Carbon Mitigation Analysis for the Forestry and Land Use Sector in Malawi

by

Victor Kasulo and Nick Hanley

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1. Introduction

In the context of global climate change, the forest sector is a major player in net carbon emissions (Nabuurs *et al*., 2007; Hanley, 2007). But within the forest sector itself choices must be made regarding the best economic option for cutting emissions, because resources for carbon mitigation are limited, particularly for developing countries like Malawi. Making such a policy decision requires information on the costs and benefits of different mitigation options in addition to their carbon implications (Makundi and Sathaye 1999). Hence, the major objective of this paper is to identify carbon mitigation options and analyse their costs, benefits and impact in the forest and land use sector in Malawi. In particular we want to identify a number of options that are likely to provide the desired forestry products and services at the least cost and minimum negative environmental and social impacts.

Forests in Malawi play an important role in both social and economic development of the country. Forests supply about 93 percent of the country's energy needs, provide timber and poles for construction and industrial use, supply non-timber forest products for food security and income, support wildlife and biodiversity, and provide recreational and environmental services. Among the environmental services provided by forests is carbon sequestration. Carbon sequestration is the uptake and storage of carbon on land which reduces atmospheric accumulation and thus delays its impact on global climate.

Despite the important role that forests play in Malawi, forest resources are under threat. For instance, in 1975, 57 percent of Malawi was classified as forest while in 2000 only 28 percent was classified as forest. Other records show considerable reduction in forestland from 4.4 million hectares in 1972 to around 1.9 million in 1992. Deforestation rate is estimated at 2.8 percent per annum, but is highest in the northern region where the rate is at around 3.4 percent per annum (EAD, 1998; 2001).

Causes of deforestation can be classified into three levels: indirect or underlying causes; direct or immediate or proximate causes; and predisposing conditions

(UNFCCC, 2006; Barbier *et al*., 1994). Underlying causes of deforestation are broader economic, political, cultural, demographic and technological forces that underpin proximate causes. Proximate causes of deforestation are those activities that directly remove forest cover and include agricultural expansion, logging and forest fires. Predisposing conditions are not directly or indirectly linked to the act of clearing land but belong to a category of generic social and geographical issues that determine whether land can be cleared or not. Examples include environmental factors such as land topography and soil fertility.

In Malawi the major indirect causes of deforestation are high population growth and increased woodfuel demand while the direct causes are agricultural expansion and wild forest fires (DREA, 1994). Malawi's population is estimated at 11 million. Its growth rate of about 2 percent per annum exerts great pressure on forest land and resources. The demand for woodfuel for instance, exceeds available sustainable supply and the deficit is increasing every year. In 1999 the deficit was 5.8 million cubic metres and it is estimated to grow to 10 million cubic meters by the year 2010 (NEC, 2000). Household use, tobacco leaf curing, brick burning, fish processing, tea processing and beer brewing amongst others cause the high woodfuel demand.

Rapid expansion of agriculture from the mid 1975 to late 1980s led to extensive deforestation. Agricultural land under estate farming increased from 67, 000 hectares in 1967 to 850,000 hectares by 1998. It is estimated that 95 percent of rural households have only a hectare or less as farmland. Hence smallholder farmers migrate on to steep slopes, riverbanks and/or encroach upon forest reserves in search of farmland, thereby, causing further forest and land degradation (DREA, 1994).

Wildfires burn and destroy considerable amounts of forest resources every year. For example, in 2001, 64 fire-devastating incidences were recorded national wide, damaging a total of 1,520.04 hectares. This represented a decrease in hectares burnt since in the years 1998, 1999, and 2000 the total area burnt were 5,026.1, 1,912.34 and 1,657.8 hectares respectively (DOF, 2002).

The destruction of forests through burning and decaying of woody biomass results directly to significant contribution of carbon to the atmosphere. However, the expansions of forests and maintenance of existing stands can capture carbon from the atmosphere and maintain it on land over decades. Thus, it is import for Malawi to identify mitigation options in the forest and land use sector that would reduce the atmospheric accumulation of carbon thereby delaying its impact on global climate change.

2. Carbon Mitigation Models in Forestry

The literature presents a number of models that are used in analysing carbon mitigation potential in forestry. The models can be categorised into top-down and bottom-up models[1] (Makundi and Sathaye, 1999; Nabuurs et. al., 2007). Top-down models are used for global assessment of forest mitigation potential, while bottom-up models are used for country, regional or continental assessment.

