling *et al*., 2007) has highlighted the potential impacts of climate change on forest ecosystems. New findings indicate that negative climate change impacts may be stronger than previously projected and positive impacts are being over-estimated as well as the uncertainty on predictions.

Recent literature indicates that the projected potential positive effect of climate change as well as the estimated carbon sink in mature forests may be substantially threatened by enhancing or changing the regime of disturbances in forests such as fire, pests, drought, and heat waves, affecting forestry production including timber (Fuhrer *et al.,* 2007; Sohngen *et al*., 2005; Ciais *et al.,* 2005).

Most model limitations persist; models do not include key ecological processes, and feedbacks. There are still inconsistencies between the models used by ecologists to estimate the effects of climate change on forest production and composition, and the models used by foresters to predict forest yield (Easterling *et al*., 2007). Despite the achievements and individual strengths of the selected modelling approaches, core problems of global land-use modelling have not yet been resolved. For a new generation of integrated large-scale land-use models, a transparent structure would be desirable (Heistermann *et al.,* 2006).

Global change, including the impacts of climate change, can affect the mitigation potential of the forestry sector by either increasing (nitrogen deposition and CO_2 fertilization), or decreasing (negative impacts of air pollution,) the carbon sequestration. But, recent studies suggest that the beneficial impacts of climate change are being overestimated by ignoring some of the feedbacks (Körner, 2004) and assumption of linear responses. Also, the negative impacts may be larger than expected (Schroter *et al.,* 2005), with either some effects remaining incompletely understood (Betts *et al.,* 2004) or impossible to separate one from the other.

9.5.2 Mitigation and adaptation synergies

The mitigation and adaptation trade-offs and synergies in the forestry sector are dealt with in Klein *et al*. (2007). Many of the response strategies to address climate change, such as Global Environmental Facility (GEF) and Clean Development Mechanism (CDM), Activities under Article 3.3 and Article 3.4 and the Adaptation Fund aim at implementation of either mitigation or adaptation technologies or policies. It is necessary to promote synergy in planning and implementation of forestry mitigation and adaptation projects to derive maximum benefit to the global environment as well as local communities or economies, for example promoting adaptive forest management (McGinley & Finegan, 2003). However, recent analyses not specifically focused on the Forestry sector point out that it may be difficult to enhance synergies. This is due to the different actors involved in mitigation and adaptation, competitive use of funds, and the fact that in many cases both activities take place at different implementation levels (Tol, 2006). It should also be taken into account that activities to address mitigation and adaptation in the forestry sector are planned and implemented locally.

It is likely that adaptation practices will be easier to implement in forest plantations than in natural forests. 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, changes in rotation periods, salvaging dead timber, shifting to species more productive under the new climatic conditions, landscape planning to minimize fire and insect damage, and to provide connectivity, and adjusting to altered wood size and quality (Spittlehouse and Stewart, 2003). A primary aim of adaptive management 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 (Fischlin *et al*., 2007). While regrowth of trees due to effective protection will lead to carbon sequestration, adaptive management of protected areas also leads to conservation of biodiversity and reduced vulnerability to climate change. For example, ecological corridors create opportunities for migration of flora and fauna, which facilitates adaptation to changing climate.

Adaptation practices could be incorporated synergistically in most mitigation projects in the forest sector. However, in some cases, mitigation strategies could also have adverse implications for watersheds in arid and semi-arid regions (UK FRP, 2005) and biodiversity (Caparros and Jacquemont, 2003). To achieve an optimum link between adaptation and mitigation activities, it is necessary to clearly define who does the activity, where and what are the activities for each case. Several principles can be defined (Murdiyarso *et al*., 2005): prioritizing mitigation activities that help to reduce pressure on natural resources, including vulnerability to climate change as

Table 9.8: *Adaptation and mitigation matrix*

Mitigation option	*Vulnerability of the mitigation option to climate change*	*Adaptation options*	*Implications for GHG emissions due to adaptation*
A. Increasing or maintaining the forest area			
Reducing deforestation and forest degradation	Vulnerable to changes in rainfall, higher temperatures (native forest dieback, pest attack, fire and, droughts)	Fire and pest management Protected area management Linking corridors of protected areas	No or marginal implications for GHG emissions, positive if the effect of perturbations induced by climate change can be reduced
Afforestation / Reforestation	Vulnerable to changes in rainfall, and higher temperatures (increase of forest fires, pests, dieback due to drought)	Species mix at different scales Fire and pest management Increase biodiversity in plantations by multi-species plantations. Introduction of irrigation and fertilisation Soil conservation	No or marginal implications for GHG emissions, positive if the effect of perturbations induced by climate change can be reduced May lead to increase in emissions from soils or use of machinery and fertilizer
B. Changing forest management: increasing carbon density at plot and landscape level			
Forest management in plantations	Vulnerable to changes in rainfall, and higher temperatures (i.e. managed forest dieback due to pest or droughts)	Pest and forest fire management. Adjust rotation periods Species mix at different scales	Marginal implications on GHGs. May lead to increase in emissions from soils or use of machinery or fertilizer use
Forest management in native forest	Vulnerable to changes in rainfall, and higher temperatures (i.e. managed forest dieback due to pest, or droughts)	Pest and fire management Species mix at different scales	No or marginal
C. Substitution of energy intensive materials			
Increasing substitution of fossil energy intensive products by wood products	Stocks in products not vulnerable to climate change		No implications in GHGs emissions
D. Bio-energy			
Bio-energy production from forestry	An intensively managed plantation from where biomass feedstock comes is vulnerable to pests, drought and fire occurrence, but the activity of substitution is not.	Suitable selection of species to cope with changing climate Pest and fire management	No implications for GHG emissions except from fertilizer or machinery use

a risk to be analysed in mitigation activities; and prioritizing mitigation activities that enhance local adaptive capacity, and promoting sustainable livelihoods of local populations.

