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Chapter 9 Forestry

CONTENTS

CONTENTS

EXECUTIVE SUMMARY

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

We project a gradually increasing mitigation impact of forestry measures globally (Figure 9.26). By 2040 the <u>economic potential</u> of a combination of measures in afforestation, avoided deforestation, agroforestry, and bioenergy, could yield (at 20 \$/ton CO2) an additional sink of around -1.1 Gt C y^{-1} (medium confidence).[1] This sink enhancement/emission avoidance will be for 80% located in the tropics (high confidence), be found mainly in above ground biomass, and for almost half achieved through bio energy (medium confidence). In the short term, this potential is much smaller, with -0.2 Gt y^{-1} (high confidence) (Fig Exe Summ 1). The <u>market potential</u> is probably a small fraction of these numbers as is reflected by current slow processes of implementation of forestry measures under the Kyoto Protocol (medium confidence).

> Insert figure Exe Summ 1.

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[1] In this chapter, negative carbon figures refer to sinks and positive figures to sources of emissions.

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

There is a lack of integrated and global economic assessments of carbon mitigation potential in the literature. Many case studies, with different assumptions, methods and tools provide a preliminary assessment of options. Most modelling studies have shown that forest ecosystems and biodiversity are likely to be adversely impacted, constraining or threatening their mitigation potential. Mitigation and adaptation synergy exists in the forest sector. Wherever possible, adaptation strategies or practices should be incorporated in mitigation projects.

Policies have been generally most successful in making forestry activities more sustainable where they both align with and amplify underlying profitability objectives and there is sufficient political will and regulatory and institutional capacity for effective enforcement. Available evidence suggests that policies that seek to alter forestry activities where these conditions are not met have had limited effectiveness.

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

There is also a successful history of policies to create new forests, and these have lead to the creation of local carbon sinks in new forests. Care must be taken however to make sure that at plantation creation, there is no displacement of economic or subsistence activities that will lead to new forest clearing elsewhere. Policies to increase the substitution of fossil fuels with bioenergy have also had a large positive impact on net emissions.

Notably and despite considerable effort, integrated and non-climate policies have had minimal impact on slowing tropical deforestation, the single largest contribution of the land-use sector to global carbon emissions.

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

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

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

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

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

9.1 Introduction

In the broader context of global change and sustainable development, forestry stands at the centre of choices to be made when addressing the climate change problem. Forests are actively involved in the global carbon cycle and they can play an important role in mitigation. But forests are also affected by global change and their ability to contribute to mitigation strategies will be constrained by stresses resulting from global change. As a major form of land cover globally, many world citizens depend on the goods, services and financial values provided by forests, and land-use changes can negatively affect those that most closely depend on natural resources for their livelihoods.

The world's forests have a substantial impact on the Earth's climate, through their role in the global carbon cycle, surface hydrology and albedo, and other effects. The terrestrial biosphere as a whole is believed to sequester 0.51 Gt C y^{-1} out of the fossil fuel emissions (1993-2003) of which forests would cover the larger part (IPCC 2007, Brasseur *et al*. 2007). In addition, Brasseur et al's (2007) most likely estimate of the emissions from deforestation is 0.95 Gt C y^{-1}, which is (partly) being sequestered on the land as well.

The Third assessment report (TAR) (WG III, ch 4) concluded that an additional sequestration of 1.47 Gt C y^{-1} as a biological/technical potential would be possible on average until 2050. These figures were obtained from an analysis conducted for the Second Assessment Report, and for the Special Report on LULUCF (IPCC 2000). TAR mentioned the relation to other land-use issues and stated that carbon sequestration was often most successful when part of integrated land-use strategies. However, a thorough economic analysis did not take place. Neither did a thorough integration of forestry issues into other rural issues, other land uses, or the role of forestry in sustainable development. The TAR estimate of mitigation potential therefore needs to be reassessed as part of a more complex system.

Carbon mitigation in forests has been reported to be more cost-effective than mitigation options in other sectors. Conservation and enhancement of forest sinks and reservoirs implies not only sustainable management of forests, but also emission reductions or avoidance through appropriate use of land, materials and energy. The options include reducing emissions from deforestation and subsequent agricultural/urban land use, enhancing the sequestration rate in existing or new forests, and by providing products as a substitute for fossil fuels and for more energy-intensive materials. Properly designed and implemented, forestry mitigation options may have substantial co-benefits in terms of employment and income generation opportunities, biodiversity and watershed conservation, provision of timber and fibre, as well as aesthetic and recreational services.

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

Developments since TAR

Since TAR, the science on forest-based mitigation has advanced in specific areas. New estimates have become available, especially concerning the effect and costs of mitigation measures. Major economic reviews have become available (Richards and Stokes 2004, Van Kooten *et al*. 2004). There is a beginning of research into the integration of mitigation and adaptation options and the linkages to sustainable development (Millennium Ecosystem Assessment). There is now more evidence that climate change impacts can also constrain the forest potential, as shown, for example in the 2003 drought in Europe (Ciais *et al*. 2005). Furthermore, attention is paid to substitution and bio energy (Lindner et al. 2005) . However, fully integrated multiple land-use studies that assess larger scale economic potentials in the forestry sector are very rare in the literature. Furthermore, the literature still displays an enormous variety in outcomes, partly due to the natural variability in the system, but partly also due to differences in (baseline) assumptions, type of potential studied, methods and data quality.

On the other hand, Parties to the Convention are improving their forest carbon balance estimates through the design and implementation of a National System for forest inventories and forest carbon accounting. The latter has, amongst others, been facilitated by the release of the Good Practice Guidance for Land Use, Land-use Change and Forestry (IPCC 2003).

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

Goals of the Chapter

The primary aims of this chapter are a) to provide an updated estimate of the economic potential (Figure 9.1) to reduce emissions of carbon and increase carbon sequestration from forests through human activity. This will be done in the frame of the stabilisation scenarios as given in chapter 3.2 (Figure 9.2), b) to examine the causes of the apparent contradiction between a large theoretical potential versus an incipient use of it, and c) to integrate the estimates of the economic potential with considerations of both adaptation and mitigation in the context of sustainable development

Insert Fig 9.1

Insert fig 9.2

Boundaries

Forestry in itself is a multi-faceted form of land use, to which many of the other chapters in WGIII are related (Figure 9.3). These relations have to be kept in mind when drawing boundaries around this chapter and when taking into account all the effects of the often sector-specific decisions being made. (For further discussion see Section 9.4.1).

Insert fig 9.3.

This chapter's technical boundaries are delineated (where literature allows) by inclusion of:

- Pools of carbon in forest ecosystems and their change from land use and land-use changes: included are live forest biomass, dead wood, litter, and soil organic carbon (as defined in the IPCC GPG (IPCC 2003);
- Harvested Wood Products: wood products in use are included, but only their carbon stock and flux; disposal of materials is discussed in the waste chapter (WG III, Chapter 10);
- The measures (vegetation types) included are forests, and open forests to dry woodlands, agroforestry systems, afforestation, reforestation, forest management changes, and avoided deforestation.
- Bio-energy/substitution: substitution effect of commercial and non-commercial bio-energy is taken into account as far as it concerns commercial residue removal and fellings for bio energy. The agriculture chapter deals with short rotation forestry geared towards bioenergy;
- Gases: we include mainly CO_2; where literature allows, we take into account CH_4 and N_2O as well;
- Time scale of analysis: focus of analysis period is from 2000 to 2030 – 2040. The long-term aspects of activities are addressed in Section 9.9;
- Baseline: focus is on economic potential against a baseline as determined by simulations with the IMAGE model (IMAGE team 2001, Brinkman *et al*. 2005) for the A1f and the B2 scenario (see Chapters 2.4 and 3.2);
- Interface with agriculture and land-use changes: competition for land is taken into account through joint development of baseline conditions. Carbon implications of the land-use change are accounted by the land use to which the change occurs, as per the IPCC GPG (IPCC 2003). Only immediate effects of deforestation are dealt with in the current chapter.
- Spatial scale: technical options at the stand or parcel scale are addressed briefly, our main focus is on large-scale aspects;

The results are assessed against:

- consistent baselines and initial conditions (e.g. age-class structure) by having an impact on response direction, magnitude and duration;
- the variety of assumptions in the baselines as well as in the assessments in literature;
- the uncertainties and limitations of comparisons;
- ancillary benefits and synergy in the frame of adaptation, mitigation and sustainable development.
- recent experience and effectiveness with climate and non-climate policies in the forestry sector
- feedbacks with climate change: climate induced risks (see also chapter 'ecosystems' and chapter 'food, fibre, products' in WG II) and direct feedbacks on climate (through albedo changes) are discussed but not quantified.

This chapter first identifies the current trends in the forest sector worldwide (9.2), then summarises the current role of forests in the global carbon cycle (9.3). In subsequent sections an assessment of mitigation options is conducted (9.4), together with their relation to adaptation (9.5). Follow-up sections deal with policies, opportunities and challenges (9.6), ancillary effects (9.7), technology (9.8), and the long-term outlook of the sector (9.9).

9.2 Status of the Sector and trends

9.2.1 Forest area changes

The global forest cover amounts to about 3,869 Mha, which is about 30 percent of the world's land area. Globally the forest area decreased by 9.4 Mha y^{-1} the 1990s (Table 9.1, Figure 9.2), which was slightly lower than in the 1980s (FAO, 2001). Loss of natural forests was 16.1 Mha y^{-1}, resulting from deforestation to other land uses (14.6 Mha y^{-1}) and conversion to forest plantations (1.5 Mha y^{-1}). Natural expansion was 3.6 Mha y^{-1}, and therefore a net loss of natural forest of 12.5 Mha y^{-1} remains. Over 97% of the deforestation took place in the tropics (Figure 9.4). Recent estimates from Brazilian Amazon indicate, however, a renewed increase by about 30% since 1990s in the annual average deforestated area (INPA 2005).

The area of forest plantations increased by 3.1 Mha y^{-1} in the 1990s, and they covered about 187 Mha in 2000 (FAO 2001). Over 60% of the plantations are in Asia. According to the Millenium Ecosystem Assessment (2005) scenarios, forest area in the industrialised regions will increase between 2000 and 2050 by about 60 to 230 Mha, while in the developing regions forest area will decrease by about 200 to 490 Mha.

Insert Table 9.1

Insert Fig 9.4.

In addition to the decreasing forest area globally, the condition of forests has been worsening due to degradation (defined as decrease of density or increase of disturbance in forest classes) which affected in the tropics 23.8 Mha in the 1990s or 2.4 Mha y^{-1}. It appears that forest degradation was reduced: the estimate for 1980s was 35 Mha or 3.5 Mha y^{-1} (FAO, 2001).

According to the recent UN report (UN Millenium Project 2005), five primary direct drivers for environmental change in forests are land-cover changes resulting from land clearing for agricultural uses (including crop plantation, commercial forestry, and ranching), inappropriate exploitation of natural resources, invasive alien species, pollution and climate change. Indirect drivers of forest degradation are demographic change, economic factors and institutional gaps.

9.2.2 Wood volume and biomass

FAO (2001) has estimated the global volume of forests to be 386 billion m^3 and the estimate for worldwide above-ground woody biomass to be 422 billion tonnes in 2000 (Table 9.2, Figure 9.5.). Wood volume increased by 9 billion m^3 or 2% during the 1990s, largely because of increment in temperate and boreal forests. This is confirmed by results from forest inventories from several European countries indicating increasing wood volumes and ageing of forests due to fact that fellings have been and are below the annual increment (e.g. Finnish Forest Research Institute 2004, Official Statistics of Norway 2003, www.bundeswaldinventur.de). At the same time the above-ground woody biomass decreased globally by about 7 billion tonnes or 1.5%. A simultaneous increase of volume and decrease of woody biomass can be explained by the fact that volume loss of tropical forests affected considerably more biomass compared to volume gains in the boreal forests. In other words, tropical forests on average have larger biomass expansion factors (BEF, IPCC 2003) than boreal forests.

Insert Table 9.2.

Insert Fig 9.5.

9.2.3 Biological diversity

Conversion of forests to other land uses is the greatest threat to forests and their diversity (FAO 2001b). The Millenium Ecosystem Assessment (2005) provides other direct drivers which have had high, moderate or low impact on biodiversity over the last century as well as the drivers' current trend for different forest zones (Figure 9.6). Many of the drivers show increases or very rapid increases of the impact. Roughly 10-20% of current forestland is projected to be converted to other uses by 2050 primarily because of expanding agriculture, and secondarily due to expansion of cities and infrastructure (Millenium Ecosystem Assessment 2005). Warm mixed forests, tropical forests and tropical woodlands are among those biomes that a projected to lose habitat and local species at the fastest rate. These trends do not mean that protection of biodiversity has not been of concern. There are several national and international initiatives trying to improve the situation (e.g. Convention on Biological Diversity, Convention on International Trade in Endangered Species of Wild Fauna and Flora, Ministerial Conference on the Protection of Forests in Europe, UNEP World Conservation Monitoring Centre).

Insert Fig 9.6.

9.2.4 Forest management

Nearly 90% of forests in industrialized countries are being managed "according to a formal or informal management plan" (FAO 2001). National statistics on forest management plans are not available for many developing countries, but preliminary estimates show that at least 123 Mha, or about 6 percent of the total forest area, are covered by a "formal, nationally approved forest management plan covering a period of at least five years" (FAO 2001). This does not necessarily mean that the plan is appropriate, being implemented as planned or having the intended effects. In addition, many countries are members of initiatives for sustainable forest management, although implementation of criteria and indicators at the national level varies considerably. Forest certification was initiated as a market-driven instrument to confirm that certain predefined minimum standards of forest management in a given forest area at a given point in time have been achieved. The area of certified forests worldwide is increasing. Under the Programme for the Endorsement of Forest Certification (PEFC) and Forest Stewardship Council (FSC) schemes approximately 190 Mha have been certified in 2005 (http://www.pefc.org/internet/html/index.htm, http://www.fsc.org/en/whats_new/fsc_certificates), while at the end of 2000 about 80 Mha was certified. Most certified forests are located in boreal and temperate, industrialized countries. In recent years, discussion has also focused on illegal logging and trade. Countries have been urged to improve law enforcement in the forest sector and to control illegal trade in forest products. Forest Law Enforcement and Governance (FLEG) at the East Asia Ministerial Conference and the EU Action Plan for Forest Law Enforcement, Governance and Trade (FLEGT) are the most comprehensive plans to fight illegal logging and associated trade. World Bank estimates that illegal logging is generating between US$10 billion and $15 billion every year.

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

Information on harvested area, harvesting intensity and volume harvested is imperfect for the tropical countries as a whole, but FAO (2001) suggests that in 2000 in Africa the area under timber harvesting schemes was 5.9 Mha, of which 3.3 Mha were harvested annually, in Asia and Oceania 27.3

and 6.2 Mha, and in tropical America 16.7 and 1.9 Mha, respectively. Annual fellings in the temperate and boreal regions on forests available for wood supply were 1,341 million m3 over bark in the mid-1990s (UN-ECE/FAO 2000), which was 53% of the net annual increment. There are rather wide differences between regions. In general, a larger portion of the increment is harvested in those regions with well-established forest industries. Thus, the proportion is 79% in North America, 72% in the Nordic countries and 63% in central-western and northwestern Europe. In the CIS it is only 17%, while in other countries of the temperate and boreal region it is 52% (UN-ECE/FAO 2000).

About half the world forest plantation estate is for industrial end-use, one-quarter for non-industrial end-use (e.g. for wood energy, carbon sequestration) and one-quarter is not specified (FAO 2001). Although accounting for only 5% of global forest cover, forest plantations were estimated in 2000 to supply already about 35% of global roundwood.

There are only very few developing countries among the major producers and consumers of forest products (Table 9.3.), except in case of wood fuel production (FAO 2005). Worldwide wood energy accounts for 7 to 9% of energy consumed, and up to 80-95% in some developing countries (http://www.fao.org/forestry/index.jsp). Wood fuels account for nearly 55% of global roundwood production. More than 2 billion people are dependent on wood fuel for cooking, heating and food preservation, and several million people are involved in the production, distribution and sale of fuelwood and charcoal.
Insert Table 9.3

The increase in the global production of forest products has resulted in an increase in the value of international trade of forest products by 50% from 100 to 150 billion USD between 1993 and 2003 (Unasylva 2004). The growth in forest products trade has been, however, less than the growth of trade in other merchandise goods. Therefore, the share of forest products in total merchandise exports declined from 2.9% in 1990 to 2.2% in 2000 (Lebedys 2004.). It should be noted that most of the roundwood and non-wood forest products are traded domestically (Mersmann 2004). Total employment in the (formal) forestry sector increased by about 4% over the last decade, from 12.4 million in 1990 to 12.9 million in 2000 (Lebedys 2004). In 2000, total gross value-added in the forestry sector amounted to 354 billion USD, the pulp and paper industry accounted for about half of the total gross value-added in the forestry sector (Lebedys 2004). During the last decade, the contribution of the forestry sector to GDP has declined from 1.6% in 1990 to 1.2% in 2000 because the global economy has expanded while value-added in the forestry sector has not increased at all. At the global level, employment is divided roughly equally between forestry activities, the wood industry and the pulp and paper industry.

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

9.3 Regional and global trends in greenhouse gas emissions and removals and other effects of forest cover on climate.

The contribution of the forest sector to greenhouse gas emissions and removals from the atmosphere remained the subject of active research, which produced a very extensive body of literature. The major scientific advances are related to (1) evolving consensus on broad global patterns of C sources and sinks on land, (2) technological advances that improved observational data, (3) consideration and in some cases quantification of previously overlooked fluxes and effects on climate, and (4) improved understanding of limitations and uncertainties of current estimates and needs for an integrated approach to evaluating the impact of terrestrial ecosystems on climate (Marland *et al*. 2003, Canadell *et al*. 2004).

At the global scale, during the last decade of the 20th century, deforestation in the tropics and forest regrowth in temperate and parts of the boreal zone remained the major factors responsible for emissions and removals, respectively (Table 9.4). Two distinct approaches to examining the role of terrestrial biosphere in C exchange with the atmosphere produced results that are relevant to defining the role of the forest sector. Top-down methods based on inversion of atmospheric transport models estimate the net terrestrial carbon sink for the 1990’s, which is the net balance of sinks in northern latitudes and source in tropics (Ciais et al. 2000, Plattner *et al*. 2002, Gurney *et al*. 2002). The new estimates support the previously-found increase in the terrestrial C sink in the 1990’s over the 1980’s (Watson *et al*. 2001), but the new sink estimates and the rate of increase may be smaller than previously reported (Plattner *et al*. 2002). Improved spatial resolution allowed estimating the land atmosphere C flux for some continents separately. These estimates generally suggest greater sink or smaller source than the bottom-up estimates based on analysis of forest inventories and remote sensing of change in land-cover (e.g. Houghton 2000, 2005, Achard *et al*. 2002, DeFries 2002). The continued loss of forest cover in tropical regions plays an important role in C losses to the atmosphere while expanding forest areas and accumulating woody biomass contribute to C sink in the northern boreal and temperate zone (UN-ECE/FAO 2000). At the global scale the losses of forest cover continued during 1990’s with net annual loss of 9.4 million ha, while the uptake of C on land apparently increased in the 1990’s. The processes that could account for this increase remain unknown; the increase in woody biomass in many developed countries, Russia and China (Table 9.4, Fig. 9.7) may account but for some of it. Chapter 7, WG1 reports the latest estimates for the terrestrial sink for the decade 1993 -2003 at 0.51 Gt C y-1, ignoring emissions from land-use change (Brasseur *et al*. 2007).

While the estimates of forest expansion and regrowth in the temperate and boreal zones appear relatively well constrained by available data and consistent across published results, the rates of tropical deforestation remain uncertain and hotly debated (Table 9.4, Fearnside and Laurance 2004, Mayaux et al. 2005). Studies based on remote sensing of forest cover report lower rates than the UN-ECE/FAO (2000) and lower emissions of carbon (Achard *et al*. 2002, DeFries 2002). A recent estimate puts global net emissions from land-use change in the tropics at 1.1 ± 0.3 Pg C yr^{-1} (see also Chapter 7, WG III) and includes emissions from conversion of forests (representing 71% of budget) and loss of soil carbon after deforestation (20%), emissions from forest degradation (4.4%), emissions from the 1997–1998 Indonesian exceptional fires (8.3%), and sinks from regrowth (-3.3%) (Achard *et al*. 2004). Over the last three decades, Earth Observation satellites have increased in number and sophistication and tremendous progress has been made in methods for extraction of thematic information (Janetos and Justice 2000; Belward *et al*. 2003). Remote sensing methods are expected to play an increasing role in future assessments, especially as a tool for mapping land cover and its change over time, however, converting these maps into estimates of C sources and sinks remains a challenge and will continue to depend on in-situ measurements and modelling.