A number of studies have used top-down models to assess global mitigation potential of forests. Recent examples as presented by Nabuurs *et al*. (2007) include: Sohngen and Sedjo, (2006); Sathaye *et al.* (2007); Benitez-Ponce *et al.* (2007); Vuuren *et al.* (2007); Waterloo *et al*. (2003); Strengers *et al*, (2007); and Riahi *et al*. (2006). These studies offer roughly comparable results and present a large potential for climate mitigation through forest activities. For instance, results from these studies indicate that the global annual potential in 2030 is approximately 13,775 $MtCO_2$/year (at carbon prices less than or equal to 100 US$/t CO2) 36 percent of which could be achieved under a price of 20 U$/t CO_2 (Nabuurs *et al*., 2007).

Global top-down models provide broad trends but less detail than bottom-up models. Bottom-up models are mostly useful for studying mitigation options that have specific sectoral, technological and economical implications. These models include the Comprehensive Mitigation Assessment Process (COMAP) (Sathaye and Meyers, 1995) and COPATH[2] model (Makundi *et al*., 1991, Makundi *et al*., 1995).

[1] Other models such as Markal-Macro combine bottom-up and top-down approaches but such models are currently not used in forestry.
[2] COPATH takes its name from the initials of the names of its component modules which are carbon uptake, other land uses, pasture, agriculture, and harvest.

COMAP is intended to guide an analyst in undertaking a comprehensive assessment of the role of the forest sector in a country's climate change mitigation effort (Sathaye and Meyers, 1995). It mainly aims at finding the least expensive way for government and private companies of providing forest products and services while reducing the most amount of carbon emitted from the land use sector (Makundi and Sathaye, 1999). In using the model, the first step is to identify and categorize the mitigation options that are suitable for implementation in a country. The next step is to determine the forest and agricultural land area that might be available to meet current and future demand, for both domestic consumption and export. Surplus land in the future if available can be considered for carbon sequestration and other environmental purposes. In many countries there may not be enough land available. In such cases some of the wood demand may have to be met through increased wood imports or through using substitutes for forest products. Thus, alternative combinations of future land use and wood product demand patterns will lead to different scenarios of the future. But a baseline scenario is chosen against which the others are compared. The baseline scenario predicts the level of forest loss in the absence of any intervention measures.

Then, the potential for carbon sequestration and costs and benefits per hectare of each scenario are determined. This information is used to establish the cost effectiveness of each mitigation option and its ranking among other options. Furthermore, this information, in combination with land use scenarios, is used to estimate the total and average cost of carbon sequestration or emission reduction. Finally the barriers, policies and incentives needed for the implementation of each scenario are explored.

Several country studies have used the COMAP model to estimate carbon mitigation potential and cost and benefit of different forestry mitigation options. For instance most developing countries have used the COMAP model in preparation of national communications to the Conference of Parties of the United Nations Framework Convention on Climate Change[3]. Other examples include the climate change studies under the United States Country Studies Programme[4], the Asia Least Cost

[3] http://unfccc.int/national_reports/non-annex_i_natcom/items/2979.php
[4] http://www.gcrio.org/CSP/index.html

Greenhouse Gas Abatement Strategy studies[5], and country studies carried out under the auspices of the F7 Tropical Forestry Climate Change Research Network[6].

Sathaye *et al*. (2001) and Makundi and Sathaye (2004) report about the seven country studies that were carried out under the Tropical Forestry Climate Change Research Network. These studies were carried out in Brazil, China, India, Indonesia, Mexico, Philippines, and Tanzania. The authors comprise Fearnside (2001) for Brazil; Xu *et al*. (2001) for China; Ravindranath *et al*. (2001) for India; Boer (2001) for Indonesia; Masera *et al*. (2001) for Mexico; Lasco and Pulhin (2001) for Philippines; and Makundi (2001) for Tanzania. Using data on a per hectare basis on carbon sequestration, emission avoidance, and costs and benefits from these studies, Sathaye *et al*. (2001) and Makundi and Sathaye (2004) estimated cost-effectiveness indicators based on monetary benefits per t C, total mitigation costs and carbon potential. The results of the analysis showed that about half of the cumulative mitigation potential (of about 6.9 Gt C) between 2000 and 2030 in the seven countries could be achieved at a negative cost and the other half at a cost not exceeding US$100 per t C. Negative cost indicated that non-carbon revenue is sufficient to offset the direct cost of these options.