Considering adaptation to climate change during the planning and implementation of CDM projects in forestry may also reduce risks, although the cost of monitoring performance may become very complex (Murdiyarso *et al.*, 2005). Adaptation and mitigation linkages and vulnerability of mitigation options to climate change are summarized in Table 9.8, which presents four types of mitigation actions.

Reducing deforestation is the dominant mitigation option for tropical regions (Section 9.4). Adaptive practices may be complex. Forest conservation is a critical strategy to promote sustainable development due to its importance for biodiversity conservation, watershed protection and promotion of livelihoods of forest-dependent communities in existing natural forest (IPCC, 2002).

Afforestation and reforestation are the dominant mitigation options in specific regions (e.g., Europe). Currently, afforestation and reforestation are included under Article 3.3 and in Articles 6 and 12 (CDM) of the Kyoto Protocol. Plantations consisting of multiple species may be an attractive adaptation option as they are more resilient, or less vulnerable, to climate change. The latter as a result of different tolerance to climate change characteristic of each plantation species, different migration abilities, and differential effectiveness of invading species (IPCC, 2002).

Agro-forestry provides an example of a set of innovative practices designed to enhance overall productivity, to increase carbon sequestration, and that can also strengthen the system's 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 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 to 2.2 PgC in terrestrial ecosystems over the next 50 years (Albrecht and Kandji, 2003). Agro-forestry can also help to decrease pressure on natural forests and promote soil conservation, and provide ecological services to livestock.

Bio-energy. Bio-energy plantations are likely to be intensively managed to produce the maximum biomass per unit area. To ensure sustainable supply of biomass feedstock and to reduce vulnerability to climate change, the practices mentioned above for afforestation and reforestation projects need to be explored such as changes in rotation periods, salvage of dead timber, shift to species more productive under the new climatic conditions, mixed species forestry, mosaics of different species and ages, and fire protection measures.

Adaptation and mitigation synergy and sustainable development

The need for integration of mitigation and adaptation strategies to promote sustainable development is presented in Klein *et al*. (2007). 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, 2007). Currently, there are very few ongoing studies on the interaction between mitigation, adaptation and sustainable development (Wilbanks, 2003; Dang *et al.*, 2003). Quantification of synergy is necessary to convince the investors or policy makers (Dang *et al.*, 2003).

The possibility of incorporating adaptation practices into mitigation projects to reduce vulnerability needs to be explored. Particularly, Kyoto Protocol activities under Article 3.3, 3.4 and 12 provide 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

This section examines the barriers, opportunities, and implementation issues associated with policies affecting mitigation in the forestry sector. Non-climate policies, that is 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. Many factors 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, policy options and their effectiveness are examined separately for 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. This provides 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). The causes of tropical deforestation are complex, varying across countries and over time in response to different social, cultural, and macroeconomic conditions (Geist and Lambin, 2002). Broadly, three major barriers to enacting effective policies to reduce forest loss are: (i) profitability incentives often run counter to forest conservation and sustainable forest management (Tacconi *et al.,* 2003); (ii) many direct and indirect drivers of deforestation lie outside of the forest sector, especially in agricultural policies and markets (Wunder, 2004); and (iii) limited regulatory and institutional capacity and insufficient resources constrain the ability of many governments to implement forest and related sectoral 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 (Sizer *et al.,* 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 have proven effective in maintaining 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 (Mertens *et al.*, 2004).

China (Cohen *et al.*, 2002), the Philippines and Thailand (Granger, 1997) have significantly reduced deforestation rates in response to experiencing severe environmental and public health consequences of forest loss and degradation. In India, the Joint Forest Management programme has been effective in partnering with communities to reduce forest degradation (Bhat *et al.,* 2001). 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 commitment to enforcement can significantly reduce deforestation rates.

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. Relatively high transaction costs and insecure land and resource tenure have thus far limited applications of this approach in many countries (Grieg-Gran, 2004). However, 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.

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, and the International Tropical Timber Organization have provided support to national forest planning efforts but have not yet had demonstrable impacts on reducing deforestation (Speth, 2002).
- The World Bank has modified lending policies to reduce the risk of direct negative impacts to forests, but this does not appear to have measurably slowed deforestation (WBOED, 2000).
- The World Bank and G-8 have 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.
- The Food and Agricultural Organization (FAO) Forestry Programme has for decades provided a broad range of technical support in sustainable forest management (FAO, 2006b); assessing measurable impacts has been limited by the lack of an effective monitoring programme (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. This raises the possibility that, with sufficient institutional capacity, financial incentives, 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 International, 2004; Stern, 2006).

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 CDM in the Kyoto Protocol's first commitment period was in part based on methodological concerns. These concerns are particularly associated with additionality and baseline setting and whether leakage could be sufficiently controlled or quantified to allow for robust carbon crediting (Trines *et al.*, 2006). In December 2005, COP-11 established a two-year process to review relevant scientific, technical, and methodological issues and to consider possible policy approaches and positive incentives for reducing emissions from deforestation in developing countries (UNFCCC, 2006).

Recent studies 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 (Schlamadinger *et al.*, 2005; Trines *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. The emission reductions could then be 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.