Another novel tool for land-based observations are flux towers that provide a wealth of information on environmental controls on C exchange of terrestrial vegetation including forests over relatively small spatial scales (e.g. Law *et al*. 2002). Converting these measurements into large area estimates can be problematic because flux towers generally miss the major C emission events (e.g., following fires, clearcut harvest, and insect outbreaks) that tend to be short-lived and stochastic in forest ecosystems (Körner 2003). Several studies that used flux tower measurements in regional analyses therefore had to rely heavily on other types of measurements (Law *et al*. 2004, Janssens *et al*. 2003).

Insert Table 9.4.

The differences between estimates from top-down and bottom up approaches (Table 9.4) have not been fully reconciled but potential explanations have been put forward. Recent analyses highlight the important role of carbon flows that were largely overlooked by earlier research, including C export through river systems (Raymond and Cole 2003), volcanic activity and other geological processes, outgassing (Richey *et al*. 2002), transfers of material in and out of products pool (Nabuurs *et al*. 1997, Pacala *et al*. 2001), and uptake in freshwater ecosystems (Janssens *et al*. 2003). Put together these relatively small flows were shown to be quite significant for the overall C budget of the USA (Pacala *et al*. 2001). Janssens *et al*. (2003) used estimates for Europe from different sources to constrain the resulting range of estimates. Moreover, House *et al*. (2003) show that the differences in estimates can provide insights into the role of different processes. For example, the difference between atmospheric inversion and inventory-based estimates in northern extra-tropical regions suggest that C accumulation in soils and non-forest vegetation may account for nearly half the terrestrial uptake in this region. Estimates of the effects of land-use change in tropics may fail to fully account for the impact of CO_2 fertilization, climate change, effects of prior disturbance history, and other factors that contribute to C uptake in these forests.

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

Insert Figure 9.7.

Large year-to-year and decadal scale variation of regional carbon sinks was reported (Bousquet *et al*. 2000, Houghton *et al*. 2000, Kurz and Apps 1999, Pacala *et al*. 2001, Rodenbeck *et al*. 2003, Shvidenko and Nilsson 2003) making it difficult to define distinct trends. The variation reflects the effects of climatic variability, both as a direct impact on vegetation and through the effects of wild fires and other natural disturbances. Fires in tropical forests are reported to grow in area and frequency (Cochrane 2003). During the 1997/98 El Nino, global emissions from fires were an estimated 2.1 ± 0.8 Pg C yr, 90% from tropics (Van der Werf *et al*. 2004). During 1998, an extreme fire year in the boreal zone an estimated 290-383 Tg C were released into the atmosphere (Kasischke and Bruhwiler 2003). There are indications that higher temperatures in boreal regions will increase fire frequency and associated greenhouse gas emissions (Flannigan *et al*. 2000, Flannigan *et al*. 2005); possible drying of the Amazon basin would increase fire frequency there as well (Cox *et al*. 2004). *(WGII ref).*

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

Changes in carbon emissions and removals in the forest sector over the next several years to decades will be driven by:

- future sectoral changes (including demands for wood, product mix, processing technology, progress in silviculture, and planting stock improvement)
- changes in other sectors (including demand for agricultural land, technological change in energy sector, development patterns, especially adoption of strategies for sustainable development, construction technology, consumer choice, and waste management)
- environmental change (including direct and indirect impacts of changes in climate, atmospheric composition, changing species distributions, especially weeds and invasive species, disturbances, pests and pathogens)
- legacies and delayed effects of current and past changes in land use and management going back years to centuries into the past. For example, changes in disturbance regimes in past decades affect the age-class distribution in boreal forests, which in turn will affect their future carbon balance;
- political factors including carbon accounting and trading systems, relative incentives for choices in land, materials and energy use, policies focussed on production and consumption patterns etc.

The potential effect of projected climate change on the net carbon balance in forests remains uncertain (WGII ref). While considerable uncertainty underlies projections of future carbon emissions and removals in the forest sector, available evidence indicates that for several decades (1) deforestation in the tropics will continue to be a major source of carbon emissions (Canadell et al. 2004), (2) Carbon sink in some or all countries with economies in transition may decrease as forests mature and possibly reverse if their rebounding economies cause increased logging; (3) C stocks in forests of many developed countries will continue to grow unless they choose to rely more on their forests to meet the demand for timber, however the strength of C sink may gradually decrease as forests age; (4) aggressive reforestation programs in previously deforested countries (e.g. Europe, China) can produce new C sinks. The timing, extent, and impacts of future net emissions from forests are in part contingent upon the application of mitigation options described below.

9.4 Assessment of Mitigation Options

9.4.1 Conceptual introduction

All organic carbon stored in the above and belowground biomass, dead wood, litter and soil carbon pools of terrestrial ecosystems has, at one point, been removed from the atmosphere through photosynthesis. An estimated 30-40 Pg C y^{-1} cycle through forest ecosystems globally as NPP (WG 1), but only the net balance of the large emission and removal fluxes contributes to net C storage or net C losses. Forest management activities aimed at mitigating the rate of carbon increase in the atmosphere include targeted measures to alter the net balance by reducing sources and increasing sinks.

Under the United Nations Framework Convention on Climate Change and the Kyoto Protocol, countries are reporting the net carbon stock changes in their forests and other woody biomass stocks. Forest management decisions could be implemented that would reduce emissions by sources and increase removals by sinks. However, each measure has an impact on several carbon pools and possibly on other sectors as well. For example stopping all harvesting activities could result in increases in forest biomass carbon stocks, but this decision would reduce the amount of timber and fibre available to meet society's needs. Other products (concrete, aluminium, steel, plastics) would instead be used to meet human needs and the increased use of these products would result in higher emissions.

To address "dangerous anthropogenic interference with the global climate system" net greenhouse gas emission to the atmosphere need to be minimized. The "optimum" strategy towards this goal cannot be developed by a single sector: portfolio approaches will be more effective. It should prevail that any actions should be assessed within the context of sustainable development. Benefits from forest management strategies aimed at maximizing carbon stock in forests may be diminished if the reduction in available timber and fibre triggers increased emissions from other sectors as humans seek to meet their needs (Figure 9.8). Moreover, increasing forest area through afforestation and reforestation programmes may affect other land-use sectors. For example, the increase in forest area may require more intensive agriculture on the remaining land area, with consequent higher agricultural emissions from increased fertilizer use that could off-set some of the carbon removals in the afforested areas.

The estimates of mitigation potential related to forest activities must be considered carefully to determine whether they are based on atmospheric exchanges or on assumptions and/or political considerations. Richards and Stokes (2004) conclude many studies are incomparable due to differences in scope (e.g. biological potential versus economic potential at a certain carbon price), assumptions, methods and terms. Cannell (2003) notes that the conservatively achievable mitigation is often only 10-20% of the theoretical potential for both in-forest sequestration and bioenergy plantation scenarios. The IPCC (1996) guidance states "the net flux to or from a particular site will always be reflected in the change of carbon stocks on site and/or in the products pool associated with the site." The clear link between the forest and their products is frequently lost in the literature due to the default assumption that all harvested biomass is instantly oxidized, therefore it is difficult to asses the mitigation potential since many studies do not take into consideration wood products as carbon stocks.

Applying the instantaneous oxidation after harvest default assumption tends to focus the analyses on the forest in isolation from other sectors. This can lead to a conclusion that all forests should be protected because this would prevent carbon loss through harvesting, which would be assumed to equal avoiding emissions. It can also lead to considering the forest only for its on-site sequestration capacity, rather than its broader benefits (Cannell, 2003).

Developing mitigation strategies involving forests should therefore not be attempted without assessing the implications on net greenhouse gas emissions across all affected sectors. Moreover, other factors such as albedo and the hydrological cycle will also have to be considered when assessing climate impacts of mitigation options. Mitigation options can also affect biodiversity and ecological processes and they will have other socio-economic impacts that are beyond the scope of this chapter. Keeping in mind the complexity of the issues (Figure 9.8), what options are available to reduce sources and increase sinks in the forest sector in a sustainable manner and what contribution can this sector make to the global “stabilization wedges”, are critical questions that need to be addressed.

Insert Fig 9.8.

The options available to reduce emissions by sources and/or increase removals by sinks in the forest sector can be grouped into four general categories:

- **increasing or maintaining the forest area** using afforestation/reforestation and sustainable forest management through the avoidance of deforestation;
- **increasing the stand-level carbon density** (tonnes of C per ha) using planting, site preparation, tree improvement, fertilization, uneven-aged stand management, or other silvicultural techniques;
- i**ncreasing the landscape-level carbon density** using longer forest rotations, forest conservation, fuel management and protection against fire and insects, and
- **increasing product substitution** using forest-derived biomass to substitute products with high fossil fuel requirements and increasing the use of biomass-derived energy to substitute fossil fuels.

The reduction in fossil fuel use in forest management activities, forest nursery operations, transportation and industrial production provides additional opportunities that are similar to those in other sectors and will not be discussed here. The options available in agro-forestry systems are conceptually similar to those in other parts of the forest sector. 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.

As shown in the conceptual diagram, some of the activities in the four categories interact with each other and with activities in other sectors (see also Figure 9.3 that highlights the many relations to other sectors). Increased use of forest fertilization affects fossil fuel use and nitrogen-based GHG emissions. Forest conservation and longer rotations affect the amount of timber and fibre available to meet society’s needs. The development of forest mitigation strategies should therefore, ideally, assess the impacts on the net GHG balance (all sources and sinks of all greenhouse gasses). Moreover, forest management decisions can also affect the climate system through other, not always positive, consequences (for example changes in albedo and hydrological cycle) (Chapin III *et al.* 2005).

9.4.2 An overview of the technical impacts of measures on carbon sinks and sources

Temporal carbon dynamics of forest ecosystems are often characterised by long periods of gradual build-up of carbon stocks in biomass and dead organic matter, interspersed with short periods of massive carbon loss during disturbances. Forest stands thus switch between sources and sink of carbon, depending on the stage of stand development, time since last disturbance or the specific management regime and activities (Figure 9.9). Large areas of forest consist of a mosaic of patches in different stages of stand development. Although such areas may not act as a net sink of carbon, they represent large stocks. Harvesting or deforestation of such sites will therefore lead to substantial loss of carbon stock in a short timeframe. In managed forests, trees are harvested in more or less regular intervals. Large parts of the European forest, some other parts of the temperate zone, and increasingly also tropical plantations, are managed in the even-aged system. In this system, the main ‘crop’ consists of trees of equal age and species. During a rotation, several thinnings can be carried out, followed by a final harvest. Harvests will decrease the amount of carbon in the living biomass, but increase the amount of carbon in the soil/deadwood compartment because of the slash (topwood, branches, foliage, and roots) that is left after harvest (Figure 9.9), and increase the amount of carbon in the wood products. However, in sustainably managed forests the biomass harvested is usually less than or equal to the biomass increment, meaning the total forest stock rarely decreases. Rotation lengths can range from a few years for fast growing Eucalypt pulp plantations to well over 100 years for quality sawlogs of slower growing species. Figure 9.9. Box 9.1 illustrates the development of carbon stocks in a managed and an unmanaged stand.

Sinks at the stand level cannot increase indefinitely: as trees become over mature, the total stand biomass begins to decline adding carbon to dead organic matter pools. The stand age of maximum biomass carbon storage differs greatly among forest ecosystems and in most, the age of maximum total carbon storage (including dead organic matter and soil) will be decades or centuries after the age of maximum biomass C storage. The boundaries under consideration (forest, products, related impacts), and the analytical methods used will largely determine the preferred mitigation activities identified (Loza-Balbuena, 2005, Schlamadinger and Marland, 1996).

Insert Box 9.1.

Start Box 9.1.

Insert Figure 9.9 (Box)

Afforestation and reforestation is an important and widely practiced land management activity that helps alleviate the negative effects of deforestation and often meets the needs of sustainable development while providing a mechanism for mitigating C accumulation in the atmosphere. The net mitigation effect tends to saturate over long term (100 years) similar to what can occur in the energy sector if the baseline scenario is also subject to improvements. Given the equal initial mitigation effect, emission reductions in the energy sector or C sequestration on land may be more effective depending on the target time frame and the efficiency of biomass use to replace fossil fuels (Figure Box 9.9). The relative importance of these measures for sustainable development will likely drive the choice of the type of mitigation strategy.

The sequestration scenario in Figure Box 9.9 assumes a conservative C sequestration rate of 1 tC/ha/yr over 100 ha (100 tC/yr). Each year 0.5% of the area is lost to fire; the entire forest is harvested after 50 years, after that the harvested and the burned area re-grows at the same rate. The net mitigation effect includes C sequestration in live tree biomass only (no soils or detritus) and product and energy substitution with harvested wood (Schlamadinger *et al*. 1996). The dotted line shows a reference scenario without harvesting. This scenario is still subject to fire on 0.5% of the forest area in each year, after which the forests begins to regrow.

The mitigation scenario in industrial/energy sector assumes a process that burns 200 tC per year initially. At time zero an emission reduction activity is implemented that reduces the emissions to 100 tC per year, so that the annual mitigation is 100 tons C as above. This could be done by using a fossil fuel that is half as carbon intensive (gas instead of coal, or increasing efficiency by a factor of two). So, initially the mitigation of the energy measures ise exactly the same as the sequestration of the forest. The baseline scenario (without activity) includes the assumption of a greenhouse-gas efficiency improvement of 1% per year. Project emissions (with the activity) are assumed constant for 50 years, starting at half the rate of the baseline scenario (i.e., 100 tons per year). Fifty years is a likely lifetime of large power plants. After 50 years, another emission-reduction activity takes place, reducing emissions by another 50%.

End Box 9.1

Afforestation/Reforestation

Description: Afforestation is defined in the framework of the Kyoto Protocol as direct human-induced conversion of land that has not been forested for a period of at least 50 years to forested land through planting, seeding and/or the human-induced promotion of natural seed sources. Whereas reforestation is defined as the direct human-induced conversion of non-forested land to forested land through planting, seeding and/or the human-induced promotion of natural seed sources, on land that was forested in the last 50 years but that has been converted to non-forested land. For the first commitment period of the Kyoto Protocol, reforestation activities will be limited to reforestation occurring on those lands that did not contain forest on 31 December 1989. The main purpose of afforestation or reforestation usually lies in other goals, but carbon sequestration can be one objective.

Main Potential: The GHG mitigation potential of Afforestation lies in the increase of forest area, increase of carbon stock density in biomass and soil pools and associated wood product pools. Forest land usually represents a higher carbon reservoir and lower net emissions than other land uses.

Technical feasibility: Technically feasible in large parts of the world. However a land use change is a drastic change and a choice for a long term land use practice. Therefore the changes are occurring at a slow pace. (see also section 9.2)

Implication for GHG mitigation / biodiversity: Increased carbon stocks on the longer term due to increased biomass and potentially increased soil carbon. The system changes from a low biomass system (where most of the NPP is harvested and removed) to a high biomass system (see Figure 9.10)

Insert Figure 9.10

Forests, particularly under longer rotations, tend to be less intensively managed than other land uses and as such receive less agrochemicals. Forest soils have methane oxidation rates an order of magnitude higher than pastoral or cropland soils (Tate et al. in press), and are considered as sinks of methane. The usually intensive ploughing of agricultural soils is ceased and a more moderate (moist) climate is created, which is beneficial for soil carbon. Furthermore, grasslands emit N2O, which will largely cease when afforested. It is clear that most profound effects are found in above-ground biomass and litter layers, the effects on the soil organic matter pool are much smaller, making it hard to detect within the uncertainty ranges (Chen et al. 2000, Paul et al. 2003 a,b, Zhang and Xu 2003) .

It is widely recognised that the net result on soil C of the afforestation depends very much on the initial situation. If the initial stocks are low (for the soil type considered) then afforestation can yield considerable results in the soil C as well. Accumulation rates in the order of 0.3 to 0.4 Mg C ha-1 y-1 are mentioned by Post and Kwon (2000) (Figure 9.11). However also losses are reported for afforestation on extensive grasslands with a high clay content (Lopez-Ulloa et al. 2005).

Insert Figure 9.11

Implications for biodiversity depend on the previous land use, previous biodiversity values and on the surrounding landscape. Large scale afforestation of natural grasslands or culturally rich historical small scale landscapes could lead to the loss of specific species, while afforestation of intensively used agricultural areas could improve biodiversity values (REF). Effects of afforestation on biodiversity should therefore probably be judged by the diversity of the newly created landscape. Effects on biodiversity also depend on the species that are used for afforestation.

Revenues and costs: Cost effectiveness of this measure is moderate to low if measured in terms of carbon sequestration in biomass only, but wider boundaries improve the performance of forestry both in absolute terms and relative to other land uses (Ford-Robertson et al. 1999). Robertson et al. (2004) suggest the practicality and cost of monitoring, reporting, and verification of carbon stock changes will limit the promotion of afforestation activities. Van Kooten (2005) concludes that economic realities are largely underestimated and will restrict both forestry activities and bioenergy opportunities. Loza-Balbuena (2005) has also highlighted the importance of economic factors such as land value and discount rates.

Inclusion of soil carbon increase after the activity and reduction of N2O emissions from former land uses (i.e. grasslands) will increase the cost effectiveness slightly. However, afforestation can serve many goals and can have many positive side-effects. A review study by Richards and Stokes (2004) suggests that secondary benefits of afforestation might actually be as great as the costs.

Constraints (Social, institutional, environmental): Afforestations take place slowly. These are drastic changes that are usually driven by other goals, or by developments in agriculture. Socila contratin may apprar as well, for example large scale afforestation leads to losses in employment and abandonment of the rural areas, farmers oppose the idea to convert good agricultural land that often has been in family possession for centuries). Further, afforestation can change the appearance of a landscape drastically affecting other uses (externalities).

Potential magnitude of technical measure: The potential of afforestation depends largely on the availability of abandoned agricultural land. Since these are usually marginal lands, the productivity is not very high. On the other hand, the available area could be considerable and the increase in carbon stocks is for a large part permanent.

Reducing deforestation

Description. Deforestation leads to an immediate loss of carbon in living biomass, and sometimes followed by a decrease of soil carbon due to decreased litter input and increased decomposition due to soil disturbance and increased temperature (less shading), as well as soil erosion. Avoiding deforestation is the prevention of the transition of forest to another land use that would both contain less carbon. Sustainable forest management involves avoiding degradation and deforestation, as well as provision of forest products and services.

Main potential: The main potential of this measures is avoiding carbon emissions from current stocks in both biomass and soil carbon. Deforestation is occurring mainly in the tropical forest zone (see Figure 9.4.), however degradation and deforestation also occurs in the industrialized countries through e.g. urban sprawl. Conversion of forest to other land uses will result initially in significant emissions of carbon.

Implication for GHG mitigation / biodiversity: The implication of reducing deforestation on the greenhouse gas budget is avoiding large carbon emissions in both the short and long term. Implications for biodiversity can generally be judged as positive since the practice is like conservation of existing forest, it would mean a prevention of loss of current biodiversity. This depends of course on the previous biodiversity values and to which land use the transition is.

Revenues and costs: Direct costs of avoiding deforestation are minimal, but indirect costs could be high. The mitigation cost of deforestation depends on the driver of deforestation such as for meeting timber or fuelwood needs or conversion to agriculture or for grazing land or for settlement or infrastructure. An attractive carbon price also could determine the potential for avoiding deforestation. The cost of mitigation through avoided deforestation depends on the compensation to be paid to the individual or company or the government department in a country and can vary for different countries or regions. For example, slowing deforestation in Rest of Asia is higher, due to quality timber export needs, compared to Africa where the opportunity cost is lower (Sathaye et al. 2005).

Constraints (Social, institutional, environmental): Deforestation is a complex process driven by a multitude of factors having to do with the so-called “proximal” causes such as expansion of agriculture, cattle production and illegal logging, as well as structural causes linked to land tenure, fiscal policies, perverse incentives due to cross subsidies among productive sectors and other factors (see section 9.6). To date, reducing deforestation has proved very difficult in most developing countries. In many Western and Central European countries deforestation is only allowed under very high restrictions. Deforestation that occurs is usually for road construction or house building, and under the provision that the forest area is compensated elsewhere. In such cases, interests are often high, and it is unlikely that this kind of deforestation could be prevented. Bauer et al. (2004) conclude in an overview of forest laws of 23 European countries that in general: “Changes of forest land into other forms of land use (agriculture/ urbanisation/ industrialisation) need a separate and specific regulation procedure by the national forest law.” However, in the national UNFCCC reporting for a small country like The Netherlands, an annual gross deforestation of about 1,100 ha was reported (Nabuurs et al. 2004).