COPATH is a spreadsheet model for estimating carbon emissions and sequestration from deforestation and harvesting of forests. The model has two parts, the first estimates carbon stocks, emissions and uptake in the base year, while the second part forecasts future emissions and uptake under various scenarios. The forecast module is structured after the main modes of forest conversion to agriculture, pasture, forest harvesting and other land uses. Thus, the model allows for the use of forest inventory data to estimate carbon stocks and predicts carbon emissions and sequestration under various land use policies. COPATH has been used in a number of studies including the F7 Tropical Forestry Climate Change Research Network studies (Makundi *et al* (1995). However, unlike COMAP, COPATH does not analyse the costs and benefits of different mitigation options but only focuses on their carbon implications.

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[5] http://www.rrcap.unep.org/projects/algas and http://www.adb.org/Documents/Reports/ALGAS/default.asp

[6] http://www.epa.gov/sequestration/mitigation.html. These studies were coordinated by the Lawrence Berkeley National Laboratory and the United States Environmental Protection Agency.

This study uses the COMAP model because it meets our objective which is to analyse the costs, benefits and impact of carbon mitigation options in the forest and land use sector. Furthermore, because this model is widely used in most developing countries, it will make our results easily comparable to those of other countries.

3. The COMAP Model

The COMAP framework is a spreadsheet model that runs in EXCEL. It has four main modules namely Forestation, Protection, Bioenergy and Biomass. With the exception of Biomass module, the rest correspond to the main types of mitigation options in forestry. Each module has a set of sub-modules, which are used to analyze specific options.

3.1 Forestation Option

This option includes all projects and policies intended to re-plant an area, ranging from natural reforestation, enhanced natural reforestation, afforestation, short rotation forestry, agroforestry, community and urban forestry, etc. Where non-forest tree plantations such as rubber are not included under agricultural sector mitigation assessment, then they can be analysed under this module as afforestation/reforestation options. The sub-modules are run under different land use categories with input data for area (ha), carbon density, rates of growth of biomass and cost and benefits. All modules are run for both baseline and mitigation scenarios. The model then calculates the annual changes in carbon stocks and the cost-effectiveness indicators associated with the scenarios.

3.2 Protection Option

Some of the low cost and most effective mitigation options involve protecting existing forests from being deforested and/or degraded, leading to carbon emission. There are a number of options which call for halting deforestation of a given forest in a region or conversion of a threatened forest into a protected area. The forest protection module uses data on area under relevant categories, biomass density, carbon stocks, carbon sequestration rates, and costs and benefits, to estimate the associated annual and cumulative changes in carbon stocks and the cost effectiveness indicators for the mitigation policy. This is done for both baseline and mitigation scenarios so as to obtain net reduction in carbon emission.

3.3 Bio-Energy Option

This bio-energy mitigation option analyses the substitution of GHG-intensive products such as the use of sustainably grown biomass (biofuel) substituting fossil fuels. This may delay the release of carbon from the fossil fuels for as long as the fossil fuels remain unused. Other examples include the use of efficient stoves and charcoal kilns, wood-derived from renewable sources when used as a substitute for wood obtained from depleted natural forests, and the use of biomass products to replace emission-intensive products such as concrete, steel, and plastics.

3.4 Biomass Module

The biomass module is actually a biomass balance module aimed at tracking demand and supply of forest products in the sector. This is important since one of the main roles of the forestry sector in any country is to meet the current and projected biomass demand such as for fuelwood, industrial wood, and sawnwood. These demands can be supplemented by imports when necessary. When the demand on biomass exceeds the rate of growth, a decline in the size of the forest estate (deforestation) or degradation of the biomass density becomes evident. Indeed in many countries some of the mitigation options can not be implemented without arrangements for meeting biomass demands, including imports to cover biomass deficits.

Given the population increase and declining land productivity in many developing countries, more and more forestland is being converted to agricultural land for food production and other farm output. Furthermore, forestland is also converted to infrastructure and human settlements. Thus, it is necessary to analyze the current and projected changes in land use patterns and the resulting changes in biomass supply, with a goal to match it with the demand on biomass. The biomass module is used to track the dynamics of land use patterns over time, including changes in biomass pools, product supply and demand.