One advantage of a national-sectoral approach over a project-based approach to reduce emissions from deforestation relates to leakage, in that any losses in one area could be balanced against gains in other areas. This does not entirely address the leakage problem since the risk of international leakage remains, as occurs in other sectors.

Other proposals emphasize accommodation to diverse national circumstances, including differing levels of development, and include a suggestion of separate targets for separate sectors (Grassl *et al.*, 2003). This includes a "no-lose" target, whereby emission allowances can be sold if the target is reached. No additional emission allowances would have to be bought if the target was not met. A multi-stage approach such that the level of commitment of an individual country increases gradually over time; capacity building and technology research and development; or quantified sectoral emission limitation and reduction commitments similar to Annex 1 commitments under the Kyoto Protocol (Trines *et al.*, 2006).

Proposed financing mechanisms include both carbon market-based instruments (Stern, 2006) and non-market based channels, for example, through a dedicated fund to voluntarily reduce emissions from deforestation (UNFCCC, 2006). Box 9.3 discusses recent technical advances relevant to the effective design and implementation of climate policies aimed at reducing emissions from deforestation and forest degradation.

9.6.2 Policies aimed to promote afforestation and reforestation

Non-climate forest policies have a long history in 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 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.

9.6.3 Policies to improve forest management

Industrialized countries generally have sufficient resources to implement policy changes in public forests. However, the fact that these forests are already managed to relatively high standards may limit possibilities for increasing sequestration through changed management practices (e.g., by changing species mix, lengthening rotations, reducing harvest damage and or accelerating replanting rates). There may be possibilities to reduce harvest rates to increase carbon storage however, for example, 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

BOX 9.3: Estimating and monitoring carbon emissions from deforestation and degradation

Recent analyses (DeFries *et al.,* 2006; UNFCCC, 2006) indicate considerable progress since the Third Assessment Report and the IPCC Good Practice Guidance for Land Use, Land-Use Change and Forestry (IPCC, 2003) in data acquisition and development of methods and tools for estimating and monitoring carbon emissions from deforestation and forest degradation in developing countries. Remote sensing approaches to monitoring changes in land cover/land use at multiple scales and coverage are now close to operational on a routine basis. Measuring forest degradation through remote sensing is technically more challenging, but methods are being developed (DeFries *et al.,* 2006).

Various methods can be applied, depending on national capabilities, deforestation patterns, and forest characteristics. Standard protocols need to be developed for using remote sensing data, tools and methods that suit both the variety of national circumstances and meet acceptable levels of accuracy. However, quantifying accuracy and ensuring consistent methods over time are more important than establishing consistent methods across countries.

Several developing countries, including India and Brazil, have systems in place for national-scale monitoring of deforestation (DeFries *et al.,* 2006). While well-established methods and tools are available for estimating forest carbon stocks, dedicated investment would be required to expand carbon stock inventories so that reliable carbon estimates can be applied to areas identified as deforested or degraded through remote sensing. With sound data on both change in forest cover and on change in carbon stocks resulting from deforestation and degradation, emissions can be estimated using methods described by the new IPCC Inventory Guidelines (IPCC, 2006).

government programmes promote the establishment, retention, and improved management of forest cover on private lands, often of marginal agricultural quality (Box 9.4; 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 9.5). Africa, for example, had about 649 million forested hectares as of 2000 (FAO, 2001). 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).

Policies aimed at liberalizing trade in forest products have mixed impacts on forest management practices. Trade liberalization in forest products can enhance competition and can make improved forest management practices more economically attractive in mature markets (Clarke, 2000). But, 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).

The recent FAO 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 forest protection against natural disturbance agents may reduce net emissions from forest lands (Richards *et al.*, 2006). 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 (Schelhaas *et al.,* 2003).

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 Western USA, 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).

Voluntary certification to sustainable forest management standards aims to improve forest management by providing incentives such as increased market access or price premiums to certified producers who meet these standards. 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 (Gullison, 2003). However, voluntary certification efforts to date continue to be challenged in improving the management of forest managers operating at low standards, where the potential for improvement and net emissions reductions are greatest. One possible approach to overcome current barriers in areas with weak forest management practices is to include stepwise or phased approaches to certification (Atyi and Simula, 2002).

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 bio-energy for many non-climate reasons, including increasing energy security and promoting rural development (Parris, 2004). 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). The Australian Government's Mandatory Renewable Energy Target, which seeks to create a market for renewable energy, provides incentives for the development of renewable energy from plantations and wood waste (Government of Australia, 2006).

Building codes and other government policies that, where appropriate, can promote substitution of use of sustainably harvested forest products wood for more energy-intensive construction materials may have substantial potential to reduce net emissions (Murphy, 2004). Private companies and individuals may also modify 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 they are consistent with underlying 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 policies to reduce net

Box 9.4: Non-climate forest policies as an element of carbon management in the United States

Many programmes in the United States support the establishment, retention, and improved management of forest cover on private lands. These entail contracts and subsidies to private landowners to improve or change land-use management practices. 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; Forestry Incentives Program, and Partners for Wildlife; (Richards et al., 2006). For example, in the 20-year period between 1974 and 1994, the Forestry Incentives Program spent 200 US$ million to fund 1.34 million hectares of tree planting; 0.58 million hectares of stand improvement; and 11 million hectares of site preparation for natural regeneration (Gaddis *et al.*, 1995).