Potential magnitude of technical measure: Reducing deforestation is the measure with the highest mitigation potential and one with the highest environmental benefits in the short to medium term globally (See section 9.3).

Changing the forest management

Description: A large number of practices are included within this mitigation option, ranging from the use of chemical fertilizers to increase productivity, improving genetic quality, drainage, irrigation, extending rotation lengths, changes in the timing and intensity of thinnings, irrigation, continuous cover forestry versus clear cut systems (reduced impact logging), changes in tree species, minimizing site preparation, decrease of impact of fires, decrease of wind damage, decreasing vulnerability to pests and others. Nabuurs et al. (2005) presents a comprehensive review of the mitigation potential, costs, associated impacts and constraints of each option.

Main potential: Some of the options aim at increasing productivity and will thus lead to an increased carbon sink. Other practices –like increasing rotation length- will on average lead to a larger amount of biomass at the site, and thus to a larger carbon stock. Practices oriented to maintain a continuous presence of forest cover leads to less fluctuation of the carbon stocks and fluxes at the site, and probably to a higher average stock present at the site.

Technical feasibility: Given the wide range of practices, there are options suitable for almost any forest condition.

Implication for GHG mitigation / biodiversity: The effects on GHG mitigation are positive in general, but the magnitude depends on the specific measure and local conditions. For example, the potential sequestration can be diminished by the increase of emissions of N2O due to the use of fertilizers. Also, drainage of forest soils, and specifically of organic soils like peatlands may lead to substantial carbon loss from the soil due to enhanced respiration (e.g., Harden et al. 2000, Ikkonen et al. 2001), although counterevidence also suggest increased peat C accumulation in case of moderate drainage (Minkkinen et al. 2002). Increasing rotation lengths has a positive influence in some carbon pools and negative in others (Figure 9.12).

Insert Figure 9.12

Biodiversity: Impacts on biodiversity differ greatly among the specific options. On the one hand, intensive fertilization and use of GMO will have a negative effect on local species. Irrigated plantations will likely be managed intensively with negative impacts to biodiversity. On the other hand, systems that encourage a continuous forest cover lead to more diversity in forest structure and are believed to better resemble the natural situation for some biomes. Therefore, effects on biodiversity are believed to be positive. However in biomes like boreal forests, where large scale disturbances occur, clearcut is the more natural way or regenerating. It allows regeneration of understorey and creates open spaces leading to wider habitat diversity (Moore, 2000)

Revenues and costs: Investment costs tend to be higher than the conventional system in most alternatives. For these reasons, for example, intensive irrigation is currently only applied in crops with short rotations, with highly productive species. Discounted costs over longer rotations will probably be very high. Revenues due to increased biomass sink depend on the price of carbon, type of fertilizer and increase in productivity obtained and the delay in time to get them.

Constraints (Social, institutional, environmental): Conflicts with the ‘natural’ idea of forests, could lead to protests of local forest users particularly when dealing with fertilization and GMO. Availability of water is a constraint to irrigation. Increased rotation lengths will lead to larger trees which may not be able to be processed by timber industry. Reduced impact logging and other practices that encourage a continuous forest cover are usually more complicated and demand more insight and knowledge of the foresters.

Products substitution

Wood products are an component of assessing the atmospheric impact of forestry activities. Not only do products retain or store for different time periods carbon sequestered in forests, but also they provide a service so that non-wood products are not required. However, wood products are currently viewed unfavourably since harvested carbon is classified as an emission in current GHGs inventories for forestry sector as soon as it leaves the forest site (Macqueen et al, 2004). Strategies to improve the contribution of wood to climate mitigation should aim to achieve a greater proportion of wood products, a longer useful life, and increased recycling.

Implication for GHG mitigation / biodiversity: Wood products extend the time before sequestered carbon is returned back to the atmosphere. Wood-based materials therefore offer a means of reducing fossil fuel emissions by substituting for non-wood materials. When the carbon in products cannot be reused or recycled any longer, it can be used as a source of renewable energy. Wood products can be seen as a long term way to overcome the problem of saturation, since it will allow a continuous flow from the forest to be stores out ot the forest itself.

Revenues and costs: (to be added)

Constraints (Social, institutional, environmental): Macqueen et al. (2004) note that it is frequently what happens outside the forest sector that is most important in determining the fate of the forest. International consumers can therefore play a positive role by valuing wood and by demanding it comes from legal and sustainable sources.

Potential magnitude of technical measure: The EU forest sector (Anon, 2005) suggests that a wooden house could contain up to 150 tonnes of CO2 and each house built with timber instead of brick reduces carbon emissions by 10 tonnes. Furthermore, by using the full potential of wood (sink and substitution effects) in buildings, Europe could reduce emissions of CO2 by 300 million tonnes or 15 to 20%. Studies in Australia suggest each new house could be built with a saving of 25 tCO2e if predominantly wood products are used (Anon, 2004). Macqueen et al. (2004) estimate that substituting one tonne of virgin card for glass, plastic, steel or aluminium results in an average saving in excess of 1.1 tonnes of CO2 savings whereas using a cubic metre of wood rather than construction alternatives (concrete, blocks or bricks) results in an average of 0.8 tonnes of CO2 savings. The European forest industries (Anon, 2005) claim to be the lowest fossil-fuel intensity manufacturing sector, as well as the largest producer and consumer of renewable energy.

Bioenergy

Forest biomass and ‘waste’ products can be used to produce energy. Chapter 4 describes a number of bioenergy pathways to generate energy both directly (e.g. harvesting residues, processing wastes, construction and demolition waste) and via intermediate biofuels (e.g. wood pellets, bioethanol, biogas).

Description: Wood for bioenergy is globally an important energy carrier. In its non commercial version, much of the global population depends on it for heating and cooking. Forest management can be enhanced/improved in order to accommodate this, but also its commercial version. Forest residues usually constitute 25-45% of the harvested wood (IEA Bioenergy 2002), but are widely dispersed and the ability to recover it is very much affected by local terrain and the harvesting methods employed (EECA, 2001). Residues, which consist of stem and branch waste and smaller residue occur in piles scattered throughout the forest. This residue is potentially recoverable, though is not currently used for energy to any significant degree due to the issue of cost.

Implication for GHG mitigation / biodiversity: If all the harvested biomass is burned, whether for energy recovery or to waste, there will be minimal delay before the carbon sink is reversed and the sequestered carbon is returned to the atmosphere. It is usually only in cases of deforestation (usually for agricultural or urban expansion) or energy forestry that the loss of forest biomass stocks is followed rapidly by emissions. It is more likely that at least part of the harvested carbon will be transferred to products and hence the emission will be delayed.

Bioenergy is frequently assumed to be "emission free" and by including the avoided fossil fuel emissions, bioenergy appears to be equivalent to a carbon sink. For example Chapter 4 in this report states "If the 46 EJ of energy from biomass were to be provided by a mix of fossil fuels instead, atmospheric carbon emissions would be greater by about 1.3 Gt/yr (Kaltschmitt, 1998)". Van Kooten (2005) notes that carbon emissions per unit of energy from biomass are 90% higher than from methane (natural gas), 45% higher than from oil and 18% higher than from coal. Widely used emission factors suggest fossil fuels emissions range from around 0.05 tCO2/GJ (natural gas) to 0.08 tCO2/GJ (coal), whereas wood is 25 to 50% higher at around 0.1 tCO2/GJ. In reality, bioenergy is at best carbon neutral when the entire carbon cycle is considered, but the sink remains in the forest and this is reversed on oxidation of the biomass. Removing biomass will result in slower accumulation of soil organic matter due to the decreased litter input to the soil. However, felling residues make up only a minor part of the total litter input over a rotation period (Lundborg 1998), and stump and roots remain on the site in most cases.

The effect on biodiversity is unclear, although overharvesting for non commercial fuel wood clearly leads to forest degradation. In its commercial form, harvest residue removal means less deadwood on the site, but in practice at least 30% of the aboveground residues are left for technical reasons. Experience indicates that residue extraction has little negative impact on biodiversity (IEA Bioenergy 2002). The return of wood ash can help to prevent deficiencies of mineral nutrients (except nitrogen).

Revenues and costs: The main barrier is the high price for production of forest chips from residues (Hakkila 2003). Current high energy prices make the recovery more attractive.
Conversion to biofuels tends to involve some energy loss, and while this may be justified on economic grounds it does not improve the emissions per unit of useful energy relative to fossil fuels. The low energy density of biomass means the CO2 emissions per unit of energy are higher than for fossil fuels.
Constraints (Social, institutional, environmental etc.): A widely used source of forest energy is the processing residues. EECA (2001) estimate approximately 20 - 25% of the plantation harvest in NZ is converted to wood residues but more than half the wood processing residue is used directly within the wood processing industry for energy or fibre products.

9.4.3 Regional assessments

Stand level carbon sink estimates (of section 9.4.2) cannot simply be multiplied with a certain area to obtain an estimate for economic potential of the carbon sequestration of a global region. In order to do this type of upscaling, many more factors need to be taken into account. These include a.o. the wide variety in sites and forest types, trends and issues in the forest sector regionally, trends in other land based sectors, socio economic factors amongst which the carbon price, and the mutual exclusion of the different measures. A varying mix of these factors is taken into account in regional studies available in literature. As such these regional assessments vary from projecting the total area forest sector sink trend (Karjalainen et al. 2003) to studies that assess the purely additional economic potential carbon sequestration of specific measures (Benitez-Ponce 2005, McKenney et al. 2004, Sathaye et al. 2005). Here we have gathered regional carbon sequestration assessments and have compared them against baselines as provided by the IMAGE model for the A1f scenario (Brinkman et al. 2005, IMAGE Team, 2001). From this compilation we try to make a best guess for the economic potential carbon sequestration in the forestry sector in the region.

OECD North America

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

Figure 9.13 shows one attempt at deriving estimates of the theoretical potential of management actions aimed at modifying the net carbon balance in Canadian forests (Chen et al. 2000). Of the four scenarios examined, the theoretical potential was largest in the scenario aimed at reducing regeneration delays by reforesting after natural disturbances. The estimate of the potential increase in the carbon sink was -0.085 Gt C y-1 by 2050. The second largest estimate was obtained with annual, large-scale (125 Mha) low-intensity (5 kg N ha-1 y-1) nitrogen fertilization programme with an estimated sink potential -0.056 Gt C y-1. Neither of these scenarios is realistic, however, and large uncertainties are associated with these estimates. Other studies have explored the potential of large-scale afforestation. Mc Kenney et al. (2004) project that at a carbon price of 25 $/ton CO2, 7.5 million ha of agricultural land would become economically attractive for poplar plantations (at medium growth rates) in western and eastern Canada. Yemshanov et al. (2005) confirm that, at low carbon prices, almost no land would be attractive for afforestation in Canada. These economic constraints are contributing to the declining trend in afforestation rates in Canada from about 10,000 ha y-1 in 1990 to 4,000 ha y-1 in 2002 (White and Kurz, 2005). Several research projects are currently ongoing to assess the potential of other forest management strategies aimed at reducing sources and increasing sinks, including considerations of active suppression of forest insect outbreaks.

Insert Figure 9.13

Insert Figure 9.14

For the USA a possible baseline is given in Figure 9.14 for the A1f scenario. The sink in the LULUCF sector may increase due to afforestation and ongoing build up of biomass in the forests. A large variety of results from literature concerning sequestration options in forestry appears. A lot of studies are however more concerned with projecting the trend of the forest sector rather than quantifying additional sequestration under certain price schedules. The studies by Alig et al (1997) and Adams et al (1993) come closest to this, and quantify the additional options at respectively -0.04 Gt C y-1 and -0.058 Gt C y-1. For the USA, the best options that hook into issues in forestry and can thus be seen as most sustainable, are: some additional afforestation, reducing urban sprawl, management activities that make better use of the mortality in second growth forests, and bioenergy options (see 9.4.4). Clearly the options should be combined to adaptation questions, and can be sought in combining carbon sequestration with nature restoration, with water retention and by providing natural pathways to connect the fragmented nature reserves. In this way, the mitigation options will contribute to sustainable development as well (see also WG II ch 'ecosystem services'.

Insert Figure 9.15

The figures mentioned above are in the same range as given by Lee et al (1996) at a carbon price of 15 $/ton CO2 (Figure 9.15). They present a cumulative sequestration in all forest measures of 4 Gt C by 2050; this represents an annual sequestration of -0.08 Gt C y-1.

Europe

The forest resources of Europe can be characterised as intensively managed, with no primary forests left any more. Most of the forests are rather young; harvesting is approximately 60% of the increment. There is a clear trend towards nature oriented forestry. Figure 9.16 projects a possible baseline under the A1f scenario, in which the LULUF sector is projected to show an increasing sink until 2010-2020, after which it saturates. Most of the assessments that are shown were projections of the forest resource as a whole. Studies that looked into additional effect of measures were done by Cannell (2003), Benitez et al (2005) and Lindner et al (2005). Over a forest baseline sink of -0.1 Gt C y-1, the studies present additional achievable sinks of -0.02 to -0.04 Gt C y-1. Economic analyses were never done at a very large scale, only country studies were done, e.g. Hoen and Solberg (1994) for Norway. Issues in European forestry where options can be found are in afforestation of abandoned agricultural lands, bio energy from complementary fellings, and forest management that aims at curbing the saturation. Clearly the options should be combined to adaptation questions, and can be sought in combining carbon sequestration with nature restoration, with water retention and by providing natural pathways to connect the fragmented nature reserves. In this way, the mitigation options will contribute to sustainable development as well (see also WG II ch 'ecosystem services'). In the very long term, the goal of curbing the saturation seems feasible as most climate change impact studies predict on average enhanced forest growth in Europe (Nabuurs et al. 2002, Schröter et al. 2005). However, exception is the Mediterranean, where drought and fires will increase, and ecosystem services are under pressure (Schröter et al. 2005).

Insert Figure 9.16

Countries in Transition

The forest resource in the former Soviet Union is a huge resource of primary (mostly) boreal forests. In the more densely populated areas, it consists largely of second rotation growth. Natural disturbances (fire) play a major role in the carbon balance with emissions of up to 0.04 to 0.055 Gt C y-1 (Zhang et al. 2003). Large uncertainty surrounds the estimates for the current C balance (Dixon and Krankina 1993, Krankina et al. 1996). *Recent improvements of the estimates were not found (check for SOD).*

Insert Figure 9.17

Most estimates indicate that the Russian forests are neither a large sink nor a large source. From year to year they may be fluctuating around 0. This puts analyses of additional carbon sequestration options also in a large uncertainty bound. Figure 9.17 gives some estimates where especially the estimates of Krankina et al. (1996) and Shvidenko et al (1997) are estimates of biological potential of forestry measures, ranging between -0.02 to -0.2 Gt C y-1. Given the large uncertainties, the already existing large forest resource, as well as its inaccessibility, but on the other hand low land prices, brings us to a guesstimate of economic potential of -0.02 to -0.04 Gt C y-1.

OECD Pacific

For OECD Pacific (mostly Australia and new Zealand) few, but rather old assessments were found. Two studies that provide estimates of carbon sequestration potential without analyzing costs suggest that Australia and New Zealand could capture carbon at a rate of 7 million tons per year and 5 million tons per year, respectively, for 25 to 30 years (Barson and Gifford 1990; Tasman Institute 1994).

Only baselines are plotted in Figure 9.18. Clearly, even baseline assessments differ a lot. This is understandable from the point of view that the land cover and its management vary a lot in this region, and assessments of its baseline C balance give very different results. The plant cover varies from tropical moist forests with net deforestation in Northern Australia to immense areas of dry woodland and savannah like systems, down to large areas of primary forests and intense plantation forestry in New Zealand. Apparently there is no agreement on the net balance of this region. Still, options seem available in reducing tropical forest deforestation, reducing degradation of the savannah like systems, and in afforestation and optimised plantation management. At medium carbon prices, the economic potential can be estimated at -0.01 to 0.02 Gt C y-1.

Insert Figure 9.18

Middle East

For the Middle East (stretching Turkey, Saudi Arabia, to Iran) no economic assessments were found. Therefore, only baselines are plotted in Figure 9.19 which presents a small but continuous sink in this desert and steppe like region.

Insert Figure 9.19

Options may be found in restoring dry woodlands, and shrub like vegetation, thus contributing to sustainable development as well by providing shelter, fuelwood and reducing soil erosion. Additional curbing of baselines might be estimated at -0.005 to -0.01 Gt C y-1.

Japan

Japan is covered with semi natural and natural forests already to a large extent. Thus options have to be found in changing management that will curb the saturation of the baseline (Figure 9.20). Issues in Japanese forestry where options can be found are in bio energy from complementary fellings, and forest management that aims at curbing the saturation. Clearly the options should be combined to adaptation questions, and can be sought in combining carbon sequestration with nature restoration, with water retention and by reducing soil erosion. From the assessments it seems that the sequestration options are not large, in the range of -0.01 to -0.02 Gt C y-1.

Insert Figure 9.20

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 shrublands. The baseline projects a significant source for the whole of the LULUCF sector (Figure

9.21). More detailed country assessments for the forest sector all project a small sink ranging from -0.02 t -0.1 Gt C y-1, however the additionality of these figures is unclear. In addition, Kohn et al. (2003) project a significant sink potential at -0.4 Gt C y-1. Given the large areas, the fast economic development (and thus demand for wood products) we estimate the additional potential in the region at -0.05 to -0.1 Gt C y-1. Issues in forestry with which the carbon sequestration goal can be combined sustainably are reduction of degradation tropical and dry woodlands, afforestations, and bioenergy from complementary fellings.

Insert Figure 9.21.

Wet and dry Tropics

A recent estimate puts global net emissions from land-use change in the tropics at 1.1 ± 0.3 Pg C yr (see also Ch 7, WG III) and includes emissions from conversion of forests (representing 71% of budget) and loss of soil carbon after deforestation (20%), emissions from forest degradation (4.4%), emissions from the 1997–1998 Indonesian exceptional fires (8.3%), and sinks from regrowth (-3.3%) (Achard et al. 2004). The baseline projection is presented in Figure 9.22.Considering tropics as a whole, the net forest cover gained is only 2.34 Mha annually, compared to a net forest cover loss of 11.67 Mha (Section 9.2), highlighting the large potential to mitigate climate change by avoiding deforestation and enhancing afforestation and reforestation.

Insert Figure 9.22

Assumptions of future forest cover and rates of deforestation vary significantly across several studies by model structure and factors driving land use change. The projections made by Sathaye et al. (2005), using current trends, given in Figure 9.23, shows deforestation rates to continue in all the regions, particularly at high rates in Africa and South America. In Africa alone nearly 500 Mha are projected to be lost during the present century. Currently, afforestation rates account for only a fifth of deforestation rates in the tropics (Figure 9.23). Projections based on current trends by Sathaye et al. (2005) given in Figure 9.23 show that large area will be brought under afforestation in all the regions, particularly in Asia. China and rest of Asia will dominate future afforestation at the global level. This has implications for carbon stocks in forests and in sequestering carbon from atmosphere contributing to stabilization of CO_2 concentration in the atmosphere.

Insert Figure 9.23

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

Land availability for mitigation could be considered at three levels namely, technical, economic and market potential (Sathaye et al. 2001). The existing literature does not distinguish between different potentials and largely reflects the technical potential, where barriers are not considered. Land available for forestry mitigation options, in climate mitigation context, is also dependent on price of carbon, among many other social, financial, tenurial and policy factors. Land area available for mitigation at the continental level for an example Scenario of Carbon price of US$ 10 + 5% annual carbon price increment is given in Table 9.5 (Sathaye et al. 2005) and for selected countries of South and South-east Asian countries in Table 9.6.