3.5 Cost-effectiveness Indicators

COMAP model generates a number of cost-effectiveness indicators which can help us to compare and select from different mitigation options. These indicators include net present value (NPV) of benefits per hectare and per tonne of carbon, initial cost of forest protection per hectare and per tonne of carbon, present value of costs (endowment cost) per hectare and per tonne of carbon, and the benefits of reduced atmospheric carbon (BRAC).

The NPV of benefits provide the net direct benefit to be obtained from a project or a mitigation scenario. For most plantation and managed forests this is expected to be positive at a reasonable discount rate. For options such as forest protection, the NPV indicator can also be positive if indirect benefits and forest values are included.

The "initial cost of protection" does not include future discounted investments costs that are needed during the implementation of the option. This indicator simply provides information on the amount of resources required to establish the project.

The present value of costs is the sum of establishment costs and the discounted value of all future investment and recurring costs during the lifetime of the project. This indicator is also referred to as endowment cost because it provides an estimate of present value of resources necessary to maintain the project for its duration.

The BRAC indicator expresses the net present value of a project in terms of the amount of atmospheric carbon reduced, taking into account the timing of emission reduction and the atmospheric residence of the emitted carbon. Thus, it estimates the benefit of reducing atmospheric carbon instead of reducing net emissions. The formulation of the indicator varies with the rate at which economic damage might increase.

4. Baseline Scenario

The baseline scenario represents a set of assumptions about the likely changes in land-use and land-cover patterns in a country based on historical data and emerging demographic and economic trends (Sathaye et. al., 2001). It is therefore defined in several different ways depending on the underpinning assumptions. Three main typologies of baseline definitions found in the literature are the economic efficient case, the business-as-usual case, and the most likely case (Halsnaes *et al*., 1999). Under the economic efficient case, the economy is assumed to utilise all production factors efficiently implying that the implementation of mitigation options will always have a positive cost. The business-as-usual case is constructed on the assumption of a continuation of current trends in production, consumption and land use activities, while the most likely case is a compromise between the two. It assumes a transformation of the economy to efficient utilisation of all factors of production.

A common method used to specify a baseline scenario is extrapolation of current trends of land use, tree planting and forest protection as well as consumption of forest products and services into the future (Makundi and Sathaye, 1999). This would represent the business-as-usual case. A recommended method, however, is to use end-use scenarios, which are mainly driven by the projections of the demand for wood products and for land in a country (Makundi and Sathaye, 1999; Sathaye and Meyers, 1995). This would involve describing existing land use distribution among and within sectors, the rate at which land is being converted from one use to another, and identifying the factors that drive land use changes. Factors such as population and economic growth rates would have to be used to extrapolate future changes in land use. Such as an analysis would represent the most likely case.

However, construction of the most likely scenario is quite complex. In its simplest form, current consumption per capita is projected into the future, by adjusting for factors such as population growth and national income. This can be improved by making further adjustments using known or estimated income elasticities of demand for the product in question. A slightly difficult way of constructing the most likely scenario involves statistical estimation of a product's consumption function, using a few explanatory variables to get the necessary coefficients for making projections. A more rigorous variation of the statistical approach involves econometric analysis of the product market (both demand and supply), plus the use of some form of a land-use allocation model for tracking the required forest areas needed to meet such demands. Thus, in general the application of this method requires a good amount of data on production, consumption and price structure of the forest products, and applicable factors of production and technology. This type of data is rarely available in most developing countries including Malawi, and as such this method is not widely used in the forest sector (Sathaye and Mayers, 1995).

Due to lack of sufficient data (as explained above), this study uses the business-as-usual approach in constructing the baseline scenario. In particular, future forest land has been projected by linear extrapolation of the past trends. The main source of data for this extrapolation has been the various reports produced by the Food and Agriculture Organisation (FAO) of the United Nations, such as the State of the World's Forest reports (FAO, 2003; 2005a; 2007), the Global Forest Assessment reports (FAO, 2001; 2006), and the Global Forest Resource Assessment 2005: Malawi Country Report (FAO, 2005b). Additional information was obtained from the Malawi forest resources mapping and biomass assessment, undertaken jointly by the Department of Forestry in the Ministry of Mines, Natural Resources and Environment, and the SSC Satellitbild of Swedish Space Corporation in 1992/93 (DOF,1993).