Richards *et al.* (2006) suggest that substantial gains in carbon sequestration and storage could be achieved by increasing the resources and scope of these programmes and through new results-based programmes, which would reward landowners based on the actual carbon they sequester or store.

Box 9.5: Non-climate forest policies as an element of carbon management in Africa

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 local leaders. Most land and resources were under relatively sustainable management by nomadic or agro-pastoralist communities who developed systems to cope with vulnerable conditions. Agriculture was typically limited to shifting cultivation, with forest and range resources managed for multiple benefits.

Under *central government systems*, land-use policies are sectoral-focused, with 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 common. Negotiations demanding decentralization and equity in resource distribution may lead to changes in land tenure systems in which communities and official organizations will increasingly agree to collaboration and joint management in which civil societies participate. Parastatal institutions, established in some countries, formulate and implement policies and legislation 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 small percentage) and *state lands* (the majority of the land under government control). Each faces many problems generated by conflicting rights of use and legislation that gives 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 government owned land that farmers use on lease systems. Even large-scale farmers who are allocated large areas for cultivation, abandon the land and leave it as bare when it becomes non-productive. Forest lands reserved and registered under community ownership are communally managed on the basis of stakeholder system and shared benefits.

Evidence from many case studies in Sudan suggests that integrated forest management where communities have access rights to forest lands and are involved in management, is a key factor favouring the restoration of forest carbon stocks (IUCN, 2004). These projects provide examples of a collaborative system for the rehabilitation and use of the forest land property based on defined and acceptable criteria for land cultivation by the local people and for renewal of the forest crop.

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 "Payment for Environmental Services" (PES) systems 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 large on-site 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 bio-energy 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 change 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).

9.6.6 Lessons learned from project-based afforestation and reforestation since 2000

Experience is limited by the fact that Joint Implementation is not operational yet, and the first call for afforestation and reforestation (A/R) methodologies under CDM was only issued in September 2004. In addition, the modalities and procedures for CDM A/R as decided in December 2003 are complex. Nevertheless, the capacities built up through the development of projects and related methodologies should not be underestimated. As of November 2006, 27 methodologies were submitted, 17 from Latin America, four from Asia and Africa respectively, and two from Eastern Europe. The four which were approved by the CDM Executive Board relate to projects located in China, Moldova, Albania and Honduras and all consist of planting forests on degraded agricultural land. In anticipation of Joint Implementation, several projects are under development in several Annex I countries in Eastern Europe, notably in Romania, Ukraine and the Czech Republic.

There are voluntary project-based activities in the USA, with a programme for trading certificates established by the Chicago Climate Exchange (Robins, 2005). The Voluntary Reporting (1605 (b)) Program of the US Department of Energy (USDOE, 2005) provides reporting guidelines for forestry activities. Since the Special Report on LULUCF (IPCC, 2000a), there has been methodological progress in several areas discussed below.

9.6.6.1 Leakage

There is no indication that leakage effects are necessarily higher in forestry than in project activities in other sectors but they can be significant (Chomitz, 2002). Some studies 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. In land protection projects, logging companies may shift operations or buy timber from outside the project area to compensate for reduced supply of the commodity (activity outsourcing). Secondary leakage is not linked to project participants or previous actors on the area. It is often a market effect, where a project increases (by forest plantation) or decreases (deforestation avoidance) wood supply. Quantitative estimates of leakage (Table 9.9) suggest that leakage varies by mitigation activity and region.

The order of magnitude and even the direction of leakage (negative versus positive), however, depend on the project design (Schwarze *et al.*, 2003). Leakage risk is likely to be low if a whole country or sector is involved in the mitigation activity, or if project activities are for subsistence and do not affect timber or other product markets. There are also well-documented methods to minimize leakage of project-based activities. For example, afforestation projects can be combined with biomass energy plants, or they may promote the use of timber as construction material. Fostering agricultural intensification in parallel can minimize negative leakage from increased local land demand. Where a project reduces deforestation, it can also reduce pressure on forest lands, for example, by intensifying the availability of fuel wood from other sources for local communities. Projects can be designed to engage local people formerly responsible for deforestation in alternative income-generating activities (Sohngen and Brown, 2004).

Leakage appears to have a time dimension as well, due to the dynamics of the forest carbon cycle and management (for example, timing of harvest, planting and regrowth, or protection). Analysis in the USA indicates that national afforestation in response to a carbon price of 15 US$/t$CO_2$ would have 39% leakage in the first two decades, but decline to 24% leakage over five to ten decades, due to forest management dynamics (US EPA, 2005).

9.6.6.2 Potential non-permanence of carbon storage

The reversibility of carbon removal from the atmosphere creates liability issues whenever integrating land use in any kind of accounting system. There needs to be a liability for the case that carbon is released back into the atmosphere because Parties to the UNFCCC agreed, "…that reversal of any removal due to land use, land-use change and forestry activities be accounted for at the appropriate point in time" (UNFCCC, 2001). In 2000, the Colombian delegation first presented a proposal to create expiring Certified Emission Reductions under CDM (UNFCCC, 2001). Its basic idea is that the validity of Certified Emission Reductions (CERs) from afforestation and reforestation project activities under CDM is linked to the time of existence of the relating stocks. The principle of temporary crediting gained support over the subsequent years.