The cumulative maximum land area available for Forestation (afforestation and reforestation) in Africa, Asia and Latin America (Af+As+La) is estimated to be 706 Mha, accounting for 67% of global total. The potential area under the Scenario considered for Forestation by 2050 and 2100 is estimated to be 203 and 397 Mha, respectively (Table 9.5). Af+As+La account for 52% of the global potential area for Forestation and 100% of the global area for Avoided deforestation. The feasible area available for Forestation for selected countries of South and South-east Asia is estimated to be 134 Mha, with India and Indonesia dominating with 63 Mha and 32 Mha, respectively (Table 9.6). An estimate (Table 9.7) of economic potential area available for afforestation/reforestation under CDM is shown to be 5.29 Mha in Af+As+La, with Asia accounting for 4.4 Mha (Waterloo et al. 2003).

Insert Table 9.5
Insert Table 9.6
Insert Table 9.7

The potential area available for avoided deforestation is estimated to be 403 Mha for the period 2000 to 2100 for the Af+As+La continents (Table 9.5). In principle all the currently annually deforested area of 11 Mha (section 9.3) could be considered as the technical potential available for forest conservation, if adequate financial incentive and policy support is available.

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

Insert Table 9.7A

Cost estimates for carbon sequestration projects for different regions compiled by Cacho et al., (2003) given in Table 9.7B show a wide range. The cost is in the range of \$2 to \$25/tC for forestry projects in developing countries, compared to \$5 to \$82 for forestry projects in industrialized countries. The cost value for industrial plantation or short rotation projects is \$ < 5/tC.

Insert Table 9.7B

The net mitigation potential (over the baseline or reference scenario) estimates include short rotation, long rotation and avoided deforestation. The total mitigation potential in the Af+As+La continents, under US\$5+5% price increment scenario, is estimated to be 21 GtC by 2050 and 50 GtC by 2100 and a similar trend is observed under US\$ 10+5% price increment scenario. The mitigation potential under US\$ 10+5% carbon price increase scenario is 46% higher than the US\$5+5% scenario for the period up to 2100. The avoided deforestation option dominates the future mitigation potential in the Af+As+La continents by accounting for nearly 79% of the total mitigation potential during the period 2000-50 and the share declines marginally to 66% by 2100 under the $10+5% increment in price scenario.

The contribution of different tropical regions to the mitigation potential is given for the carbon price scenario US$ 10+5% annual price increase in Figure 9.25. During the period 2000-2050, avoided deforestation in South America and Africa dominate by accounting for 18% and 57% out of the total mitigation potential of 18.6 GtC, respectively. When forestation is considered, Asia dominates by accounting for 2.7 GtC for the same period. Similar trend is observed for the period upto 2100 also, where forestation in rest of Asia accounts for 26% of the total tropical mitigation potential.

The mitigation potential of the continents Africa, Africa and Latin America dominates the global total mitigation potential by accounting for 75% and 76% of the total for the period up to 2050 and 2100, respectively in the scenario US$10+5% annual increment in price (Fig 9.24). Thus, the developing or tropical countries dominate the future mitigation potential in the forest sector.

Very few global or continental level estimates of economic or market potential land available for mitigation are available. There is a need to generate such data to enable policy makers to have a realistic estimate of potential under various policy scenarios. Exceptions are Benitez and Obersteiner (2005), Waterloo et al (2003), and Sathaye (2005).

A case study in India (BOX 9.2.) shows that only 50% of the technical potential is actually available for afforestation and reforestation, due to legal, competitive alternative uses and other barriers.

Start Box 9.2

BOX 9.2: A case study of technical and socio-economic potential of land available for forestry mitigation projects in Kolar district of India (Ravindranath et al., *in press*)

A study was conducted in Kolar district of southern part of India to assess the technical and socio-economic potential of land available for forestry mitigation projects. Technical potential area available for forestry mitigation activities is the total area recorded as available for forestation in the official records of forest and revenue department. In reality all the technical potential land area may not be available for forestation due to several reasons;
encroachment by individuals or conversion to settlements or infrastructure
requirement for future settlement or infrastructure or other developmental activities
conversion to agriculture in future
requirement for grazing; current or future
highly degraded (rocky or marshy)

Thus, socio-economic potential is the estimate of actual or feasible land area available for forestation activities obtained based on measurement of actual current area based on field visit and consultation with stakeholders (local community, local government and the relevant land departments). The socio-economic potential of land available for forestation activities ranged from 18 to 100% with an average of about 46% of the technical potential.

END Box

Sathaye et al. (2005) assessed the potential for short and long rotation forestation and avoided deforestation for seven developing countries (Brazil, China, India, Indonesia, Mexico, Philippines and Tanzania) and for the tropics as a whole (Table 9.8, 9.9, Figure 9.24).

Insert Table 9.8

Insert Table 9.9

Insert Figure 9.24

The aggregate incremental mitigation potential (over baseline) in the tropics as a whole for the period 2000 to 2030 is estimated to be -9 GtC at an annual rate of -0.29 GtC/year (Sathaye et al, 2001), accounting for 69% of tropics total, and for the seven developing countries -0.2 GtC/year.

Mitigation potential in the context of climate mitigation will also be influenced by carbon price, apart from other factors. Here two carbon price scenarios are considered from a study by Sathaye et al (2005). This study has shown that the carbon price determines the mitigation potential and as the carbon price increases more land will become available for mitigation and mitigation potential also increases and both the initial price as well as the rate of increase is critical.

Mitigation potential (gross, including the potential baseline forestation rates) estimates include short rotation, long rotation and avoided deforestation. The total cumulative mitigation potential in the Af+As+La continents, under US$10+3% price increment scenario, is estimated to be -15 GtC by 2050 and -28.6 GtC by 2050 under a US$20+3% price increment scenario. The avoided deforestation option dominates the future mitigation potential in the Af+As+La continents.

The contribution of different tropical regions to the mitigation potential is given for the carbon price scenario US$ 10+5% annual price increase in Figure 9.25. During the period 2000-2050, avoided deforestation in South America and Africa dominate by accounting for 49% and 21% out of the total mitigation potential. When forestation is considered Asia dominates. The mitigation potential of the continents Africa, Africa and Latin America dominates the global total mitigation potential for the period up to 2050 and 2100, respectively (Fig 9.25). Thus the insight that developing or tropical countries dominate the future mitigation potential in the forest sector remains.

Insert Figure 9.25

LULUCF potential of the Africa, Asia and Latin America continents and countries for the period 2012

A study by Jung (2005) has estimated the mitigation potential (Table 9.10) of plantations, avoided deforestation, agro-forestry, and forest regeneration options for period 2008 to 2012. In all the three continents and in the dominant tropical countries such as Brazil, Indonesia, Venezuela and India, avoided deforestation dominates the mitigation potential of LULUCF sector. Latin America, India and Brazil are the dominant countries for avoided deforestation option with a mitigation potential in the high range of -0.755, -0.2, and -0.2 Gt respectively cumulative for the period 2008 - 2012. When plantation forestry is considered Asia and China dominate by accounting for -0.05 Gt C cumulative for the period up to 2012.

Insert Table 9.10

9.4.4 A specific case globally: commercial biomass for bio energy

Type of forest residues

In this chapter we only focus on biomass from forestry from either forest residues (slash) and from complementary fellings. Based on the place where the biomass becomes available for energy purpose, one can distinguish three categories of biomass types: primary residues (available after or with harvest), secondary residues (available when processing the forest products) and tertiary residues (available after end use). For forest residues there is furthermore an additional potential category, namely the flow that can be extracted when primary forests become managed forests.

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

- The amount of forest area and amount of wood harvested;
- The way the forests are managed;
- The recoverability of the residues, both primary, secondary and tertiary residues;
- The demand for other bio-material products that compete with the use of energy, e.g. for fiber, for feedstock in the steel or petrochemical industry.

In addition we mention the use of fuelwood, mainly extracted from natural forests or produced with the purpose of using it for cooking and direct heating. These is considered non commercial bioenergy and not included here.

Assessment of future technical potential of bioenergy from forestry

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

Most global assessment studies use a timeframe between 30 – 100 years. They combine bottom-up insight on the recoverability of residues and growth levels of forests with more top down analyses on the future demand for wood based on GDP and population factors. Residue to product ratios are used combined with recoverability factors. The latter are also used to assess the availability from the processing residues. Typical values used are between 25 – 50 % of the logging residues and between 33 – 80% of the processing residues. Lower values are often assumed for developing regions (Williams, 1995; Hall et al., 1993; Yamamoto et al., 2001; Smeets et al., 2005, Sørensen, 1999, Swisher and Wilson, 1993). Higher values up to 100% have been assumed for instance for black liquor, a processing residue in the pulp and paper industry (Yamamoto et al. 1999).

At a global level, scenario studies on the future energy mixture (e.g. SRES, 2001, Sørensen 1999, WEC, 1998) have also included residues from the forestry sector in their energy supply (market potential). However in most scenario studies, the distinction between the contribution of residues and the contribution of energy crops is not made explicit. Most regional studies use comparable approaches, but have shorter timeframe and include more detail especially in the production levels of the forests, the ecological constraints and the costs.

Comparison of the results

We have compared the results of the global studies on the technical potential of primary biomass sources at a regional level. Table 9.11 shows the lowest and highest estimates of regionally aggregated results for timeframe 2020 - 2050. The large timeframe has been used as the results among the studies vary more than the variations among the timeframe.

Insert Table 9.11

Based on this table one can conclude that biomass from forestry can contribute to about a few percent to about 15% when compared to current primary energy consumption of about 400 EJ/y, and this may avoid 0.4 Gt C of emissions.

Economic assessments for bioenergy

There are no global studies that include the production costs of forestry residues. Even at a regional basis there are limited studies on the costs of biomass from forestry sector. This is mainly because the costs are complex. The cost of biomass from residues depends on one hand on the physical aspects, e.g. costs of collecting, cost for transporting and cost of chipping. But furthermore it depends on the opportunity costs of the residues; e.g. on the competing options of residues. Some assessments of the costs in Europe indicate levels ranging from 2.3 – 7.7 $€_{2000}$/GJ[2] (Lindner et al., 2005). For Denmark costs have been assessed below 1 $€_{2000}$/GJ (Nord-Larson et al., 2004). For the US, estimates indicate that almost 0.5 EJ/y forest residues would be available at cost levels below 1.2 $€_{2000}$/GJ and around 1 EJ/y would cost below 3 $€_{2000}$/GJ. An amount of 1.7 EJ/y of mill residues would become available at same cost levels. The latter type of residues is barely available at cost levels below 1.9 $€_{2000}$/GJ. Biomass forest residues calculations for New Zealand including transportation costs indicate that thinnings from forestry may be delivered at costs around 1 – 2 $€_{2000}$/GJ depending on the transportation costs (Sims, 2004). In general one can conclude that the delivery or production costs of forestry residues are expected to be at a level of 1 – 8 $€_{2000}$/GJ for the short and medium term, with most estimates at the lower level of this range, from 1 – 3 $€_{2000}$/GJ. At these costing levels, the economic potential can be guesstimated at 10-20% % of the values given in Table 9.11.

Smeets et al., 2005, estimated a global economical potential of biomass from the forestry sector for 2050 without cost estimations using the assumption that the forest area available technically is also available for the economic potential but the biomass residues are extracted using the current incremental growth of commercial growing stock. This does not include the cost comparison with alternative fuels. He concluded that at a global level the economic potential of all types of biomass residues is 14 EJ/y, or about 3% of current primary energy use.

Potential of non commercial fuelwood

There are around 2 billion people that rely on fuelwood for their basic energy supply. In around 16 countries the share of traditional biomass in the energy mixture is over 80%

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[2] Assessed at 25 – 85 €/m^3

(UNDP/UNDESA/WEC, 2000). Examples of such countries are Bhutan and Nepal. The use of fuelwood is difficult to estimate as mostly they are based on limited samples and per capita extrapolations. Projections for the future use are therefore also difficult to estimate. They depend on assumptions regarding economic development, population growth and technological development regarding e.g. cookstoves. Smeets et al., 2005 have made an overview of fuelwood estimates in various sources. This overview indicates that the current use of fuelwood is estimated at a level of around 1Gton fuelwood (around 16 EJ/y). For the short term (2020 – 2030) various estimates have been found, resulting in a range of around 1.1 – 2.3Gton of fuelwood (17 – 34 EJ/y). These values are in the order of a few percent of current total primary energy use. This is outside the scope of this assessment.

9.4.5 Global assessment

9.4.2.1 Summing the regional results

One approach here is to sum all regional results as presented in section 9.4.3 and 9.4.4 (Table 9.12).

Insert Table 9.12

Insert Figure 9.26.

Our overall results give a guesstimate of the economic potential under an approximate carbon price of 20US$/ton CO2 of some -0.5 to -1.2 Gt C /y-1 achievable by 2040 through af/reforestation, agro forestry and avoidance of deforestation. Most of this in the tropics and originating from avoided deforestation. Adding bio-energy options from forestry, the overall assessment comes to -1.1 to -1.7 Gt C /y by 2040.

Large uncertainty surrounds these results. This uncertainty originates from:
uncertainty over the use of different baselines
difference in methods and time frames applied in the studies
different or no economic assumptions
no insight in the use of baselines and the impact that the baseline might have on the assessment results
uncertainty over the long term forest dynamics and lack of data concerning
the assumptions concerning policies and measures and their additionality
the uncertainty how studies have distinguished between afforestation, avoided deforestation and bioenergy options.

All these together lead us to the conclusion that the most likely range of the assessment is in the very lower end of the ranges given above.

9.4.2.2 Other global assessments,

Other global assessments carried out with econometric and integrated land use models are available from Benitez et al (2005), Waterloo et al (2003) and Sathaye (2005). They provide us with independent estimates for the globe, harmonized across countries and regions. Furthermore, they provide us in some cases with more detailed insight in where the options are. Benitez et al (2005) have applied a gridded land cover database together with econometric modeling to arrive at global estimates for economic potential of carbon sequestration from afforestation and reforestation (Figure 9.27).

Insert Figure 9.27

They project that at a price of 50$/t C (13.6 $/t CO2) the annual sequestration from afforestation and reforestation for the first 20 years amounts on average to -0.14 Gt C/y. For the first 40 years, the average annual amounts to -0.22 Gt C /y. These are very well inline with our summation of regional results. They however found that most land becomes economically attractive in Africa with a cumulatively sequestered amount of 40 Gt C. The price range of 50US$/t C that Benitez et al (2005) use, should make carbon sequestration through afforestation and forest management an attractive land use option in many cases as it is in range of median values for costs that Richards and Stokes give with 3.75 to 47 US$/t C. Although Van Kooten et al. (2004) present marginal costs rising to tens of thousands of dollars per ton C.

Another assessment was carried out by Waterloo et al. (2003). They used a simpler modeling approach (areas times an emission factor) and applied various sets of constraints and certification levels, arriving in effect at an assessment of market potential (Table 9.13).

Insert Table 9.13

From their results it became clear that the potential sink for afforestation-reforestation is reduced to a large part when project success rates or CDM criteria are taken into account. Waterloo et al. (2003) project a cumulative sink of only -1.2 Gt C achievable under the CDM for the period 2000-2100 under rather stringent CDM criteria (market potential). Longer rotation period led to higher sequestration in the long-term and sustainability of this type of forestry might be easier to demonstrate than for a short-rotation. Highest afforestation/reforestation potential was identified for India, China and Brazil. The costs ranged from 2.22 (Democratic Republic of Congo) to 8.76 US$ per tonne C (Argentina) (no criteria adopted) to 4.27 to 46.73 US$ per t C (all criteria adopted). The regional costs in the latter case range from 7.31 US$ per t C for Africa to 28.25 US$ per t C in South America, respectively, using a 20% buffer. Figure 9.28 gives the regional distribution.

Insert Figure 9.28

Waterloo et al. (2003) also looked into deforestation avoidance options. Using a 1% annual deforestation avoidance rate, and a certification precision of 20%, Waterloo et al. (2003) estimate the cumulative emission avoidance globally for the period 2008-2012 at -0.114 Gt C. See for the Sathaye study, section 9.4.3 and Table 9.9. By 2050, they project cumulated carbon gains as an economic potential from afforestation and avoided deforestation together. Sathaye's results are much higher than in the Waterloo study, because they address economic potential. In the moderate carbon price ranges, the cumulated carbon gains by 2050 add up to -15 Gt C to -28 Gt C (-0.3 GtC /y to -0.56 Gt C /y). All these together lead us to the conclusion that the most likely range of the economic potential is in the very lower end of the ranges given in section 9.4.5.1, in Table 9.12, and in Figure 9.26 (see also 9.4.5.3.).

9.4.2.3 Putting the regional and global estimates in an economic perspective

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

Few studies within each of the three scales above, let alone across these scales, use consistent, directly comparable definitions, assumptions, and methods for estimation of mitigation potential. In addition, the eligibility of carbon pools, land use practices, and GHG accounting methods is likely to be specified by any given mitigation policy or program window (e.g., the Clean Development Mechanism under Article 12, or afforestation, reforestation, and deforestation national reporting under Article 3.3, of the Kyoto Protocol; the EU's Emissions Trading System) (Kolshus, 2001; Kurz et al, 2002).

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

Evaluating existing forestry mitigation estimates in terms of these mitigation potential types is challenging. Section 9.4.6 includes a box on a case study in India's Kolar region that presents a ten-village potential forestation project analysis in comparison to a reference case, finding that the socioeconomic potential in hectares is 45.7% of the estimated technical potential. Several major review articles compare bottom-up engineering cost estimates with top-down sectoral model estimates of national and global forestry mitigation potential (e.g., Richards and Stokes, 2004; Kolshus, 2001). These studies generally evaluate the economic potential response by forest land owners or users to a potential market price for GHG benefits (carbon price), and do not directly compare technical vs. economic potential estimates.

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

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

While the range of economic potential as a percentage of technical potential is 2%-150%, this ratio varies with the carbon price assumed: at carbon prices less than $25/tC, the highest estimate of economic potential is 16% of the technical potential. At carbon prices from $100/tC to $183/tC, the range of economic potential is estimated to be 58%-150% of the technical potential (Table 9.14).

Insert Table 9.14

9.5 Interactions with adaptation and vulnerability

Mitigation and adaptation have been considered separately in the global negotiations as well as in the literature. In the Third Assessment Report of IPCC mitigation was addressed in the Working Group III and impact and adaptation was considered in Working Group II and the potential synergy and trade-off issues were not addressed. There is a realization on the need to explore and promote synergy between mitigation and adaptation while addressing climate change. This section attempts to explore the synergy between mitigation and adaptation by considering the forest sector, which on the one hand is projected to be adversely impacted under the projected climate change scenarios and on the other provides opportunity to mitigate climate change (Ravindranath, 2005). Thus, the potential and need for incorporating adaptation strategies and practices in mitigation projects is presented with a few examples. Firstly, there is a need to ensure that mitigation programmes or projects do not increase the vulnerability of forest ecosystems and plantations. Secondly, several adaptation practices could be incorporated into mitigation projects to reduce vulnerability.

Is mitigation alone adequate? Now it is well known that even with the most ambitious mitigation policy, climate change seems likely to occur. Even under a most aggressive mitigation scenario, climate change is likely to leave an impact, particularly given the long life of different GHGs in the atmosphere (Bruce *et al.*, 1996). Thus, adaptation is a necessary strategy to complement mitigation efforts (IPCC 2002).

9.5.1 Climate Impacts and Adaptation

The forest ecosystems are subjected to many pressures such as land-use change, harvesting, over-grazing by livestock, fire, introduction of new species and natural climate variability. Climate change constitutes an additional pressure that could change or endanger these ecosystems. Chapters 4 and 5 of Working Group II have highlighted the potential impacts of climate change on forest ecosystems. They have confirmed the findings of Third Assessment Report. The future synergistic impacts of direct human-induced stresses and climate change will induce significant biodiversity loss. It is also virtually certain to drive the migration and dieback of tree species, resulting in changes in the geographic distribution of forest types, new combinations of species within forests, and to alter productivity . Modeling studies show potential significant disruption of ecosystems under climate change. Climate change can affect the species distribution and productivity of forest ecosystem, impacting on forestry operations (Gitay *et.al.*, 2001).

Given the likely adverse impacts of projected climate change, adaptation to climate impacts in the forest sector is critical, since climate change could cause irreversible damage to unique ecosystems and biodiversity, rendering species extinct, locally and globally (IPCC, 2001d). A detailed assessment of adaptation strategies in th forest sector is given in Chapters 4 and 5 of Working Group II of Assessment Report 4.