4.1 Land Area Change

In this assessment, land in Malawi has been classified into inland water bodies, forest land, and other land. Inland water bodies include land for all major rivers, lakes and water reservoirs. Forest land is all land spanning more than 0.5 hectares with trees higher than 5 meters and a canopy cover of more than 10 percent, or trees able to reach these thresholds *in situ*. It does not include land that is predominantly under agricultural or urban land use. *Other land* includes all land that is not classified as "Forest". Thus, it includes all land that is under agricultural and urban land use[7].

The total land for Malawi is the sum of these three categories and is estimated at 11,848,000 hectares. Table 1 shows the changes in land area for these categories from

[7] Some of this land may have some tree cover for agroforestry or urban forestry purposes and can be sub-categorised as "Other land with tree cover".

1990 to 2005. The table shows that other land has been increasing overtime while forest land has been declining. The figures indicate that in general there is an annual loss of 33, 000 hectares of forest land representing 0.9 percent (FAO, 2007). This rate has been used to project change in forest land for the baseline scenario. It is estimated that at this rate forest land will decline to 2,577,000 hectares by 2030. The figures suggest that the decline in forest land is mainly due to the conversion of land from forestry to agriculture and urban developments.

Table 1: Changes in Land Area: 1990 – 2005

Category	Area (1,000 hectares)		
	1990	2000	2005
Forest	3,896	3,567	3,402
Other Land	5,512	5,841	6,006
Inland Water Bodies	2,440	2,440	2,440
Total	11,848	11,848	11,848

Source: FAO (2007; 2005b)

4.2 Forest Area Change

In this assessment, forest land has been classified into primary (natural) forest land, modified (disturbed) natural forest land, and productive plantation forest land. Primary forest land is forest land containing native species, where there are no clearly visible indications of human activities and where the ecological processes are not significantly disturbed. It therefore includes some land in game reserves and national parks. Modified natural forest land is that land of naturally regenerated native species where there are clearly visible indications of human activities. Productive plantation forest land is the land of native or introduced species, established through planting or seeding mainly for the provision of wood or non-wood goods. It therefore includes all land for private and public forest plantations in Malawi. The total forest area for each year is equal to the sum of these three categories.

Although total forest area has been declining, plantation forest and modified natural forest areas have been increasing over time while primary forest land has been declining together with the decline in total forest land. This information is depicted in Table 2. The figures in Table 2 imply that the annual loss of primary forest land was 39,7000 hectares between 1990 and 2000, and 39,600 hectares between 2000 and 2005 (FAO, 2005b). At this rate and without any mitigation measures, the area for primary forest is projected to decline to 142,000 hectares in 2030 and to completely disappear by 2040. Thus, the fall in forest land can be traced to the disturbance and loss of primary (natural) forests due to human activities.

Table 2: Changes in Forest Area: 1990 - 2005

Category	Area (1,000 hectares)		
	1990	2000	2005
Forest	3,896	3,567	3,402
Other Land	5,512	5,841	6,006
In Land Water Bodies	2,440	2,440	2,440
Total	11,848	11,848	11,848

Source: (FAO, 2005b)

4.3 Forest Growing Stock and Biomass

In this assessment forest growing stock has been defined as volume over bark (o.b.) of all living trees more than 5 cm in diameter at breast height. It includes the stem from ground level or stump height up to a top diameter of 2 cm, and also includes branches to a minimum diameter of 2 cm. The average volume used is 109.5 m^3/ha (FAO, 2005b). This volume is more applicable to natural forests and not to planted forests.

Biomass has been divided into above-ground biomass (AGB) and below-ground biomass (BGB). It does not include dead wood biomass. Above-ground biomass is all living biomass above the soil including stems, stumps, branches, bark, seeds and foliage. Below-ground biomass is all living biomass of live roots. Fine roots of less than 2mm diameter are excluded because these often cannot be distinguished empirically from soil organic matter or litter. The calculation of biomass is based on growing stock and is given by:

AGB = Growing stock * wood density * BEF

BGB = AGB * 0.24

where wood density = 0.58 tonnes/m^3, and BEF (biomass expansion factor[8]) = 1.2. The factor 1.2 has been used considering that branches down to 2 cm were included in the growing stock figure (FAO, 2005b).