Table 9.9: *Forestry mitigation activity leakage estimates by activity, estimation method and region from the literature*

Activity	Region	Leakage estimation method	Estimated leakage rate (% of carbon mitigation)	Source
		Afforestation: tropical region estimates		
Afforestation of degraded lands	Kolar district, Karnataka, India hypothetical project	Household wood demand survey	0.02	Ravindranath, et al., 2007
Plantations, forest conservation, agro-forestry of degraded lands	Magat watershed, Philippines hypothetical project	Historical rates of technology adoption	19 – 41	Authors estimates based on Lasco *et al*., 2007
Afforestation on small landowner parcels	Scolel Té project, Chiapas, Mexico	Household wood demand survey	0 (some positive leakage)	De Jong *et al*., 2007
Afforestation degraded uplands	Betalghat hypothetical project, Uttaranchal, India	Household wood demand survey	10 from fuelwood, fodder	Hooda *et al*., 2007
Afforestation, farm forestry	Bazpur hypothetical project, Uttaranchal, India	Household wood demand survey	20 from fuelwood, poles	Hooda *et al*., 2007
		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 forest management jointly	USA-wide	PEM	-2.8 [a)]	US EPA, 2005
		Avoided deforestation: tropical region estimates		
Avoided deforestation	Bolivia, Noel Kempff project and national	PEM	2-38 discounted 5-42 undiscounted	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 Northwest USA	PEM	8-16	US EPA, 2005
Avoided deforestation (reduced timber sales)	Pacific Northwest USA	Econometric model	43 West region 58 Continental US 84 US and Canada	Wear and Murray, 2004
Biofuel production (short rotation woody crops)	USA	PEM	0.2	US EPA, 2005

a) Negative leakage rate means positive leakage; PEM means partial equilibrium model of forest and/or agriculture sector(s).

Source: Sathaye and Andrasko, 2007

Consequently, the Milan Decision 19/CP.9 (UNFCCC, 2003) created two types of expiring CERs: temporary CERs - tCERs and long-term CERs - lCERs. The validity of both credit types is limited and reflected on the actual certificate. The credit owner is liable to replace them when they expire or when the relating stocks are found to be lost at the end of the commitment period. Afforestation and reforestation projects need to be verified first at a time at the discretion of the project participants, and in intervals of exactly five years thereafter. The value of temporary CERs critically depends on the market participants' mitigation cost expectations for future commitment periods. Assuming constant carbon prices, the price for a temporary CER during the first commitment period is estimated to range between 14 and 35 % of that of a permanent CER from any other mitigation activity (Dutschke, *et al.*, 2005). This solution is safe from the environmental integrity point of view, yet it has created much uncertainty among project developers (Pedroni, 2005).

9.6.6.3 Additionality and baselines

A project that claims carbon credits for mitigation needs to demonstrate its additionality by proving that the same mitigation effect would not have taken place without the project. For CDM, the Executive Board's Consolidated Additionality Tool offers a standardized procedure to project developers. Specific for CDM afforestation and reforestation (A/R), there is an area eligibility test along the forest definitions provided under the relevant Decision 11/CP.7 in order to avoid implementation on areas that prior to the project start were forests in 1990 or after. In the modalities and procedures for CDM, there are three different baseline approaches available for A/R. So far, only one has been successfully applied in the four approved methodologies.

9.6.6.4 Monitoring

For project monitoring, there is now an extended guidance available (IPCC, 2006; USDOE, 2005). Monitoring costs depend on many variables, including the project complexity (including the number of stakeholders involved), heterogeneity of the forest type, the number and type of carbon pools, and GHG to be monitored and the appropriate measurement frequencies. There is a trade-off between the completeness of monitoring data and the carbon price that can be achieved: monitoring costs can sum up an important share of a project's transaction costs. Proper design of the monitoring plan is, therefore, essential for the economic viability of forestry projects. If project developers can demonstrate that omitting particular carbon pools from the project's quantification exercise does not constitute an overestimate of the project's GHG benefits, such pools may be left outside the monitoring plan.

9.6.6.5 Options for scaling up

Despite relative low costs and many possible positive side-effects, the pace with which forest carbon projects are being implemented is slow. This is due to a variety of barriers. Barriers can be categorized as economic, risk-related, political/bureaucratic, logistic, and capacity or political will (the latter barrier also occurring in industrialized countries; Trines *et al.,* 2006). One of the most important climate-related barriers is the complexity of the rules for afforestation and reforestation project activities. This leads to uncertainty among project developers and investors. Temporary accounting of credits is a major obstacle for two reasons: (1) The future value of temporary CERs depends on the buyer's confidence in the underlying project. This may limit investor interest in getting involved in project development. (2) The value of temporary CERs hinges on future allowance price expectations because they will have to be replaced in future commitment periods. Furthermore, EU has deferred its decision to accept forestry credits under its emissions trading scheme. Even if EU decided to integrate these credits, this would come too late to take effect in the first commitment period because trees need time to grow. Given the low value of temporary CERs, transaction costs have a higher share in afforestation and reforestation than in energy mitigation projects. Simplified small-scale rules were introduced in order to reduce transaction costs, but the maximum size of 8 kilotonnes of average annual CO_2 net removal limits their viability.

For forestry mitigation projects to become viable on a larger scale, certainty over future commitments is needed because forestry needs a long planning horizon. Rules need to be streamlined, based on the experience gathered so far. Standardization of project assessment can play important roles to overcome uncertainty among potential buyers and investors, and to prevent negative social and environmental impacts.