9.5.2 Mitigation and Adaptation Synergies

The mitigation and adaptation trade-offs and synergies are dealt with in detail in Chapter 18 of Working Group II. UNFCCC and Kyoto Protocol have led to several response strategies to address climate change. Some examples relevant to the LULUCF sector are: the Global Environmental Facility (GEF), Clean Development Mechanism (CDM), Activities under Article 3.3 (afforestation, reforestation and deforestation) and 3.4 (forest and grassland management, etc.), and the Adaptation Fund. Many of them aim at implementation of either mitigation or adaptation technologies or policies. New mechanisms to address mitigation and adaptation may emerge in the future. Thus, it is necessary to explore if a synergy is possible in planning and implementation of mitigation and adaptation projects to derive maximum benefit to the global environment as well as local communities or economies. The synergy is addressed with a few examples of mitigation and adaptation practices and projects. Further, climate change adaptation activities can promote conservation and sustainable use of biodiversity, and in turn conserve or enhance the carbon stocks in forest ecosystems (IPCC, 2002).

9.5.3 Incorporating Adaptation in Mitigation Projects

The ecological impacts of climate change mitigation such as afforestation are a key uncertainty with respect to their impacts on biodiversity and ecosystem functioning (Chapter V, Working Group II). LULUCF sector mitigation projects are already being implemented or are in the planning stage. Thus, there is a need to explore adaptation opportunities in the mitigation projects under forest conservation, afforestation, reforestation, fossil fuel substitution and other activities. Some of the opportunities to integrate adaptation in mitigation projects are presented (based on Ravindranath, 2005).

i) *Forest conservation*: Area under forests declined by around a net 9.3 Mha per year, resulting from deforestation to other land uses annually during 1990s (Table 9.1). Forest conservation projects aimed at halting deforestation and forest degradation, constitute important mitigation options (Section 9.4). Forests or plantations consisting of multiple species are also an attractive adaptation option as they are more resilient or less vulnerable due to different climate tolerance of different species, different migration abilities and effectiveness of invading species (IPCC, 2001b). Forest conservation is also a critical strategy to promote sustainable development due to its importance for biodiversity conservation, watershed protection and promotion of livelihoods of forest dependent communities (IPCC, 2002). A primary management adaptation is to reduce as many ancillary stresses on the forest resource as possible. Maintaining widely dispersed and viable populations of individual species minimizes the probability that localized catastrophic events will cause extinction (Chapter 4, Working Group II).

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

ii) Afforestation and reforestation: Afforestation and reforestation are the dominant mitigation opportunities, currently being pursued in the global negotiations and their mitigation potential is discussed in Section 9.4. Afforestation and reforestation activities are included under Article 3.3 as well as Article 12 (CDM) of the Kyoto Protocol. The annual area brought under afforestation globally is around 3.1 Mha annually during 1990s (FAO, 2001). There is a large opportunity to undertake afforestation and reforestation globally, particularly in tropical countries.

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

iii) Biomass energy plantations: Bioenergy requires production of biomass feedstock. Normally bioenergy plantations are likely to be intensively managed to produce biomass for energy. Refer to Section 9.4 and Chapter 8 of Working Group III for a detailed discussion on the biomass energy potential. To ensure sustainable supply of biomass feedstock and to reduce vulnerability to climate change it is necessary to adopt the practices mentioned above for afforestation and reforestation projects such as, rotation periods, salvaging dead timber, shifting to species more productive under the new climatic conditions, mixed species forestry, short rotation species and fire protection measures.

iv) Agro-forestry: Agro-forestry practices including perennial multi-purpose trees and leguminous species can reduce the vulnerability of crop production to climate change, particularly droughts. Agro-forestry provides a particular example of a set of innovative practices that are designed to enhance productivity in a way that often contributes to climate change mitigation through enhanced carbon sequestration, and that can also strengthen the systems ability to cope with adverse impacts of changing climate conditions. Agro-forestry management systems offer important opportunities creating synergies between actions undertaken for mitigation and activities undertaken for adaptation (Verchot et al, 2005). Agroforestry systems are receiving wider recognition not only in terms of agricultural sustainability but also in issues related to climate change. The area suitable for agroforestry is estimated to be 585-1215 Mha with a technical mitigation potential of 1.1-2.2 Pg C in terrestrial ecosystems over the next 50 years (Albrecht and Kandji, 2003). Agroforestry can also have an indirect effect on C sequestration when it helps decrease pressure on natural forests, which are the largest reservoir of terrestrial C. Another indirect avenue of C sequestration is through the use of agroforestry technologies for soil conservation, which could enhance C storage in trees and soils. Agroforestry systems with perennial crops may be important carbon sinks, while intensively managed agroforestry systems with annual crops are more similar to conventional agriculture (Montagnini and Nair, 2004).

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

Adaptation practices could be incorporated synergistically in most mitigation projects in the forest sector. Further, many of the mitigation projects such as forest conservation or protected area formation are also adaptation activities reducing the vulnerability of forest ecosystems. However, it is important to note that the mitigation strategies such as afforestation and reforestation could also have adverse implications for water yields in arid and semi-arid regions (UK FRP, 2005) and biodiversity (Caparros and Jacquemont 2003), particularly due to over planting of fast growing exotic species. Table 9.15 shows a qualitative ranking of forest activities in terms of their mitigation and adaptation potential.

Insert Table 9.15

9.5.4 Mitigation in adaptation strategies and projects

From the perspective of adaptation, there might be direct feedbacks with mitigation efforts (Adger, 2001), which can themselves serve as mitigation measures (Wheaton and Maciver, 1999). It must be noted that there is little information on how mitigation practices can be incorporated into any primarily an adaptation project. Some examples of adaptation options and practices, which also contribute to mitigation by reducing CO_2 emissions or sequestering carbon in adaptation projects, are as follows (Ravindranath, 2005):

- *Soil and water conservation*; a key adaptation practice aimed at reducing vulnerability also reduces carbon loss from soils as well as enhances soil carbon density by increasing biomass growth rate of forests or plantations or grassland.
- *Drought resistant varieties or clones*; not only reduce vulnerability of tree and grass species to droughts and water stress but also contribute to carbon sequestration.
- *Enhancing soil organic matter content*; through organic manuring to increase moisture retention and soil fertility, not only reduces the vulnerability to drought and moisture stress but also increases the carbon sequestration rates of tree as well as grass species.
- *Forest and biodiversity conservation;* through halting deforestation, expanding protected areas and adoption of sustainable harvest practices are important adaptation strategies to reduce vulnerability of forest ecosystems. All such programmes or practices could also be considered as mitigation options to conserve forest carbon sink.
- *Urban park and tree planting in residential compounds;* promotes adaptation to heat stress in urban areas by reducing air conditioning needs, also leads to carbon sequestration in trees and soil.
- *Agroforestry;* options may provide opportunity for mitigation along with promotion of adaptation (Verchot et al., 2005). Agroforestry is a means for diversifying production systems and increasing the adaptive capacity of smallholder farming systems. The most worrisome component of climate change from the point of view of smallholder farmers is increased interannual variability in rainfall and temperature. Tree-based systems have some obvious advantages for maintaining production during wetter and drier years. Thus, diversifying the production system to include a significant tree component may buffer against income risks associated with annul crops' productivity and climatic variability. Thus, potential synergy is high through agroforestry.

Thus, it is interesting to note the complementarity or synergy between many of the adaptation options and mitigation (Dang et al, 2003). However, there could be many dedicated adaptation strategies or practices which may be neutral or may reduce mitigation potential for example; mixed species forestry based afforestation, silvicultural practices such as thinning, sanitation harvest and fire protection.

9.5.5 Adaptation and mitigation synergy and sustainable development

The need for integration of mitigation and adaptation strategies to promote sustainable development is presented in Chapter 18 of Working Group II. 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, 2005). All the examples of adaptation practices in mitigation projects, such as forest and biodiversity conservation, are also strategies to promote sustainable development, even in the absence of climate change concerns.

It is necessary to address the synergy, and if any trade-offs, between mitigation and adaptation, while addressing climate change. No mitigation activity should increase the vulnerability of forest ecosystems, plantation forestry, food production, etc. Further, it is necessary to explore the possibility of incorporating adaptation practices into mitigation programmes and projects, to reduce vulnerability and enhance resilience of forests. Mitigation, through Kyoto Protocol activities under Article 3.3, 3.4 and particularly CDM under Article 12, provides an opportunity to incorporate adaptation practices. 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).

Currently, there are very few ongoing studies trying to understand the interaction between mitigation and adaptation (Wilbanks, 2003, Government of Australia, 2001 and Dang et al, 2003). There is inadequate knowledge about the potential synergy between mitigation and adaptation, particularly in the biological sectors such as agriculture and forestry. Quantification of synergy is necessary to convince the investors or policy makers (Dang et al, 2003). Thus, there is a need for research and field demonstration of the linkages and synergy between addressing climate impacts through adaptation and climate mitigation.

<start box 9.3>

Box 9.3 Early Lessons Learned from the BioCarbon Fund

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

Opened in May 2004, and with a capital of US$38.8 million (March 2005), the BioCF is currently preparing CDM documentation for twenty projects with a wide geographic and activity range (www.biocarbonfund.org). It expects its first emission reduction purchase agreements mid-2005. Early findings are that:

1. The supply of LULUCF projects grossly exceeds demand. Despite a willingness to pay of $3-$4/tCO_2e and though limited to A/R activities, the BioCF has received 130+ project ideas in 30 months, representing over 500 MtCO_2e of sequestration potential. Roughly 20% of these ideas are deemed viable, though not all can be supported at current level of capitalization.

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

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

4. Simple but reliable monitoring techniques with conservative assumptions often prove preferable. Remaining uncertainties in measurements can be addressed contractually by selling less than the quantity expected to be sequestered.

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

<end box 9.3>

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

This section examines the barriers, opportunities and implementation issues associated with policies affecting net emissions in the forestry sector. Considered are both climate policies that focus specifically at reducing net emissions from the forestry sector and the broader set integrated and non-climate policies that affect forest land use. Both may have substantial impacts on net emissions. For climate policies, particular emphasis is given to the evaluation of project experience in non-Annex 1 developing countries since the IPCC Special Report on Land-Use, Land-Use Change and Forestry (IPCC 2000).

9.6.1 Integrated and non-climate policies

Integrated and non-climate policies may substantially affect net emissions in the forestry sector by promoting conservation of existing carbon stocks, by increasing sequestration, or by motivating the substitution of bioenergy for fossil fuels or biomass to replace energy-intensive materials such as cement (Brown et al. 2000.). Many factors will influence their efficacy, including whether the forested land is publicly or privately owned, the institutional and regulatory capacity of the government, the financial competitiveness of forestry as a land use, and social and cultural factors with regards to a society's relation to forests and forestry. Some of these factors typically differ between industrialized and developing countries. Industrialized countries are often characterized by: relatively small amounts of public lands, of which little or none remain unallocated; and, relatively strong institutional and regulatory capacities. Developing countries are often characterized by: proportionately large amounts of public lands, much of which may still be unallocated to specific land uses; and, relatively weak institutional and regulatory capacities. Where appropriate, the following discussion separately examines policy options and effectiveness in industrialized and developing countries.

Because integrated and non-climate policies are designed primarily to achieve objectives other than net emissions reductions, evaluations of their effectiveness focus primarily on indicators, such as maintenance of forest cover, that provide only partial insight into their potential to mitigate climate change. Under conditions with high potential for leakage, for example, such indicators may overestimate the potential for net carbon benefits (section 9.6.1.4).

9.6.2.1 Integrated and non-climate forest policies to conserve existing carbon stocks

The primary means by which non-climate forest policies can conserve existing carbon stocks in forests are: changing the use of forested lands to land uses that retain greater forest cover; reducing harvest rates and harvest damage in forests allocated to timber or fuelwood production; and, reducing forest loss to natural disturbance agents such as fire, wind, insects and disease (Richards et al., in review).

Industrialized countries: On public lands, all three approaches to conserve existing forest stocks have been applied in industrialized countries. Although the land-use planning process is relatively complete in many countries, new allocations of forested land to protected areas are still taking place (e.g., the prohibition of logging in Queensland rainforest in Australia (Queensland Government, 2005)), and large allocations to conservation are still possible (e.g Canadian Boreal Initiative, 2003). Similarly, industrialized country governments have a long history of effectively regulating harvesting practices on public lands; thus, reducing harvest rates in timber production forests to conserve carbon stocks may be a viable policy option, particularly for countries where harvest rates have not already been reduced to manage for other forest values (Richards et al., in review).

Finally, there is considerable potential for increasing the conservation of existing forest carbon stocks by increasing the effective protection of forests against natural disturbance agents (Richards et al., in review). A history of fire suppression and a lack of thinning treatments have created high fuel loads in many public forests, such that when fires do occur, they release large quantities of carbon (Goldammer, 2001). Some public agencies are attempting to restore historic fire regimes in an effort to reduce damage to forests from catastrophic fires and avoid excessive suppression costs (Mutch et al., 1993). A major technical obstacle is designing careful management interventions to reduce fuel loading and to restore landscape heterogeneity to forest structure (Covington and Moore, 1994; USDA Forest Service, 2000). Scaling up their application to large forested areas, such as in the western US, northern Canada or Russian, could lead to large gains in the conservation of existing carbon stocks (Sizer et al., 2005). Pest outbreaks, storms, and wildlife grazing also release large amounts of forest carbon (MCPFE, 2003; Sizer et al., 2005), although prospective control measures have not been as well developed as in the case of fire management.

On private lands in industrialized countries, governments often have more limited regulatory authority, and so have relied upon providing incentives to maintain forest cover, or improve management. These incentives can take the form of tax credits, subsidies, cost sharing, contracts, technical assistance, and environmental service payments. In the United States, for example, several government programs promote the establishment, retention, and improved management of forest cover on private lands, often of marginal agricultural quality (Box 9.4; Gaddis et al., 1995).

Insert Box 9.4

Voluntary certification to sustainable forestry standards is an alternative approach to regulation of forest management of both public and private forests, and aims to improve forest management by providing incentives such as increased market access or price premiums to certified producers (Upton & Bass 1996). Thus far, this market-based approach to improving forest management has led to incremental improvements in forest management in industrialized countries, largely because certification has been sought primarily for forests already managed to a relatively high standard (Ozinga, 2004).

Developing countries: In many forest-rich developing countries, the policy challenges to maintaining carbon stocks in public forests are daunting. In the face of profitability incentives that run counter to forest conservation and sustainable forest management (Clark, 1973; Rice et al., 1997), multiple additional direct and indirect drivers of deforestation (Angelsen & Kaimowitz 1999; Roper & Roberts 1999; Lambin et al., 2003) and limited regulatory and institutional capacity, forest policies at many levels have made little progress in slowing the overall loss of public forests or improving forest management (Rudel, 2001). Some major policy initiatives include:

- A variety of international forest policy processes such as the United Nations Forum on Forests, The Tropical Forest Action Plan, and the International Tropical Timber Organization have led to little measurable impacts on slowing deforestation or improving forest management (Speth, 2002), although it is plausible that these processes have supported national forest planning efforts (Mankin, 1998).
- Although trade liberalization in forest products can enhance competition and can make improved forest management practices more economically attractive in mature markets (Clarke,

2000), in the relatively immature markets of many developing countries, liberalization may act to magnify the effects of policy and market failures (Sizer et al., 1999).

- Multilateral lending agencies such as the World Bank have modified their lending policies to reduce the risk of direct negative impacts to forests, but they do not appear to have measurably slowed deforestation (WBOED, 2000). Structural adjustments imposed as conditions of loans may also continue to be an indirect driver of deforestation in some areas (Angelsen and Kaimowitz, 1999; Tockman, 2001). The World Bank has recently adopted a new forest strategy that seeks to expand protected areas, protect environmental services provided by forests, and integrate forests outside of protected areas in to sustainable economic development (World Bank, 2003). The World Bank and G-8 have also recently initiated the Forest Law Enforcement and Governance (FLEG) process among producer and consumer nations to combat illegal logging in Asia and Africa (World Bank, 2005). It is too early to assess the effectiveness of these initiatives in conserving forest stocks.
- The Global Environmental Facility has commissioned several independent evaluations of its performance during the first fourteen years of operations. A major conclusion is that while the project portfolio has likely made significant contributions to biodiversity conservation (including forests), assessing measurable impacts has been limited by the lack of an effective monitoring program (Christoffersen et al., 2002; Dublin and Volante, 2004).

At the national level, a variety of approaches have been developed to maintain forest cover, including:

- Reducing drivers of deforestation: Poverty, landlessness, distorted agricultural policies, structural adjustment, population growth, lack of political will, and under funded environment agencies are just some of the factors that have been shown to contribute to deforestation in developing countries. Despite knowledge of the severity of the problem and its environmental consequences, little progress has been made in slowing clearing rates, perhaps due to the complexity of causes (Rudel, 2001). Even the removal of policies that lead directly to deforestation, such as subsidies to ranchers, or settlement schemes, has not demonstrably slowed forest loss. Indeed, deforestation rates in 2003/4 were near record highs in some countries such as Brazil (INPE, 2005).
- Illegal logging is a particularly prominent driver of forest degradation and deforestation in some countries. Illegal logging increases loss of existing forest stocks both through harvest and direct damage to forest biomass (Panfil and& Gullison, 1998), and may indirectly catalyze deforestation by providing access to forested land, speeding its conversion to agriculture (Verissimo et al., 1995) and increasing its susceptibility to fires (Nepstad et al., 1999). A number of national initiatives are underway to combat illegal logging (e.g., Consulate General of Brazil, 2005; Sizer, 2005). While these have increased the number of charges and convictions, it is too early to assess their impact on forest conservation.
- Where deforestation rates have slowed, important contributing factors include geographic constraints (e.g., Thailand (Granger, 1995)), increased political will generated by devastating environmental consequences of deforestation (e.g., China (Cohen et al., 2002), Philippines (Granger, 1995)), and economic recession reducing available funding for public infrastructure projects and private investments (Fearnside, 2005).
- Allocating public land to uses that increase conservation of existing forests: such uses include protected areas, indigenous reserves, non-timber forest reserves and community reserves. The effectiveness of this strategy is mixed. In some places, protected areas and indigenous reserves have protected forests, while in others, a lack of resources and personnel result in the conversion of legally protected forests to other land uses (Bruner et al., 2001; Kainer et al., 2003; Mertens et al., 2004). Current limitations on the ability to assess the effectiveness of this ap-

proach to conserving forest stocks includes the lack of a comprehensive system for monitoring the management effectiveness of protected areas (Chape et al., 2005), and little information to assess the extent of leakage resulting from potential displacement of deforestation to less well-protected forests.

- Improving forest management: the lack of robust institutional and regulatory frameworks, of trained personnel and secure land tenure have constrained the role that sustainable forestry has played in conserving forest stocks in many developing countries (Box 9.5). Africa, for example, had c. 649 million forested hectares as of 2000 (FAO, 2002a). Of this, only 5.5 million ha (0.8%) had long-term management plans, and only 0.9 million ha (0.1%) were certified to sound forestry standards. In contrast, illegal logging is a major driver of deforestation in Africa (WWF, 2005), catalyzing the loss of 5.2 million ha of forests to deforestation over the period 1990-2000 (FAO, 2002b). Thus far, efforts to improve logging practices have met with limited success. For example, reduce-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 (Durst and Enters 2001, Holmes et al., 2002).
- Reducing emissions from natural disturbance: As in industrialized countries, natural disturbance agents, particularly fire, release large stores of carbon each year in developing countries (Goldammer, 2001). Logging and forest fragmentation greatly increase the susceptibility of forest to fire, and loss to fire is expected to increase as climate change impacts are felt (Nepstad et al., 1999). However, most developing countries currently have limited fire suppression capacity (GFMC, 2003).

Insert Box 9.5

Thus far, voluntary certification has made few inroads in conserving existing natural forest stocks in developing countries, as majority of certified forests have been plantations (Gullison, 2003; Ozinga, 2004).

Options for maintaining carbon stocks on private lands in developing countries are more limited than on public lands, as governments typically have less regulatory control. Efforts to require the retention of forest cover on private lands have had limited effectiveness (e.g., Brazil: Alves *et al.*, 1999). There are several examples of governments making environmental service payments to private forest owners in developing countries, thereby providing a direct financial incentive for the retention of forest cover. High transaction costs and insecure land and resource tenure have limited applications (Grieg-Gran, 2004), but significant potential may exist for developing national payment schemes for restoration and retention of forest cover to provide watershed protection services (Reid, 1999; Winrock International, 2004).

In developing countries where significant quantities of forests are privately-owned, efforts to reduce emissions from natural disturbance (e.g., accidental fire) may yield considerable benefits, providing that they are backed up with effective enforcement or incentive programs (e.g., the fire permitting system described for Brazil in Fearnside 2005).