5. Mitigation Options

Major mitigation options for the forestry sector can be classified into two basic types. The first type involves expanding the stand of trees and the pool of carbon in wood products and the second type involves maintaining the existing stands of the trees and proportion of forest products currently in use. Expansion of tree stands withdraws carbon from the atmosphere and maintains it on land. Maintaining existing stands can be achieved through reduced deforestation, forest protection, or more efficient conversion and use of forest products. It therefore keeps the avoided carbon emissions from entering the atmosphere for the duration of the pool maintenance.

Other mitigation options include the use of wood obtained from renewable sources like forest plantations as a substitute for non-renewable emission sources, such as fossil fuel, and forest management activities that lead to an increase in stand-level forest carbon stocks. Fuel substitution delays the release of carbon from the fossil fuel for as long as one continues to use wood from a renewable source instead of the fossil fuel. In the same way, wood derived from sustainable sources, can be used as a substitute for wood fuel derived from depletable natural forests. This also delays carbon release from the unsustainable sources (Sathaye and Meyers, 1995). Forest management activities that lead to an increase in stand-level forest carbon stocks include harvest systems that maintain partial forest cover, minimize losses of dead

[8] A factor for converting volume (in cubic metres) to biomass (in tonnes)

organic matter or soil carbon by reducing soil erosion, and practices that avoid slash burning and other high-emission activities (Nabuurs *et al*., 2007).

Based on the baseline scenario outlined above and on the mitigation options available, it is apparent that Malawi needs two interventions in order to check forest depletion. The first intervention should involve maintaining existing stocks through forest protection and conservation and the second intervention should involve expanding carbon sinks through reforestation and afforestation. Afforestation is the planting of forests in bare land while reforestation is the replanting or natural regeneration of deforested land. The difference between the two terms depends on the period of time that land has remained bare.

Mitigation options in the bio-energy field can be assessed under the energy sector. Similarly, agroforestry as a mitigation option to expand carbon sinks can best be dealt with in the agricultural sector.

5.1 Forest Protection and Conservation

From the baseline scenario, it has been established that Malawi loses an average of 33,000 hectares of forest land every year. It has further been noted that within the forest sector, an average of 39,600 hectares of primary forest land is been lost every year due to human encroachment. It therefore follows that one of the measures that the Malawi government need to undertake is to protect primary forests.

Thus, in the mitigation scenario, it is assumed that adequate steps are taken to ensure that primary forests are effectively protected and that 3,336,000 hectares of forest land estimated for 2007 remains protected until 2030. In particular we assume that the departments of Forestry, and Parks and Wildlife will be able to play a more effective role in protecting natural forests than they do now. It has been suggested for instance that the management of plantation forests be turned over to private concessionaires, so that the Department of Forestry devotes it effort to management of natural forests (Hecht, 2006). Our approach assumes that the major factor contributing towards poor forest protection is inadequate financial resources[9]. We therefore assume that improved forest protection can be attained by providing adequate financial resources to the departments involved in forest protection and management. With adequate financial resources, the departments will be able to improve their fire control measures, and law enforcement activities such as confiscating more illegal forest products like charcoal, firewood and timber, and arresting more encroachers. Thus, the departments will be able to effectively reduce forest fires, illegal cutting down of trees, charcoal burning, agricultural encroachments and other practices that degrade natural forests. In this way, protection will check the increase in carbon emissions entering the atmosphere.

5.2 Reforestation/Afforestation Option

The reforestation/afforestation mitigation option depends on the availability of suitable land for tree-planting. The question that is often asked is whether developing countries have enough land for climate mitigation activities. At a glance, the high population densities and low agricultural productivity may suggest that there might not be enough land to be used for forestation programmes. However, when an assessment of degraded land[10] is undertaken in a country, the results usually show large amounts of degraded land available for forestation (Makundi and Satahye, 2003; Sathaye *et al*., 2001, Nijnik, 2005). Assessments of this type may also provide information on the tree species that are suitable for land under a particular silvicultural (forestry) zone, and on estimated costs and benefits of afforestation for each spatial unit of the forest classification (Nijnik, 2005). Malawi is yet to carry out such a comprehensive assessment of degraded land that is available for tee-planting, defined across silvicultural zones.