9.7 Forests and Sustainable Development

Sustainable forest management of both natural and planted forests is essential to achieving sustainable development. It is a means to reduce poverty, reduce deforestation, halt the loss of forest biodiversity, and reduce land and resource degradation, and contribute to climate change mitigation. Forests play an important role in stabilization of greenhouse gas concentrations in the atmosphere while promoting sustainable development (Article 2; Kyoto Protocol). Thus, forests have to be seen in the framework of the multiple dimensions of sustainable development, if the positive co-benefits from forestry mitigation activities have to be maximized. Important environmental, social, and economic ancillary benefits can be gained by considering forestry mitigation options as an element of the broader land management plans.

9.7.1 Conceptual aspects

Forestry 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. In Article 2.1(a, b), Kyoto Protocol, Parties agreed various ways to consider potential impacts of mitigation options and whether and how to establish some common approaches to promoting the sustainable development contributions of forestry measures. In addition, a broad range of issues relating to forest conservation and sustainable forest management have been the focus of recent dialogues under the Intergovernmental Forum on Forests.

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

To manage forest ecosystems in a sustainable way implies knowledge of their main functions, and the effects of human practices. In recent years, scientific literature has shown an increasing attempt to understand integrated and long-term effects of current practices of forest management on sustainable development. But often, environmental or socio-economic effects are considered in isolation, or there is no sufficient understanding of the potential long-term impacts of current practices on sustainable development. Payment for Environmental Services (PES) schemes for forest services (recognizing carbon value) may be foreseen as part of forest management implementation, providing new incentives to change to more sustainable decision patterns. Experience, however, is still fairly limited and is concentrated in a few countries, notably in Latin America, and has had mixed results to date (Wunder, 2004).

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 sustainable development paths, involving local people and 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, identifying and accounting for them can reduce or partially compensate the costs of the mitigation measures. However, forests fulfil many important environmental functions and services that can be enhanced or negatively disturbed by human activities and management decisions. Negative effects can be triggered by some mitigation options under certain circumstances. Positive and negative impacts of mitigation options on sustainable development are presented in Table 9.10.

Stopping or slowing deforestation and forest degradation (loss of carbon density) and sustainable forest management may significantly contribute to avoided emissions, conserve water resources and prevent flooding, reduce run-off, control erosion, reduce river siltation, and protect fisheries and investments in hydroelectric power facilities; and at the same time, preserve biodiversity (Parrotta, 2002). Thus, avoided deforestation has large positive implications for sustainable development. Further, natural forests are a significant source of livelihoods to hundreds and millions of forest-dependent communities.

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

Large investments have been made in commercial plantations on degraded lands in Asia. However, lack of consultation with stakeholders (state of land tenure and use rights) may result in failure to achieve the pursued results. Better integration between social goals and afforestation is necessary (Farley *et al.*, 2004). As demand increases for lands to afforest, more comprehensive, multidimensional environmental assessment and planning will be required to manage land sustainably.

Agro-forestry can produce a wide range of economic, social and environmental benefits, and probably wider than in case of large-scale afforestation. Agro-forestry systems could be an interesting opportunity for conventional livestock production with low financial returns and negative environmental effects (overgrazing and soil degradation). For many livestock farmers, who may face financial barriers to develop this type of combined systems (e.g., silvo-pastoral systems), payment for environmental services could contribute to the feasibility of these initiatives (Gobbi, 2003). Shadow 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 practising agro-forestry (Clavijo *et al.*, 2005).

9.7.3 Implications of mitigation options on water, biodiversity and soil

The Millennium Development Goals (MDGs) aim at poverty reduction, and to improve health, education, gender equality, sanitation and environmental sustainability to promote Sustainable Development. Forest sector can significantly contribute to reducing poverty and improving livelihoods (providing access to forest products such as fuelwood, timber, and non timber products). 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). A focus on five key thematic areas was proposed (Water, Energy, Health, Agriculture, and Biodiversity -WEHAB), driving attention to the fact that managing the natural resources like forest in a sustainable and integrated manner is essential for sustainable development. In this regard, to reverse the current trend in forest degradation as soon as possible, strategies need to be implemented that include targets adopted at 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.

Literature describing in detail the environmental impacts of different forest activities is still scarce and focuses mostly on planted forests. For these reasons, the discussion focuses more on plantations. It is important to underline that while benefits of climate change mitigation are global, co-benefits and costs tend to be local (OECD, 2002) and, in accordance, trade-offs have to be considered at local level.