9.6.2.2 Integrated and non-climate forest policies to increase sequestration

Non-climate forest policies can increase carbon sequestration by encouraging the reforestation or afforestation of land that currently lacks forest cover, and by changing forest management to increase sequestration rates, for example by changing species mix, lengthening rotations, or accelerating replanting rates (Richards et al. in review). Some changes, such as faster replanting, may align with underlying profitability incentives. Where this is the case, the magnitude of regulatory effort or financial incentives that policies will require for successful implementation will be substantially less than those required to maintain carbon stores. Other changes, such as lengthening rotation periods, are likely to run counter to underlying profitability incentives (Brown 2000), and therefore may require larger incentives or more regulation to achieve significant uptake.

Creating new forests: there is a long history of the successful creation of plantation forests on both public and private lands in developing and developed countries. As of 2000, the global plantation estate was estimated to be c. 186 million ha, with annual planting rates of new forests of 4.5 million ha y^{-1} (FAO, 2000).
If governments have strong regulatory and institutional capacities, they may successfully control land use on public lands, and reforest these lands directly. In cases where the state presence is weak, governments may enter into joint management agreements with communities, so that both the costs and benefits of plantation establishment on public lands are shared (Williams, 2002).

Governments may choose to subsidize the establishment of plantations on private lands in cases where social returns from plantation establishment (e.g., from watershed protection, carbon sequestration, and soil protection) exceed private returns (Enters *et al.,* 2003). 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). 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 (Cossalter and Pye-Smith, 2003). Third-party certification to sustainable forestry standards has made considerable inroads in plantation forestry, even in developing countries. However, as is the case of certification of natural forest management, it is the plantations that already had the highest standards of management which thus far have sought certification, such that certification's impact on plantation management has been limited (Gullison, 2003; Ozinga, 2004).

Changing forest management: the relatively high standards of forest management in the public forests of developed countries may limit the possibilities for increasing sequestration through changing management practices (e.g., by faster replanting after harvest). Furthermore, current forest management reflects planning for multiple uses, including generating environmental and social benefits, and public opposition might be expected to major changes that increased carbon sequestration, but negatively impacted other values (Richards *et al.*, in review). On private lands, management standards often are lower, particularly for small landowners. Here, governments have a broad range of effective policy tools for influencing management (Section 9.6.1.1)).

As discussed in Sections 9.6.1.1, the potential gains in sequestration from improving forest management in developing countries are substantial. However, progress in improving the management of natural forests has been slow. This is because the regulatory and institutional capacities of developing countries are often insufficient to counter strong financial incentives for over harvest, and because financial incentives to invest in future harvest are often limited (Rice *et al.,* 1997). Nevertheless, there are a few examples where large investments in building technical and institutional capacity have dramatically improved forestry practices (e.g., in Bolivia (Rainforest Alliance, 2005)).

9.6.2.3 Integrated and non-climate policies to increase substitution of forest-derived biofuels for fossil fuels and biomass for energy-intensive materials.

Countries may promote the use of bioenergy for many reasons, including reducing greenhouse gas emissions, increasing energy security, achieving other environmental goals such as improving air quality, and promoting rural development (Parris, 2004). The use of forestry feedstock for bioenergy may also generate a number of additional benefits (Stokes *et al.*, 2004). Wood processing creates large amounts of waste that leads to costly disposal problems, and so a reduction in disposal costs helps make the production of bioenergy financially attractive. Harvesting waste from forests can play an important role in reducing fire risk, reducing emissions from prescribed burning, reducing costs of fire treatment, as well as leading to gains in the conservation of carbon stores in existing forests.

Biomass is already an important source of industrial energy in some countries. In the U.S., for example, energy derived from biomass accounts for some 3% of total energy use, and exceeds the contribution of hydroelectric power and all other types of renewable energy (USDE, 2005). At present, forestry waste is a large source of biomass energy. It is used by the pulp and paper industry to generate industrial steam and heat, and burned in combination with municipal solid waste to generate electricity. Although most current biomass power systems are direct-fired – in other words, biomass is burned to heat water and produce steam, which in turn is introduced into turbines to produce electricity – more efficient technologies are possible. Biomass can be burned with coal in coal power plants at higher efficiencies than when direct fired, while significantly reducing emissions to air from the power plant. Gasification systems are under development to use heat to break down biomass and produce a flammable gas that can be cleaned and purified, and then burned in highly efficient combined-cycle turbines.

The importance of ethanol and biodiesel is also growing quickly, although these are currently derived from agricultural crops (USDE, 2005). Commercial applications for breaking down cellulosic biomass such as forestry waste to produce ethanol are under development.

Governments have used a variety of approaches to support the development and maintenance of their biomass industries. In Brazil, for example, the government 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 U.S. government 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 (USDE, 2005). In addition, governments invest in research that reduces the cost of developing commercial applications for emerging biomass technologies. Life cycle assessment methodologies that could form the basis for formulating policies to promote the use of wood over more energy-intensive building materials are still in early stages of development (e.g., see Trusty and Meil, 2001; Lippke *et al.*, 2004).

9.6.2.4 Policy considerations

Policies have been generally most successful in changing forestry activities where either they align with and amplify underlying profitability incentives, or where there is sufficient political will and regulatory and institutional capacity for effective enforcement. Available evidence suggests that policies that seek to alter forestry activities where these conditions do not apply have had limited effectiveness.

Policies with the greatest potential to reduce net emissions would also (1) provide relatively large net reductions per unit area (2) be potentially applicable at a large geographic scale and (3) have relatively low leakage (Brown et al., 2000; 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 the use of environmental service payments to encourage the retention of forests. In both cases there are good examples where they have been successfully implemented at small scales, and the impediments to increasing scale are well-understood. There is also a successful history of policies to create new forests, and these have lead to the large onsite reductions in net emissions. Care must be taken however to make sure that at plantation creation, there is no displacement of economic or subsistence activities that will lead to new forest clearing elsewhere. Policies to increase the substitution of fossil fuels with bioenergy have also had a large positive impact on net emissions. If feedstock is forestry waste, then there is little potential leakage. If new plantations are created for biofuel, then care must be taken to reduce leakage.

Notably and despite considerable effort, integrated and non-climate policies have had minimal impact on slowing tropical deforestation, the single largest contribution of land-use change to global carbon emissions (IPCC AR4, Working Group 1 Chapter 7, in review). Given the relatively weak regulatory and institutional capacity of many forest-rich developing countries, well-constructed carbon markets (9.6.2, Santilli et al., 2005) or other environmental service payment schemes aimed at providing a countervailing financial incentive to over harvesting and forest conversion may offer greater promise of success than approaches that rely upon regulation alone. Here too, care must be taken to reduce potential leakage (Brown et al 2000, Niesten et al., 2002).

Start BOX 9.4

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

Many programs in the United States support the establishment, retention, and improved management of forest cover on private lands, which comprise approximately 60 % of the land base, 70% in the contiguous 48 states. These are administered primarily through the US Department of Agriculture (USDA) and entail contracts and subsidies to private landowners to improve or change land use management practices. The USDA also provides technical information, research services, cost-sharing and other financial incentives to improve land management practices, including foresting marginal agricultural lands, and improving the management of existing of forests. Examples include the Conservation Reserve Program; the Forestry Incentives Program; Partners for Wildlife; Conservation Reserve Enhancement Program; and the Forest Legacy Program (Gaddis et al 1995, Richards et al in review). For example, in the twenty year period between 1974 – 1994, the Forestry Incentives Program spent US $200 million to fund 3.32 million acres of tree planting, 1.45 million acres of stand improvement, and 0.27 million acres of site preparation for natural regeneration (Gaddis et al. 1995). Similar financial incentives in the European Union between 1994 and 1999 led to the afforestation of about 1 million ha of agricultural land (European Commission 2003).

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

End box 9.4

Start Box 9.5

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

The African countries display a great diversity of geographical features, cultures and people. The history of many African countries varies from former British colonies, to national governments which impacts institutional capacity, policies, centralization and decentralization. Institutional arrangements shape the policies related to access to and use of natural resources. Land and resource tenure underwent various changes during the 20th century (IUCN 2002, IUCN 2004).

Historically, land use policies in Africa passed through two types of governance: Under *traditional systems controlled by families, traditional leaders and communities*, decisions regarding land allocation, redistribution and protection were the responsibility of traditional leaders. Land and the resources on it were under relatively sustainable management where resource management was in an integrated form. Most communities were either nomadic or agro-pastoralist who developed systems to cope with vulnerable conditions. The customary management system continued regulations and customary laws used as instruments for implementation of the management systems of the land and the natural resources. Agricultural land was limited to shifting cultivation and the forests and range resources were managed for multiple benefits.

Under government systems controlled by central governments, land-use policies are sectorally-focussed. Some sectors like agriculture have had relatively strong governance. Agriculture expansion policies typically dominate land use at the expense of forestry and range land management. The dominance of agriculture on land use has greatly influenced present day forest and range policies and practices and resulted in vast land degradation.

The adoption of centralized land management policies and legislation system has often brought previously community-oriented land management systems into national frameworks without the consent and involvement of the local communities. The central control on the national land is reflected in the large protected areas with the prevention of the entry of local communities.

Presently contradiction and conflicts in land use practices as between sectors and between sectors and communities is a common feature that negatively impacts sustainability of land and resource management. Many conflicts have resulted in wars and subsequent negotiations demanding decentralization and equity in resource distribution. The results may be expected to lead to changes in land tenure systems in which communities and official organizations will increasingly agree to collaboration and joint management regimes. Many countries have positively changed attitudes to decentralization as a result of greater involvement of civil societies.

In some countries, parastatal institutions have been established to formulate and implement policies and legislations that coordinate between sectors and to encourage community participation in land and resource management.

Three categories of land tenure may be identified. Private holdings (5 – 25 % of country's area), Communal land (usually very small percent) and State (the majority of the land under government control). Each faces many problems generated by conflicting rights of use and legislation that give greater government control on types of resource use even under conditions of private ownership.

Land control system and land allocation policy adopted by central governments have negative impacts on land and tree tenure. Local communities are not encouraged to plant, conserve and manage trees on land perceived as government. Even large scale farmers who are allocated large areas for cultivation, abandon the land and leave it as bare when it is becoming non-productive. The land is government owned and the farmers use it on lease system. Trees on small holdings privately owned land are protected and managed for multipurpose by the land lord or the families. Also forest lands reserved and registered under community ownership are communally managed on the basis of stakeholder system and shared benefits.

Many case studies in Sudan indicate acceptance of integrated forest management based on collaborative management in which communities have rights to forests and are involved in management. The approach indicates that communities have secured rights to access and values from forests. They represent case studies on collaborative management of natural forest reserves based on negotiations and agreements between the communities and the forest authorities under the assistance of donor funded projects. Elrawashda Natural Forest Reserve shown below is an example:

Rehabilitation of Elrwashda Natural Forest Reserve (Eastern Sudan) Experience.

There has been positive development towards successful involvement of the local people, living around Elrwashda forest reserve, in the rehabilitation and development process of the forest reserve. The FAO project (FAO/SUD/FDES) from its start in 1980 clearly defined the objectives of rehabilitation of the forest involving the local villagers. During the rehabilitation process, the villagers will have access to agricultural land, grazing land and water points in an agroforestry system involving crops and tree seed cultivation on the same piece of land. Forest seedlings survival counts indicated very high rates of survival during the first year. The rehabilitation employed a mixed cultivation of agriculture and forest crops in the same piece of land with the forest crop.

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

End box 9.5.

9.6.2 Climate policies

9.6.2.1 Project-based experience since 2000

Due to uncertainty over regulation, few land use projects have been undertaken since 2000. Clean Development Mechanism (CDM) afforestation and reforestation (A/R) was not operational before September 2004, when the first call for methodologies was issued by the CDM Executive Board. COP 9 decision 19/CP.9, according to which CDM A/R projects will only generate expiring certificates, has additionally dampened investors’ interest.

Projects in Annex I countries are subject to fewer limitations. In principle, all land-use related activities are eligible for crediting. Furthermore, the credits generated do not expire, because governments will remain responsible for the maintenance of the carbon stocks once built up on their territories.

The World Bank Carbon Finance Unit has ventured several LULUCF projects within their Prototype Carbon Fund. The first one going public was Plantar, which consisted in avoiding fuel change from charcoal to coke. In this context, the Plantar Group is increasing the supply of legally produced charcoal from eucalyptus by new afforestation. This project was heavily criticized by environmental NGOs and has thus far not been submitted to the CDM Executive Board. The Community Development Fund is open to small-scale LULUCF projects, but has none in its portfolio yet. The Italian Carbon Fund, which is also managed by the World Bank, does not exclude LULUCF projects either, to the contrary of most other national funds.

9.6.2.1.1 Carbon issues

Most projects developed before 2003 departed from CO_2 removals to be accounted as permanent credits. This is legitimate in the case of JI projects, the first credits for which will be issued after 2008. However, host countries may show themselves reluctant to taking over the long-term liability for carbon stocks once installed without substantive credit sharing. The European Union Emissions Trading Scheme for its pre-Kyoto period 2005 – 2007 refrains from converting any forest-related credits into European Allowance Units; be they from JI or CDM (EU 2003). Since COP 9 in its Decision 19/CP.9 on modalities and procedures for A/R projects (UNFCCC 2003) has limited the validity of the respective Certified Emission Reductions, (“long-term” or “temporary” CERs, respectively), their value critically depends on the market participants’ expectations on future commitment periods and is estimated to range between 14 and 35 percent the one of “normal” CERs during the first commitment period (Dutschke et al. 2005). Thus, given high transaction costs, the contribution to a project’s finance is minimal, and consequently additionality is difficult to determine (van Vliet et al. 2003).

9.6.2.1.2 Social Issues

Literature stresses the importance of social issues for LULUCF projects. While on the one hand, LULUCF activities have the potential to improve local livelihoods, most of all in developing countries, risks and benefits are seen to be unevenly spread between different project types. Under this aspect, there is a noticeable preference for agro-forestry projects (Smith & Scherr 2003; May, Boyd et al. 2004). Among the most important risks there is land use competition, ownership concentration, and resource access by indigenous populations (Orlando et al. 2002). Under CDM A/R, an analysis of socio-economic impacts is required, and an impact assessment is due, if one of the project participants or the host country party considers these impacts significant (UNFCCC 2003). Several sets of criteria have been proposed to assess these impacts. LULUCF projects are seen to vastly improve local livelihoods, reasons being that they potentially imply large areas under competing land uses and largely adopt traditional techniques (Robledo & Blaser 2001). Ten different areas of concern are identified: “(1) identification of social groups and social system; (2) land tenure and land-use rights; (3) perception of affected social groups; (4) credibility; (5) participation; (6) social acceptance; (7) communication; (8) local capacity building; (9) equity; and (10) livelihood improvement.” (Madlenera et al. 2003).

9.6.2.1.3 Environmental issues

For climate projects, the atmospheric benefit is the market indicator for one single environmental service (Smith & Scherr 2003), which is checked when assessing project additionality. Nevertheless, LULUCF implies a series of environmental externalities. Indicators for these are the project’s impact on water resources, soils (beyond carbon content), biodiversity and environmental education

(May et al. 2004). Biodiversity conservation is among the targets defined in Art. 2 of the ultimate objective of the UNFCCC (“allowing ecosystems to adapt naturally to climate change”) (Ott,et al. 2004), and there is an indirect reference to it in Art. 2.1 (ii) of the Kyoto Protocol (Smith & Scherr 2003). As for social issues, the CDM A/R modalities and procedures require an environmental impact analysis and an assessment if one of the project participants or the host country party deems this appropriate (UNFCCC 2003).

9.6.2.1.4 Project examples

The Romania Afforestation of Degraded Agricultural Land Project is designed to reforest 6,728 ha in the Danube floodplains that had been used for intensive agriculture. It was planned by Winrock International and implemented by the Romanian National Forest Administration (NFA) with support from the World Bank’s Prototype Carbon Fund (PCF) as a Joint Implementation project under Kyoto Protocol Article 6 to produce Removal Units from 2008 (PCF 2002). Determination was carried out by TÜV Süddeutschland.

The project areas were heavily degraded by their former use for extensive cattle grazing. The NFA owns 1,700 ha, the rest being in the hands of the State Domain Agency. Depending on specific site productivity, a mixture of native Poplar and Willow (40.5%), Robinia, naturalized for several centuries (51%) Oak and other broadleaves (8.5%) was planted between 2002 and 2005. Out of the total project area, 4,348 ha are restoration areas, where no harvesting will take place. Including harvest and timber use in the remaining areas, the overall IRR was estimated to be 2.04% and considered so low that the project was not commercially viable without carbon credits. The PCF agreed to a price of 3.50 USD during the first commitment period for the first twelve years and 3.82 USD per tonne CO_2 thereafter (Brown et al. 2002). There is a high risk of leakage caused by the NFA disregarding its legal reforestation duties in other parts of the country, and of shifting grazing practices to increase devegetation outside the project boundaries (Kapp et al. 2002).. Illegal felling will be monitored. The creation of income for poor landless people dwelling around the project area is likely to mitigate risks from invasion and shifting devegetation (Ellis 2003)

The Mexican “Scolel Te” served as a model project for developing the Plan Vivo method for agroforestry. It was jointly developed in and implemented by the Edinburgh Centre for Carbon Management (ECCM) and its local partner, the Colegio de la Frontera Sur (ECOSUR), and the Fondo BioClimatico, and it was registered under the Activities Implemented Jointly (http://unfccc.int/kyoto_mechanisms/aij/activities_implemented_jointly/items/1785txt.php).

In 1997, the local project participant started by organizing 40 peasants. This number has rapidly increased up to 400 in 15 mainly indigenous communities. In single contracts, these commit to afforest or reforest part of their properties. A management plan specifying areas and species is designed according to the peasants’ individual necessities, in dialogue with the project developer. These management plans form the basis of the carbon contract. Due to the peasants’ preferences, exotic, fast-growing species were chosen to a much higher degree than initially planned by the project ECCM and ECOSUR, which in 1998 founded a promotional organization called Ambio. In compensation for their forestry activity, peasants receive project-specific carbon credits based on the results of growth monitoring, scheduled over five to ten years. The Fondo BioClimatico serves as the buyer of these credits. While in principle payments are only due for carbon removal achieved, upfront payments do occur in exceptional cases. 10 percent of the carbon credits are retained as a buffer against unexpected losses. Each peasant has a “carbon savings account”, on which the sequestration success and the respective value of payment are reported. The total project area is dynamic; peasants are constantly joining, but in some cases, participating farmers log off too, in which case refunding of carbon payments received is due. The afforestation area per farmer hardly surpasses one area. Agricultural area losses are in many cases compensated by increased yields, due to the proximity of trees. Dynamic boundaries constitute a challenge to monitoring. Monitoring is achieved through locally trained staff, and cross-checks are carried out by the technical team of ECCM and ECOSUR (Brown & Corbera 2003).

Plan Vivo as a replicable model: Due to high transaction costs, Scolel Te´s price per ton of CO_2 equivalent is rather high. The nominal price of 3.55 USD is only achieved, because the bulk of costs for project development, validation and verification is taken over by the UK Department for International Development (DIFID) and other public donors. ECCM is developing a follow-up project based on the Plan Vivo concept, by the name of “Bagepalli CDM Afforestation Programme” in the Indian State of Bangalore. It is designed to be a small-scale unilateral project carried out by an organization called “Women for Sustainable Development” (http://www.climateindia.com). The price per ton of CO_2 equivalent is estimated at 10 – 12 EUR. Other Plan Vivo projects are currently under development in Uganda, Mozambique, South Africa and Bhutan (Anonymous 2000; Phillips et al. 2002).

9.6.2.1.5 Methodology development

As noted above, little experience has been gathered with CDM project activities. Out of the methodologies to be submitted for the first ten CDM A/R projects, only one was approved in 2005. Among those, there are seven forest restoration activities, most of which include commercial harvesting. The remaining three are agro-forestry or silvo-pastoril activities. Their size varies between 523 and 19,000 ha. All except for two were started between the years 2000 and 2005. Only two projects decided for tCER accounting, six for lCERs, and two Project Design Documents (PDDs) were silent on the issue. Lifetimes range between 20 and 60 years, the expected lifetime CERs are summing up to 18 Mt temporary CO_2 equivalents. Size and CER value does not necessarily correlate, as the latter depend on growth conditions, tree species and management practices.

Methodological problems were due in many cases to a lack of understanding of the complex modalities and procedures, and terminology, most of all where these deviate from the ones applicable under GHG source reduction projects. The treatment of leakage was often unclear. On the one hand, climate beneficial “spill-over” effects were erroneously accounted for. Doubts remained over the treatment of non-CO_2 emissions in the reference scenario. This is the case where the project activity does not influence the occurrence of non-CO_2 gases found before the project start. This is so, for example, in silvo-pastoral systems, where ruminant methane emissions are not accounted for in the baseline, but according to modalities and procedures would account as project emissions under the project scenario. The same case occurs if woodland is reforested, where traditionally charcoal is being produced by local dwellers. Once the project produces fuel wood from sustainable sources, unchanged methane emissions from kilns would have to be accounted for as project emissions.

9.6.2.2 Technical progress since the LULUCF SR

9.6.2.2.1 Leakage

Leakage is the term used for measurable external GHG effects attributable to a determined climate change mitigation activity outside its boundaries. There is no indication that leakage effects are necessarily higher in either GHG emission reduction or removal, but they can be significant in LULUCF (Chomitz 2002).

Some authors distinguish between primary and secondary effects. A primary effect is defined as resulting from activities of the “baseline agents”. Populations previously active on the project area may shift their activities to other areas. Also logging companies could buy timber from outside the area to complement the lack of supply (“outsourcing” of activity). Secondary leakage activities are not linked to project participants or previous actors on the area. This could be the case with market effects, where the project increases (as in the case of A/R) or decreases (deforestation avoidance, FM) wood supply. Also super-acceptance, i.e. an influx of population, can constitute secondary leakage (Aukland et al. 2003). The order of magnitude and even the direction (negative vs. positive) of leakage however depends on the actual project design (Schwarze et al. 2003).

Under the CDM, the definition for leakage used in UNFCCC Decision 19/CP.9 is deviating from the one for GHG emission reduction projects in Decision 17/CP.7. First, because A/R project boundaries are strictly geographic; and project-related activities like road transport are accounted for as leakage. While GHG source reduction projects allow for measurable and attributable GHG emission reductions outside the project boundaries (positive leakage) to be accounted towards its certified reductions achieved, this is not the case with A/R projects. Only measurable and attributable increases in emissions by sources outside the boundaries however lead to a discount from the credits produced. Accounting under decision 19/CP.9 is somewhat imbalanced: Net anthropogenic GHG removals by sinks are defined as the sum of carbon stock changes minus GHG project emissions, minus leakage.

There is an extensive body of literature estimating market leakage in the context of LULUCF (Chomitz 2002; Murray et al. 2002; Aukland, et al. 2003; Schwarze et al. 2003; Sohngen & Brown 2004; Vöhringer et al. 2004). Nevertheless, as under CDM A/R only emissions and not stock changes outside the project area are being accounted for, market leakage is hardly an issue in the first commitment period. Project emissions unrelated to stock change, like from the use of fossil fuels and fertilizer, are internally compensated by deducting them from the tCERs or lCERs produced. On the one hand, this procedure is biased towards the tCER model, as the deductions only take place over one certification period. On the other hand, “permanent” project emissions are accounted against non-permanent CERs (Pedroni 2004).

Not all of the above is related to leakage only, but as the boundary definition is so restricted, important parts of the core activity may be accounted for as leakage. An example for this is the case of a silvo-pastoral system, where tree planting on an area used for grazing leads to the establishment of a forest, and cattle grazing is continued. This is the case of the methodology submitted as ANM0004 to the CDM Executive Board “Methodology for estimating changes in carbon stocks in the baseline scenario of proposed project activities of afforestation on grassland sites, combined with livestock intensification” The baseline net GHG removals by sinks do not account for pre-project emissions. However, if the ruminants remain on the area, their methane emissions will have to be accounted for as project emissions. If they are moved to pastures outside the project area, this will lead to project emissions, even though what the atmosphere sees remains unchanged.

9.6.2.2.2 Additionality and baselines

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

9.6.2.2.3 Permanence

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

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

Decision 19/CP.9 (UNFCCC 2003) created two types of CERs to reflect the potential non-permanence of carbon sequestration in A/R projects. These are temporary CERs (tCERs) and long-term CERs (lCERs). Both credit types have in common that their validity is limited and notified on the actual certificate. After the end of their validity, they have to be replaced. While tCERs expire after five years, lCERs expire at the end of the last full crediting period covered by the project crediting period. This means that in general tCERs cover one period more than lCERs under the same circumstances. Replacement of tCERs can be done by any other type of emission allowance except for lCERs. Also, newly certified tCERs are accepted as a replacement for used tCERs. LCERs, on the other hand, can only be replaced by non-expiring allowances. Another common feature is that the buyer does not hold any liability during the commitment period in which they were certified. A/R projects need to be verified first at a point in time at the discretion of the project participants, and exactly every five years thereafter. In the following commitment period, the holder is liable for replacement of the tCERs submitted for compliance. Unused tCERs expire as well, but they do not need a replacement. LCERs unused during the commitment period in which they were certified cannot be used for compensation any longer. If a negative stock variation is assessed by the verifier between two verification dates, the respective part of lCERs stemming from the project will be cancelled and have to be replaced in the subsequent commitment period (Table 9.16). In spite of their longer validity, lCERs show several drawbacks, compared to tCERs (Benítez & Olschewski 2005; Dutschke et al. 2005; Olschewskia et al. 2005).

Insert Table 9.16

9.6.2.2.4 Project quality standardization

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

9.6.2.2.5 Proposed options for reducing emissions from deforestation.

In 2003, the Brazilian Instituto de Pesquisa Amazônica (IPAM) tabled a novel proposal of “compensated reductions” for deforestation avoidance of standing forests in developing countries. (Santilli et al. 2003b; Santilli et al. 2003a; Carvalho et al. 2004). Host countries would commit to the stabilization of historical deforestation rates. Based on ex-post monitoring of deforestation as compared to previous periods, emission allowances would be created and sold directly to Annex I governments or investors. According to the initial proposal, these could use part of these allowances for the compliance with their target in the first commitment period, while the rest would be valid for subsequent periods. Once allowances were transferred, the developing country party would agree to further reduce, or at least not to increase deforestation in future commitment periods.

Sectoral caps have the potential for significant reductions in transaction costs (Michaelowa et al. 2003). The IPAM proposal however is not yet explicit over problems of liability, monitoring, and national governance. Decreasing the national deforestation rate must be considered a country commitment, because investors cannot be held liable for policy failure. But also climate-change related run-off effects may occur in spite of efficient policies and measures to halt direct human-induced deforestation. It is unclear whether and how developing country governments should held liable for these effects. Morever, avoiding deforestation could still disregard ongoing devegetation, which could at one point in time result in unforeseeable deforestation once the forest cover density crosses the threshold value for forest definition.

The underlying problem is that forest inventories are often unreliable (Kleinn et al. 2002), and the investors may not be willing to pay for large-scale monitoring. Also the allocation of the funds received for deforestation avoidance will need a concentration on “hotspot” regions of high deforestation rates to be most effective. Carbon credits could however be part of a wider national system of forest-related environmental services. Thus a stable national policy framework is crucial for the international implementation of compensated reductions (Schlamadinger et al. 2005).

Similarly, the German Advisory Council on Global Change has proposed a ‘Protocol on the Conservation of Carbon Stocks of Terrestrial Ecosystems’ for future commitment periods (Graßl et al. 2003). It would consist in a negotiated cap on carbon stock degradation rights. Differently to other options however, both systems would not be linked to one another. Only in case major carbon losses were triggered by human-induced climate change and not by national land use, the targets within the *Stocks Protocol* or the corresponding GHG emission reduction obligation would be increased. With degradation rights, the Council resorts to its earlier proposal of so-called “Non utilization obligation payments (NUOPs)” (Graßl et al. 2002). Also in this case, reliable global inventories would be a precondition. The advantage of a separate protocol that negotiations on the second commitment period commitments would proceed unhindered by LULUCF issues, is at the same time its disadvantage, because – as the authors concede – “negotiations on the conservation of carbon stocks would have to start practically from scratch”. The experience with the languishing UN Forum on Forests (UNFCC) justifies some skepticism on the chances to enact a separate protocol (Scholz 2004) Furthermore, the countries rich in natural resources will not be willing to join a binding regime in which they would see themselves obliged to buy degradation rights from industrialized countries.

9.6.2.3 *Additional Issues to Resolve*

9.6.2.3.1 *Forest definitions*

The challenge posed by a lack of standardized forest definitions became apparent to climate policymakers when the 7th Conference of the Parties decided upon modalities to account for LULUCF activities. Various definitions are used under different international agreements and for FAO reporting purposes, according to their respective information needs (Killmann 2002). The FAO is undertaking efforts towards the harmonization of definitions (Carle & Holmgren 2003). As the Kyoto first commitment period system mixes gross-net and net-net accounting of carbon variations in the land cover (Schlamadinger et al in preparation), the Marrakech Accords have added new definitions for forest, afforestation, reforestation, deforestation, revegetation, forest management, cropland management, and grazing land management (UNFCCC 2001). Eligibility of and accounting for single activities critically depend on whether the respective area definition is met. The Marrakech definition for reforestation depends on whether the area was non-forested according to the forest definition on December 31, 1989. However, the definition for forests also includes “[y]oung natural stands and all plantations which have yet to reach a crown density of 10-30 per cent or tree height of 2-5 metres are included under forest, as are areas normally forming part of the forest area which are temporarily unstocked as a result of human intervention such as harvesting or natural causes but which are expected to revert to forest”. Should therefore a project area have surpassed the threshold values for the forest definition once between 1990 and the activity start, it would not be considered a reforestation, but forest management, the use of which for compliance is limited to mitigation activities in Annex I countries.

Further, each national government shall define its own threshold value within the above ranges. This is difficult for countries that include forest ecosystems within different climates and altitudes. The 1989 benchmark land use was set in order to reduce the incentive to deforest an area without accounting for it and reforest it claiming credit for this activity (temporal leakage). However, this benchmark also reduces the overall potential lands available for forest climate activities. It excludes reforestation on areas that were recently deforested, but it is in these areas that reforestation can be most effective at protecting and restoring adjacent forests (Brown et al 2000). Moreover, the regulation gives preference to the afforestation of areas that have not been forested for long periods and that may lack carrying capacity (soil, water, nutrients) for forests. Changing timeline and definitions in future commitment periods also risks inconsistencies in monitoring and reporting on the national as on the project scale (Dutschke 2002; Schlamadinger et al, forthcoming).

For future commitment periods, the problems resulting from complex forest and land-use definitions in general could be minimized if net-net accounting was applied, including emissions and removals in the base and in the target periods. Nevertheless, there is a trade-off between methodological problems on how to determine past land use change, imbalances due to saturation (Schlamadinger et al. forthcoming)**,** and harmonizing definitions.

9.6.2.3.2 *Transaction costs*

For climate-change mitigation projects, transaction costs (TACs) are costs related to generation and sales of emission permits (Michaelowa & Stronzik 2002). Under the CDM, most TACs occur in the planning and design phase, before the actual start of the project. The first proceeds from the sale of

CERs will have to cover TACs only. Minimum upfront transaction costs being estimated between 40,000 and 80,000 USD (PointCarbon 2002; Ellis, Corfee-Morlot et al. 2004; Krey 2004).

Transaction costs can be broken down as follows (Krey 2004) (Table 9.17): First, there are costs that accrue from search and negotiation activities of the unilateral project developer in order to find a buyer for the CERs. For bi- and multilateral projects, where the investors are direct project participants, these costs of governing the project investment accrue to the investor. Second, there are the actual "GHG transaction costs". These costs arise from the tasks to be performed in the project cycle that accrue until the end of the (last) crediting period.

Insert Table 9.17

Reducing TACs in the field of search, contraction, approval, registration and issuance costs or exempting them from the adaptation levy will not put at risk environmental integrity. On the other hand, control-related TACs are not spent for unnecessary exercises. Most of the GHG components originate in the incentive of both investor and host party to understate emissions and overstate net carbon uptake achieved by the project. If spurious emission allowances were created, the project-based system would not comply with its objective to find a cost-efficient solution to climate-change mitigation. By allowing free riders into the market, additional projects would be marginalized.

Finding modalities and procedures for the CDM can be usefully conceived as an optimization game (Figure 9.29). The higher CER quality-related TACs, the better the chance to exclude non-additional CERs and to single out truly additional CERs. Non-additional CERs compete with additional CERs, because they are available at zero or even negative cost. However, absolute numbers of truly additional CERs will fall, the higher the share of TACs in the market price. There are two optima, one for the cumulate absolute numbers in additional and non-additional CERs produced (R_1), which could be denoted the "economic optimum" and another one for the highest absolute number of truly additional CERs (R_2), denoted the "ecologic optimum". While free riding cannot be avoided completely, under environmental aspects, R_2 is the preferable option. The environmental optimum is reached, where any increase in control costs will deter truly additional more than non-additional activities. For large-scale project, the optima will be moved to the left, i.e. additionality tests can be achieved at much lower per-unit price. For ssc projects, the optima move to the right, because the same high quality standards will be prohibitive for small-scale projects.
Insert Figure 9.29

The project's credit output is one variable, the other one is the credits' value. Obviously, expiring CERs are worth much less than one-off allowances issued for source reduction projects (Dutschke et al. 2005). Consequently, optimal control costs are lower per unit of expiring CERs than optimal per-unit costs of CERs from GHG source reduction activities. As expiration of lCERs and tCERs is an environmental safeguard, the emissions integrity risks of free riding are the same for the different optima of quality control in A/R and source projects.

As the carbon prices vary over time, so will the optimum costs of quality assurance. Once the CER price doubles, modalities and procedures need to be revisited, in order to balance against the increased supply in non-additional activities.

9.6.2.3.3 Integration of climate change into national forestry policies

Rosenbaum et al. (2004) see worldwide little effort to introduce climate change into existing forestry legislation. This is specifically true for Annex I countries. Canada, Spain and New Zealand make some legal reference to the mitigation function of forests. Most of what is being undertaken may be considered no-regret options (Rosenbaum, Schöne et al. 2004). Most Australian Federal States and Territories have legislation in place that formalizes "Carbon Sequestration Rights (CSRs)" so that they can be traded and registered as part of the property titles, even though the definitions are different between Federal States. In no case does the state take over liability for the permanence of carbon sequestered in vegetation (Scott 2005). By contrast, some developing countries are making substantive progress in adapting forestry laws to include climate change mitigation, notably Costa Rica, the Dominican Republic, and Peru (Rosenbaum et al. 2004)

9.7 Forests and Sustainable Development

9.7.1 Conceptual aspects

Sustainable development (SD) is a complex and multidimensional issue. It is a policy objective for developing and developed countries, expressed in many interrelated sectoral dynamic goals. SD is not a stationary state to be reached at some point of the time. The main dimensions of the relation of climate change and SD are the social (e.g. equity), the economic (e.g. cost-effectiveness) and the environmental (e.g. effects of human activities and climate change on water, soils and biodiversity). SD and climate change have being recognized as intrinsically dependent on the patterns of consumption and development paths. The present section focuses on the sectoral perspective of forests, climate change and SD.

One key question in relation to SD is to know if countries moving towards it, where, how, and if they are doing it rapid or slow. A recent study concludes that most national governments are not thinking strategically about the transition to a sustainable future (Swanson *et al*., 2004). Main findings of this study are that in most nations: a) there are separate sets of social, economic and environmental indicators, and no integrated sets of indicators to allow the monitoring and analysis of trade-offs between the social, economic and environmental dimensions of SD, and in consequence there is no learning; b) SD strategies remain in the periphery of government decision-making processes; c) Co-ordination with sub-national and local institutions for SD actions is low; and d) economic instruments are under-utilised. It is clear then that, if policy initiatives are not implemented, simply creating a national SD strategy will not solve the problem.

Forests, climate change and sustainable development have a strong linkage; if a forest deteriorates all of its functions and services are threatened, and environmental and socio-economic impacts result. A vast literature has been produced in the last two decades on the SD issue, but the relationship between forests, climate change and SD has received particular attention only in recent years (World Commission on Forest and Sustainable Development, 1999). Human activities influence forests in different ways: e.g. directly through logging, but also and increasingly more so indirectly through the impacts of climate change e.g. through changes in rain patterns in tropical forests. The linkages between SD and climate change are in both directions, with focus on making development more sustainable (IPCC, 2003).

Existing forests, forests restoration activities and land use change from non forest land to forest land can be managed in a sustainable or unsustainable way. To manage forest ecosystems in a sustainable way implies to know how those systems work, which are the main functions, variables and interrelation between variables, and what the effects and impacts of different human practices can be. In recent years the scientific literature shows an increasing attempt to understand integrated and long-term effects of current practices on SD, but normally considering environmental effects or socio-economic effects in isolation. Many unknown issues are being brought to the attention of scientists and technologists. It seems clear from the literature review, that the main processes related to forest management, deforestation, and afforestation have been undertaken without sufficient understanding of their potential long term impacts on natural resources and SD.

Climate change is part of the SD concern in the forest sector, because of its huge potential impact on different forest ecosystems (AR4, Chapter 4, Group II). In addition, it is also clear that different management regimes affect the ability of forests to sequester carbon, and also influence the vulnerability of forest lands to climatic events. The mitigation potential is also a variable that human actions can influence. It is important to further investigate in what way we can use forests to mitigate climate change. It is also important to study what effect different actions, done to increase carbon sequestration, conservation or substitution, have on other offsets from forestry, such as the harvest level, the availability of forest biofuels and economic factors

Future generations will be confronted—in a dramatic way—to quantitative and qualitative scarcity of forest resources, following their over exploitation by present generations and the expected effects of climate change. The entrance into force of the Kyoto Protocol in February 2005 is a very relevant step for forest and SD. The environmental service of climate change mitigation by forests will be recognized in the market, and new signals are going to be given to decision makers. Decision patterns in relation to forests are expected to change in order to incorporate this new variable.

9.7.2 Ancillary effects of GHG mitigation policies

Ancillary Benefits (AB) of climate change measures are defined as those benefits that are not the prime objectives of the measures yet can still be positive (UNFCCC, 2003). *Ancillary benefit* refers to policies that are exclusively designed to mitigate climate change, whereas *co-benefit* is used for policies that are implemented at the same time but for more than one purpose. Policies to reduce GHGs can have both ancillary benefits and costs for public health, ecosystem. Policies that are specifically designed to encourage reductions in greenhouse gases (GHGs) have benefits that go beyond global climate protection and actually accrue at the local level" (Dudek *et al*., 2002)

The consideration of Ancillary Benefits is important because identifying and accounting these benefits can reduce or compensate the costs of the mitigation measures. The focus on ancillary effects means we are focusing on effects other than the reduction in GHGs emissions, but which occur indirectly as a consequence of those reductions. An important characteristic of AB: they are local, rather than global (OECD, 2002).

9.7.2.1 Environmental and socioeconomic benefits and costs in forests

Aside from climate change mitigation, forests fulfill many important environmental functions and services. Human activities and management decisions can enhance or negatively disturb these functions. A distinction between natural forests and planted forests is useful when considering environmental and socio-economic impacts of forests. It is also useful to distinguish forests planted or regenerated on former native forest land (e.g. natural forests that were under agricultural use before) from forests planted on former non-forest land (e.g. grasslands).

9.7.2.2 Native forests

Native forests provide habitats for biodiversity. Stopping or slowing deforestation and forest degradation contribute to maintain carbon stocks and preserve biodiversity. Restoration of natural forests can enhance biodiversity (Parrotta, 2002). Preserving forests conserve water resources and prevents flooding. Forests reduce run-off, control erosion, reduce siltation of rivers, protect fisheries and investments in hydroelectric power facilities. Hydrological benefits and costs must be evaluated site by site, because in some conditions species with high potential water demand can cause significant reduction of streamflows affecting inhabitants and biodiversity in the basin.

Forest protection may have many significant positive effects. However, under certain circumstances, negative effects may also occur. Positive effects may include the restoration of lands for productive uses, the increase in production of forests goods and services, and wealth and labour creation. Negative effects, on the other side, could include displacement of local populations, reduced income and reduce flow of subsistence products. These conflicts could be minimized. Restoring forests and proper management of secondary forests can provide benefits to combat desertification. Enlarging forest cover can –especially in boreal zones- have secondary climatic consequences as changing earth´s albedo, cloud cover, hydrological cycle, and air movement changing surface roughness. Nature and direction of these changes will depend on location, hydrological setting, etc.