Table 9.10: *Sustainable development implications of forestry mitigation*

<table>
<tr><th rowspan="2">Activity category</th><th colspan="3">Sustainable development implications</th></tr>
<tr><th>Social</th><th>Economic</th><th>Environmental</th></tr>
<tr><td colspan="4">A. Increasing or maintaining the forest area</td></tr>
<tr><td>Reducing deforestation and forest degradation</td><td>Positive
Promotes livelihood.</td><td>Positive or negative
Provides sustained income for poor communities.
Forest protection may reduce local incomes.</td><td>Positive
Biodiversity conservation. Watershed protection.
Soil protection. Amenity values (Nature reserves, etc.)</td></tr>
<tr><td>Afforestation/ reforestation</td><td>Positive or negative
Promotes livelihood.
Slows population migration to other areas (when a less intense land use is replaced).
Displacement of people may occur if the former activity is stopped, and alternate activities are not provided.
Influx of outside population has impacts on local population.</td><td>Positive or negative
Creation of employment (when less intense land use is replaced).
Increase/decrease of the income of local communities.
Provision of forest products (fuelwood, fibre, food construction materials) and other services.</td><td>Positive or negative
Impacts on biodiversity at the tree, stand, or landscape level depend on the ecological context in which they are found.
Potential negative impacts in case on biodiversity conservation (mono-specific plantations replacing biodiverse grasslands or shrub lands).
Watershed protection (except if water-hungry species are used) .
Losses in stream flow.
Soil protection.
Soil properties might be negatively affected.</td></tr>
<tr><td colspan="4">B. Changing to sustainable forest management</td></tr>
<tr><td>Forest management in plantations</td><td>Positive
Promotes livelihood.</td><td>Positive
Creation of employment
Increase of the income of local communities.
Provision of forest products (fuelwood, fibre, food, construction materials) and other services.</td><td>Positive
Enhance positive impacts and minimize negative implications on biodiversity, water and soils.</td></tr>
<tr><td>Sustainable forest management in native forest</td><td>Positive
Promotes livelihood.</td><td>Positive
Creation of employment.
Increase of the income of local communities.
Provision of forest products (fuelwood, fibre, food, construction materials) and other services.</td><td>Positive
Sustainable management prevents forest degradation, conserves biodiversity and protects watersheds and soils.</td></tr>
<tr><td colspan="4">C. Substitution of energy intensive materials</td></tr>
<tr><td>Substitution of fossil intensive products by wood products</td><td>Positive or negative
Forest owners may benefit.
Potential for competition with the agricultural sector (food production, etc.).</td><td>Positive
Increased local income and employment in rural and urban areas.
Potential diversification of local economies.
Reduced imports.</td><td>Negative
Non-sustainable harvest may lead to loss of forests, biodiversity and soil.</td></tr>
<tr><td colspan="4">D. Bio-energy</td></tr>
<tr><td>Bio-energy production from forestry</td><td>Positive or negative
Forest owners may benefit.
Potential for competition with the agricultural sector (food production, etc.)</td><td>Positive or negative
Increased local income and employment.
Potential diversification of local economies.
Provision of renewable and independent energy source.
Potential competition with the agricultural sector (food production, etc.)</td><td>Positive or negative
Benefits if production of fuelwood is done in a sustainable way.
Mono specific short rotation plantations for energy may negatively affect biodiversity, water and soils, depending on site conditions.</td></tr>
</table>

Water cycle: Afforestation may result in better balance in the regional water cycle balance by reducing run-off, flooding, and control of groundwater recharge and watersheds protection. However, massive afforestation grasslands may reduce water flow into other ecosystems and rivers, and affect aquifers layer and recharge, 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: Intensively managed plantations have nutrient demands that may affect soil fertility and soil properties, for example leading to higher erosion of the uncovered mineral soil surface (Perez-Bidegain *et al.*, 2001; Carrasco-Letellier *et al.*, 2004); and biological properties changes (Sicardi *et al.,* 2004) if the choice of species is not properly matched with site conditions. Regarding chemical properties, increased Na concentrations, exchangeable sodium percentage and soil acidity, and decreased base saturation have been detected in many situations. (Jackson, *et al.*, 2005).In general, afforestation of low soil carbon croplands may present considerable opportunities for carbon sequestration in soil, while afforestation of grazing land can result in relatively smaller increases or decreases in soil carbon (Section 9.4.2.2). Most mitigation options other than monoculture plantations conserve and protect soils and watersheds.

Biodiversity: Plantations can negatively affect biodiversity if they replace biologically rich native grassland or wetland habitats (Wagner, et al., 2006). Also, plantations can have either positive or negative impacts on biodiversity depending on management practices (Quine and Humphrey, 2005). Plantations may act as corridors, source, or barriers for different species, and a tool for landscape restoration (Parrota, 2002). Other forestry mitigation options such as reducing deforestation, agro-forestry, multi-species plantations, and sustainable native forest management lead to biodiversity conservation.

Managing plantations to produce goods (such as timber) while also enhancing ecological services (such as biodiversity) involves several trade-offs. Overcoming them involves a clear understanding of the broader ecological context in which plantations are established as well as participation of the different stakeholders. The primary management objective of most industrial plantations traditionally has been to optimize timber production. This is not usually the case in small-scale plantations owned by farmers, where more weight is given to non-timber products and ecological services. A shift from a stand level to a broader forest and non-forest landscape level approach will be required to achieve a balance between biodiversity and productivity/profitability.

The literature seems to suggest that plantations, mainly industrial plantations, require careful assessment of the potential impacts on soils, hydrological cycle and biodiversity, and that negative impacts could be controlled or minimized if adequate landscape planning and basin management and good practices are introduced. Carbon sequestration strategies with afforestation of non-forest lands should consider their full environmental consequences. The ultimate balance of co-benefits and impacts depends on the specific site conditions and previous and future land and forest management.

9.8 Technology, R&D, deployment, diffusion and transfer

R&D and technology transfer have a potential to promote forest sector mitigation options by increasing sustainable productivity, conserving biodiversity and enhancing profitability. Technologies are available for promoting mitigation options from national level to forest stand level, and from single forest practices to broader socio-economic approaches (IPCC, 2000b).

Traditional and/or existing techniques in forestry including planting, regeneration, thinning and harvesting are fundamental for implementation of mitigation options such as afforestation, reforestation, and forest management. Further, improvement of such sustainable techniques is required and transfer could build capacity in developing countries. Biotechnology may have an important role especially for afforestation and reforestation. As the area of planted forests including plantations of fast-growing species for carbon sequestration increases, sustainable forestry practices will become more important for both productivity and environment conservation.

The development of suitable low-cost technologies will be necessary for promoting thinning and mitigation options. 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, suppression of forest fires and prevention of insect and pest disease are important for mitigation.