9.7.2.3 Planted Forests

Trees can be established in grasslands, wetlands or settlements for different purposes, with environmental and socioeconomic impacts, which can largely depend on scale and landscape planning. Afforestation processes to establish commercial plantations for solid wood, pulp and multipurpose, have increased in different parts of the world (Section 9.2). Sometimes plantations have been introduced eliminating native forests, sometimes as a land use change from grassland or savannas, and sometimes they were introduced on previously deforested lands to restore forest ecosystems functions.

Planted forests on formerly forested lands may have significant positive effects if they restore lost environmental functions. On the other hand, when planted forests represent a land use change from non forest to forest land, environmental functions of previous land use may be affected. In the Temperate regions of the Southern Hemisphere most plantations have substituted grasslands.

In the TAR impacts of plantations did not had a sufficient specific consideration. However, the actual literature shows that in many countries where substitutions of grasslands for plantations have occurred important impacts are reported. It seems to be clear that a lot more needs to be known to develop really long-term sustainable systems. In general, plantations sequester more carbon than grasslands because of their higher Net Primary Productivity (NPP); and this represent an outstanding opportunity for SD and climate change mitigation. In addition plantations may have other either significant positive and/or negative environmental and social effects. Natural and socioeconomic local conditions, management practices, policies and regulations, may be crucial to take advantage of the opportunities and minimize costs. However, some undesirable social negative effects of afforestation processes, contradictory with SD, have been reported in several papers for some regions of the world, including displacement of local populations, reduced income and reduced flow of subsistence products. Large investments have being made in commercial plantations on degraded land in Asia **(**Sayer *et al.*, 2004). These initiatives are often politically driven and aspire to achieve both economic and environmental benefits, but often lack of clarity about the objectives and failure to negotiate with all concerned stakeholders may result in failure to yield either local economic or global environmental benefits. Security of tenure and use rights is an important but often neglected requirement for achieving sustainability.

Effects of plantations on SD of rural societies have been diverse, depending on countries. Plantations have the potential to positively contribute to employment, economic growth, exports, renewable energy supply and poverty alleviation. Nevertheless, some cases analyzed in the literature show that some negative socio-economic effects may happen: e.g. employment growth may be associated with high levels of precarious and informal jobs. Better integration between society and afforestation activities seems to be necessary (Farley et al., 2004). One of the so-called "crunch issues" that have been debated in determining how to implement land-use change projects within the Clean Development Mechanism is their potential impact on local livelihoods and environments (Pedroni, 2003).

Environmental impacts of plantations on native grasslands have received increased attention in recent years as a result of the growing importance of this kind of activities in Latin America, Asia and Africa. In countries like Argentina, Australia, Brazil, Chile, New Zealand, South Africa and Uruguay, plantations on grasslands have been a current practice, and are expected to continue Plantations, in particular commercial monocultures with *Pinus* or *Eucalyptus,* may present, depending on site conditions, several environmental and socioeconomic impacts which have being reported by the literature in relation to hydrological resources, soils and biodiversity.

a) Effects on hydrological cycle

Afforestation in wet areas and reforestation of basins may have benefic hydrological effects, reducing flooding. Massive afforestation of native grasslands in the Southern Hemisphere may have strong yet poorly quantified effects on the hydrological cycle (Nosetto *et al*., 2005). Authors say that more attention should be paid, in particular to water management, considering that tree plantations may continue their expansion over grasslands.

Replacement of grasslands by forests may result in increased rain interception, increased transpiration and more water consumption, and the magnitude of this will depend on stand density. Most fast growing tree species can use large quantities of water, and many have deeper access to water than grasses. As a consequence, plantations on grasslands may reduce water flow into other ecosystems and rivers (Gyenge *et al.*, 2003), and affect aquifers layer and recharge. For this reason, low density silvopastoral systems could have less hydrological effects, and even use water resources that otherwise could be lost from the system, which is reflected in higher productivity.

Farley et al. (2004) state that carbon sequestration programs, including afforestation and reforestation will alter many ecosystem processes, including water yield. Some previous analyses have addressed deforestation and water yield, while the effects of afforestation on water yield have been considered for some regions. These authors conclude that no systematic global analysis of the effects of afforestation on water yield has been yet undertaken.

b) Effects on soils

Sustaining productivity in short-rotation forest plantations over multiple rotations can be problematic, when nutrient inputs to soil are small compared to exports off-site during harvest. For example, there are concerns about sustained productivity of *Eucalyptus globulus* plantations growing on ex-pasture land in south-western Australia because nitrogen (N) inputs from fertilization and leguminous species are low. Simulations suggest that retention of harvest residues is helpful for maintaining stand productivity, but that applications of fertilizer N will be necessary to maintain current levels of productivity in the long term.

Change of land use from pasture to *Eucalyptus grandis* plantations in Uruguay resulted in lower Organic Carbon content of the upper layer (<5cm) of the mineral soil surface, with the consequence of higher erodibility of the mineral uncovered soil surface (Perez-Bidegain *et al*., 2001). They reported also lower soil water retention, increased acidity and exchangeable Al. In some soils planted with Eucalyptus, acidification may result from important removals of Ca. Similar results were reported by Powell (2001) for New Zealand, but in relation to coniferous species: in soils with low base saturation and buffering capacity, afforestation of grasslands may significantly, reduce soil pH and base cation levels, while increasing soil solutions Al concentrations. In New Zealand, afforestation of grasslands soils will reduce upper mineral soil C levels, in the short-term, by about 4.5 t/ha, but after 20 years the difference will be almost non significant (Condron, 2002). In the case of *Pinus radiata*, in New Zealand, Townsend (2002) suggests that afforestation of pastures leads to a reduction of total N, microbial biomass, and microbial activity, but a less consistent effect on soil C storage after one rotation. In relations to SOC pool and climate change mitigation potential, land cover change to *Eucalyptus sp.* plantations in Argiudols could be producing a podzolization process affecting negatively SOC (Carrasco-Letellier *et al*., 2004). An integrated biogeochemical assessment of soil profile for different types of soil may be necessary.

Land-use change from grassland to short rotation plantation forest can have significant impacts on soil nutrient dynamics and microbial processes. Levels of soil organic carbon (C), total nitrogen (N) and organic P fractions under grassland were consistently higher, but levels of inorganic P fractions, microbial biomass C and P, and phosphatase enzyme activities were lower compared with forest over all seasons. (Chen *et al*., 2002)

Sicardi *et al*. (2004) analyzed significant changes in the soil biological properties of lands converted from pastures to *Eucalyptus* plantations in Uruguay. They suggest that microbial biomass, soil respiration and enzyme activity are useful tools to assess biological soil quality changes when this changes of land use occur. The type of tillage seems to be a relevant factor in the case of soils properties when a change from pastures to plantations occurs (Perez-Bidegain *et al*., 2001). Conventional tillage showed long-term effects, organic carbon content was reduced, compaction increased, and water retention capacity decreased. Consequently, soil erosion risks may increase. On the other hand, the soils under Eucalyptus planted with no-till did not show significant differences compared to the ones under natural pastures (García-Prechac *et al*., 2001)

Management practices (e.g. type of site preparation and harvest) play a key role in the magnitude of the impacts of plantations on soils and the rest of environmental variables. Residue retention, instead of the traditional management seems to be critical to minimize risks on soils (Loch, 2002). Forest harvesting may interfere with long-term ecosystem structure and function (Blanco *et al*., 2005), and different harvesting methods will differ in their effects on soil fertility (e.g. whole-tree harvesting versus stem removal). Thinning intensity, rotation length and site quality must be assessed in order to formulate sustainable management practices. In any heterogeneous region sustainability of forestry practices is strongly site dependent. N and P were particularly sensitive to overexploitation and in no case could whole-tree removal be recommended as it may have a strong negative effect on nutrient reserves.

c) Effects on biodiversity

Usually plantations have lower biodiversity, but indirectly, they can reduce pressure on biodiversity of natural forests. Stephens and Wagner (2005) made a bibliographic review of the relations between biodiversity in plantations and native forests. They found that 94% of the works reported reduction in biodiversity. However, some works indicate an increase of biodiversity when plantations are compared with other land uses as croplands. Plantations can negatively affect biodiversity if they replace biologically rich native grassland or wetland habitats (Bregje et al., 2003). The effects of type and size of trees grown in the forest trees were significant on all the studied community attributes.

Plantations can include measures to promote biodiversity, as longer rotation times and reduced or eliminated clearing of understory vegetation, use of native tree species and reduced chemical inputs. Plantations may also constitute new habitats, favorable for a range of species. Scale, species, management, age, and rotation period affect biodivesity (Quine and Humphrey, 2005). Introducing plantations on steppe ecosystems (e.g. Argentina) has still unknown consequences on the conservation of biodiversity and ecosystem functions. Plantations may act as corridors, source, filters or barriers for different species (Rusch et al., 2004). On degraded site conditions, plantations with native or exotic species may be a tool for landscape restoration, stabilization of soils, increase of organic matter content and soil fertility (Parrota, 2005).

The literature seems to suggest that plantations require careful assessment of the potential impacts on soils, hydrological cycle and biodiversity, and that negative impacts could be controlled or minimised if adequate landscape planning and basin management and good practices are introduced. There is a need for further work to quantify the key ecosystems processes that change with afforestation (Towsend, 2002).

9.7.2.4 Agroforestry

Agroforestry can produce a wide range of economic, social and environmental benefits. For example, trees in agroforestry farms can have positive effects on control of erosion and enhance fertility and physical properties of soils, in additions to enhanced CO2 removals. Agroforestry systems could be an interesting opportunity for conventional livestock production with low financial returns and negative environmental effects (e.g. overgrazing and soil degradation). But many times livestock farmers face financial barriers to develop this type of systems; payment for environmental services could contribute to the feasibility of this initiatives (Gobbi, 2003). Shadow of trees and shelter may have also beneficial effects on livestock production and income, as reported by Bentancourt *et al*. (2003).

One main characteristic of agroforestry systems is their flexibility; the proportion of trees/crops or trees/grasslands may be more easily changed. In other words, the possibility to change the productive system is greater with agroforestry or silvopastoral systems than with dense tree plantations. Tree establishment may have multiple effects on the production and biodiversity of rangelands. In mixed (C3-C4) grasslands in the Flooding Pampas of Argentina, winter deciduous trees (*Poplar*) could favor cold season species in the understory, improving forage availability for livestock in the most critical part of the year. Little evidence of local extinctions and invasions, risking biodiversity, was found (Clavijo *et al*., 2005)

9.8 Technology, R&D deployment, diffusion and transfer

In the forestry sector, there are broad levels and categories of technologies for mitigating climate change from the national level to the forest stand level, and from forest practice approaches to socio-economic approaches. This section first takes a look at the current status and scope of the near future of technology research and development (RD) in the forest sector, the deployment, diffusion and transfer of these technologies are discussed afterwards.

Technology RD in the Forest Sector

Technological research and development in the forest sector have great potential for promoting carbon conservation and sequestration through the implementation of sustainable forest management, and also for reducing the release of carbon from fossil fuels by substitution through effective timber production and wood use for fuel.

Regarding technology for harvesting and procurement, mechanized forest machines, such as harvesters, processors and forwarders which have been developed in Northern Europe and North America, have been coming into increasing use around the world for the past several decades. Recently, mobile chippers for logging residues have also come into wide use, and bundling machines that compact logging residues including branches and tops at felling into cylindrical bales were developed in the Nordic countries, especially for fuel wood (Andersson et al., 2002). Fuel wood is less valuable than other wood products, but these machines can efficiently transport fuel wood for bioenergy at low cost. Though mechanized forestry in harvesting and procurement causes carbon emission through the burning of fuel, the emission is very small compared with the amount of carbon in the harvested timber (Karjalainen et al., 1996), and mechanization in forestry seems to be effective as a mitigation option. However, harvesting and procurement systems vary due to terrain, type of forest, infrastructure and transport regulations (Andersson et al., 2002), and appropriate systems also vary by regions and countries. For example, though cable-logging systems are costly, they are needed in steep mountainous areas. Low-impact logging (Pinard, 1996, Enters, 2002) is considered in some cases such as tropical forests. Therefore, technologies for forest machines and harvesting systems must be developed that are suitable for the specific conditions in countries and regions.

Thinning is an important practice to maintain the condition and productivity of stands by controlling stand density (Fujimori 2001). Thinning is also promoted to prevent forest fires and insect disease in the United States (LeVan-green, 2003). As the area of planted forests including plantations of fast growing species for carbon sequestration (Wright et al, 2000) increases, thinning will become more important for both productivity and the environment. However, single-tree felling and handling of small-diameter trees at thinning are labor-intensive operations which result in higher costs (Andersson et al., 2002). Recently in Japan, thinning is rarely carried out without subsidy because of the low price of timber and the high cost of labor (Sakai, 2003). The development of suitable low-cost technologies will be necessary for promoting thinning. Furthermore, 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.

Forest fires, insect and pest disease in forests often cause enormous carbon emissions and impacts on ecosystems. The suppression of forest fires and prevention of insect and pest disease are important not only for mitigation but also for protecting the ecosystem, including flora, fauna, and biodiversity. Fire and insect/pest management have been researched for a long time (Amiro et al., 2002), but further progress will have to be made to enhance mitigation options.

The increase of harvested wood products (HWP) from sustainable forestry reduces the carbon dioxide in the atmosphere (IPCC, 2001), while substitution of energy-intensive materials by forest products reduces fossil fuel consumption. Estimations of HWP stock were carried out for Finland (Pingoud et al., 1996), the United States (Skog and Nicholson, 1998), and Japan (Hashimoto and Moriguchi). Analyses of saved energy from substitution were also reported for construction materials (Buchanan, 1990) and building structures (Sakai et al., 1997). There is a wide array of technologies for using the energy of biomass derived from forests, including direct combustion, liquefaction, gasification, pirolysis, and fermentation (See Chapter 4, and also Kitani and Hall, 1989). To conserve forest resources, it is necessary to expand the recycling of wood waste material. Technology for manufacturing waste-derived board has almost been established, but further R&D will be necessary to reuse waste sawn timber or to reproduce it as recycled lumber. Quantitative analysis to estimate mitigation through forest products will be required in order to enable policies to be made to promote wood utilization. While these technologies often need large infrastructure and incentives in industrialized countries, practical devices such as efficient woodburning cooking stoves (Aggarwal and Chandel, 2004) have proved effective in developing countries as a means to use woodfuels derived from forests.

Technological research and development for proper estimation of the carbon flux is fundamental not only for monitoring and managing land use, land-use change and forestry including deforestation, reforestation and forest conservation, but also for predicting the impact of climate change and evaluating policies for mitigating climate change. Methods for estimating carbon stocks and fluxes based on forest inventories are practical and the same methodologies are employed in Good Practice Guidance for LULUCF (IPCC, 2004). At the same time, large-scale estimations of the carbon flux in the forest sector have been carried out with ecological process models such as the carbon budget model of the Canadian forest sector (CBM-CFS2, Kurz and Apps, 1999), the CO2FIX V.2 model (Masera et al, 2003), the European forest information scenario model (EFISCEN, Karjalainen et al, 2002), and the Australian FullCAM model (Richards and Evans, 2004). Some of the models available, estimate not only the present carbon flux in forests and forest products, but also the impact of land-use and forest management, and even climate change. However, the estimation of carbon flux has large uncertainties and different estimation approaches often lead to different results (Houghton, 2003). Reducing these uncertainties and differences in the methods of estimating the carbon fluxes is crucial as they may affect decisions and policy. Houghton (2003) reported that uncertainties of carbon estimation are most likely to be resolved through spatially detailed historical reconstructions of land-use change and disturbance, and that systematic monitoring of land-use changes with high-resolution satellite data is effective, especially in tropical forests. Turner et al, (2000) reported that lower spatial resolution resulted in lower estimation of net primary production (NPP) and net ecosystem production (NEP). Spatially explicit estimation of the carbon flux can effectively reduce uncertainty, and the latest models described above often use satellite images and/or Geographical Information Systems (GIS). Recently, high-resolution (< 1 meter) images have become available, so research has begun on satellite radars for NPP estimation (Kimball et al, 2004) and LIDAR (light detection and raging) for estimating forest biomass and canopy structures (Lefsky et al., 2002, Hirata et al., 2003).

Socio-economic approaches are also important for making decisions and polices for mitigation. For example, van Kooten et al (2004) showed that the costs of substitution of biomass were lowest among mitigation options in the forestry sector including forest conservation, plantation, carbon storage in wood products and substitution of biomass for fossil fuels. Perez-Garcia et al. (2002) showed that a combination of ecological and economic models could estimate the potential effects of climate change on the global forest sector including forest products and international trade. Pfaff et al. (2000) discussed methods for estimating carbon-offset supply under the Clean Development

Mechanism (CDM) which require close collaboration between social and natural scientists. For mitigation technologies in the forest sector, the integration of scientific knowledge, practical techniques, socio-economic and political approaches will become increasingly significant in the near future. Integrated multiscale sustainability assessments based on multi-criteria techniques and on sustainability indicators –such as those proposed by the Center for International Forestry Research (CIFOR) (Prahbu et al. 1999, Spilsbury, 2005) and others (López-Ridaura et al. 2001), have proved very helpful in helping understand the sinergies and trade-offs between the social, economic and environmental dimensions of forestry mitigation options.

Technology Deployment, Diffusion and Transfer

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

For technology deployment, diffusion and transfer, governments could play a critical role in providing targeted financial and technical support through multilateral agencies (such as GEF, World Bank, FAO, UNDP, UNEP), CGIAR institutions (such as CIFOR, ICRAF) and ODA, in developing and enforcing the regulations to implement mitigation options, in promoting the participation of communities, institutions and NGOs in forestry projects, and in 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. GEF could fund projects that actively promote technology transfer and capacity building in addition to the mitigation aspects.

Appropriately designed forestry mitigation and adaptation projects will also contribute to other environmental benefits such as biodiversity conservation and watershed protection, and provide socio-economic benefits to urban and rural populations through access to forest products and the creation of jobs, especially in rural areas. Ultimately, this will help to promote sustainable development (Section 9.5).

9.9 Long-term Outlook

We project a gradually increasing mitigation impact of forestry measures globally (Figure 9.26). By 2040 the economic potential of a combination of measures in afforestation, avoided deforestation, agroforestry, and bioenergy, could yield an additional sink of around -1.1 Gt C y-1 at a price of 20 $/ton CO2. This sink enhancement will be for 80% located in the tropics, be found mainly in above ground biomass, and almost half of it achieved through bioenergy.

The longer-term prospects (beyond 2040) of mitigation within the forestry sector will be influenced by both, the history of land-use and forest management processes that have taken place in the last century, particularly within the temperate and boreal regions, as well as on the recent patterns of land-use and the future path chosen, particularly within tropical regions. The baselines prepared with the IMAGE model –without fertilization effects- suggest that at a global level the LULUCF sector may continue as a source of CO2 emissions under the A1f (0.4 PgC/yr) or become a sink under B2 (-0.22 PgC/yr) in 2050, with large differences among regions. Large uncertainty surrounds these numbers, as well as in our assessment.

The mitigation potential will critically depend on which of the two scenarios (or a mix) takes place. In general, at a global level, issues that will have an effect on the long-term mitigation potential include future sectoral changes within forestry, changes in other economic sectors, environmental change, delayed effects of current and past changes in land use and management, and political factors (Section 9.3). Specific factors include:

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

Chapter 4 of WG II states that very little evidence is available on long-term impacts of climate change on forests. Most likely, the large boreal primary forests will continue to fluctuate around zero, maybe with some enhancement of growth due to climate change, counteracted by loss of soil organic matter, and maybe counteracted by increased fires. The temperate forests in USA, Europe, China and Oceania, will probably continue the vegetation rebound, and thus fill up the sink, possibly also enhanced by enhanced growth due to climate change. Large scale dieback is not foreseen. In the tropical regions, the human induced land-use changes will continue to drive the dynamics for decades. In the meantime, the (enhanced growth of) large areas of primary forests, secondary regrowth, and increasing plantation areas will increase the sink eventually. Depending on the region, the sources will revert to sinks, but this will be in the very long term (beyond 2040). In the long term as well, commercial bio energy will become more and more 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 (carbon storage) and harvesting forests to provide society with carbon-containing fiber, timber and bioenergy resources, and the trade-offs among utilization strategies of harvested wood products aimed at maximizing storage in long-lived products, recycling, and use for bioenergy.

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