Regarding technology for harvesting and procurement, mechanized forest machines such as harvesters, processors and forwarders developed in Northern Europe and North America have been used around the world for the past few decades. Mechanization under sustainable forest management seems to be effective for promoting mitigation options including product and energy substitution (Karjalainen and Asikainen, 1996). However, harvesting and procurement systems vary due to terrain, type of forest, infrastructure and transport regulations, and appropriate systems also vary by regions and countries. Reduced impact logging is considered in some cases such as in tropical forests (Enters *et al.,* 2002).

There is a wide array of technologies for using biomass from plantations for direct combustion, gasification, pyrolysis, and fermentation (see Section 4.3.3.3). To conserve forest resources, recycling of wood waste material needs to be expanded. 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 (Masera *et al.,* 2005) have proved effective in developing countries. They are effective as a means to reduce the use of wood fuels derived from forests, at the same time providing tangible sustainable development benefits for local people, such as reduction in indoor air pollution levels.

Technological R&D for estimation of carbon stocks and fluxes is fundamental not only for monitoring but also for evaluating policies. 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, 2003). Over the last three decades, earth observation satellites have increased in number and sophistication (DeFries *et al.,* 2006). 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 (Hirata *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 carbon sources and sinks remains a challenge and will continue to depend on in-situ measurements and modelling.

Large-scale estimations of the forest sector and its carbon balance have been carried out with models such as the CBM-CFS2 (Kurz and Apps, 2006), CO2FIX V.2 model (Masera *et al.,* 2003), EFISCEN (Nabuurs *et al.*, 2005, 2006), Full CAM (Richards and Evans, 2004), and GORCAM (Schlamadinger and Marland, 1996).

Micrometeorological observation of carbon dioxide exchange between the terrestrial ecosystem and the atmosphere has been carried out in various countries (Ohtani, 2005). Based on the observation, a global network FLUXNET (Baldocchi *et al.*, 2001) and regional networks including AmeriFlux, EUROFLUX, AsiaFlux and OzNet are being enlarged for stronger relationships.

New technologies for monitoring and verification including remote sensing, carbon flux modelling, micrometeorological observation and socio-economic approaches 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.

Few forest-based mitigation analyses have been conducted using primary data. There is still limited insight regarding impacts on soils, lack of integrated views on the many site-specific studies, hardly any 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 balance, against which mitigation options could be examined. There is limited quantitative information on the cost-benefit ratios of mitigation interventions.

Technology deployment, diffusion and transfer in the forestry sector provide a significant opportunity to help mitigate climate change and adapt to potential changes in the climate. Apart from reducing GHG emissions or enhancing the carbon sinks, technology transfer strategies in the forest sector have the potential to provide tangible socio-economic and local and global environmental benefits, contributing to sustainable development (IPCC, 2000b). Especially, technologies for improving productivity, sustainable forest management, monitoring, and verification are required in developing countries. However, existing financial and institutional mechanism, information and technical capacity are inadequate. Thus, new policies, measures and institutions are required to promote technology transfer in the forest sector.

For technology deployment, diffusion and transfer, governments could play a critical role in: a) providing targeted financial and technical support through multilateral agencies (World Bank, FAO, UNDP, UNEP), 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. 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. The Global Environmental Facility (GEF) could fund projects that actively promote technology transfer and capacity building in addition to the mitigation aspects (IPCC, 2000b).

9.9 Long-term outlook

Mitigation measures up to 2030 can prevent the biosphere going into a net source globally. The longer-term mitigation prospects (beyond 2030) 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 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.

Several studies have shown that uncertainties in the contemporary carbon cycle, the uncertain future impacts of climatic change and its many dynamic feedbacks can cause large variation in future carbon balance projections (Lewis *et al.*, 2005). Other scenarios suggest that net deforestation pressure will slow over time as population growth slows and crop and livestock productivity increase. Despite continued projected loss of forest area, carbon uptake from afforestation and reforestation could result in net sequestration (Section 3.2.2).

Also, the impacts of climate change on forests will be a major source of uncertainty regarding future projections (Viner *et al.,* 2006). 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 within industrialized and developing countries beyond the first half of the 21st century. The actual mitigation potential will depend ultimately on solving structural problems linked to the sustainable management of forests. Such structural problems include securing land tenure and land rights of indigenous people, reducing poverty levels in rural areas and the rural-urban divide, and providing disincentives to short-term behaviour of economic actors and others. Considering that forests store more carbon dioxide than the entire atmosphere (Stern, 2006), the role of forests is critical.

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 boreal primary forests will either be sources or sinks depending on the net effect of some enhancement of growth due to climate change versus a loss of soil organic matter and emissions from increased fires. The temperate forests in USA, Europe, China and Oceania, will probably continue to be net carbon sinks, favoured also by enhanced forest growth due to climate change. In the tropical regions, the human induced land-use changes are expected to 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 also increase the sink. Beyond 2040, depending on the extent and effectiveness of forest mitigation activities within tropical areas, and very particularly on the effectiveness of policies aimed at reducing forest degradation and deforestation, tropical forest may become net sinks. In the medium to long term as well, commercial bio-energy is expected to become increasingly important.

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 for carbon storage and other environmental services such as biodiversity and watershed conservation and sustainable forest harvesting to provide society with carbon-containing fibre, timber and bio-energy resources, and the trade-offs among utilization strategies of harvested wood products aimed at maximizing storage in long-lived products, recycling, and use for bio-energy.

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