This mitigation option has, nevertheless, been incorporated to account for the Tree Planting for Carbon Sequestration and other Ecosystem Services Programme, initiated by the Malawi government in 2007. The overall objective of the programme is to increase the area under forest cover in Malawi in order to enhance carbon

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[9] The Department of Forestry for instance is funded only a fifth of its overall financial requirements in a year.
[10] This is land that either originally contained forests or that has been left fallow and agriculture is no longer practiced for various social and economic reasons.

sequestration and other ecosystem services that contribute to the reduction of greenhouse gases, in particular carbon dioxide, in the atmosphere. The programme promotes tree planting and forest management by households and institutions. This programme will enable Malawi to contribute to the attainment of the objective of the United Nations Framework Convention on Climate Change, which aims at promoting the stabilization of the emissions of man-made greenhouse gases into the atmosphere.

The programme is being implemented in all the 193 constituencies of the country. Individuals and farm families are provided with inputs and training so that they can create their own tree nurseries and tree plantations. Participants in this programme should have some land which is to be devoted to tree management for a period ranging from 15 to 30 years depending on the tree species planted. Fast growing indigenous and exotic tree species are being promoted such as *Khaya anthotheca* (mbawa) and *Eucalyptus* spp. (bluegum). Each constituency has an allocation of 5 farmers growing 3 to 5 hectares of trees, thereby creating a national wide maximum of 4,825 hectares of plantation annually and a total of 24,125 hectares in the initial five years. The estimated cost for the initial 5 years of the programme is about MK2 billion (approximately US$ 14.6 million[11]) (Malawi Government, 2006).

6. Mitigation Analysis Results

For simplicity the mitigation analysis results are presented by option, starting with the forest protection and conservation option. The scenarios are projected up to 2030 with 2000 as the base year. Under each option we analyse and present carbon pool and flows, monetary costs and benefits of mitigation which includes cost-effectiveness indicators.

6.1 The Discount Rate

The cost-effectiveness indicators generated by COMAP include net present value of benefits per hectare and per tonne of carbon. The calculation of present value of the stream of costs and benefits require assumptions regarding the discount rate. Two

[11] At a rate of 1US$ = K137.

approaches to discounting have been noted by Halsnaes *et al*. (1999); an ethical (normative) approach based on the rates of discount that ought to be applied and a descriptive (positive) approach based on the rates of discount that are actually applied. The ethical approach leads to the use of low social discount rates of around 3 per cent while the descriptive approach leads to the use of high private discount rates (sometimes as high as 20 per cent).

Apart from the choice of the correct discount rate, there is also the question of whether the assumption behind the use of a constant discount rate is appropriate. Hapburn and Koundouri (2007) argue convincingly that the use of constant discount rate is unjustifiable particularly for medium-term (60 years) and long-term (120 years) forest projects. Instead they recommend the use of time-declining discount rates. This is based on the argument that the future state of the economy and the appropriate discount rate are uncertain. Thus, under the conditions of risk and uncertainty the discount rate should decline with time. For short-term projects (30 year) however, they conclude that the use of a constant discount rate will generally be appropriate.

In addition to discounting future costs and benefits, there is also the issue of whether or not future carbon reductions (emissions) should be discounted when compared to present reductions (emissions). The justification for discounting is that emission reduction in terms of reduced impacts has a time specific value. In particular it is argued that discounting implies that a unit of carbon removed from the atmosphere at a future date is worth less than if the same unit were removed today. Discounting carbon therefore increases the importance of any carbon sequestration particularly when it occurs in the near future (Van Kooten *et al*., 2004)

Based on the above arguments, a discount rate of 10 per cent is used. This is the rate that is used by most studies that analyse forest mitigation potential using the COMAP model and by multilateral banks in evaluating forest projects in most developing countries (Sathaye *et al*, 2001; Makundi and Sathaye, 2003). However, for comparative purposes, a low social discount rate of 3 per cent has also be used. This ethical discount rate is favoured by governments when analysing forest policies (Hanley and Spash, 1993). Furthermore, the estimation of the BRAC indicator assumes that the economic damage caused by atmospheric carbon increases at the real societal rate of discount. However, since the analysis only covers a maximum period of 30 years, the time-declining discount rates have not been used.

6.2 Forest Protection and Conservation

In this scenario, it is assumed that adequate steps are taken to ensure that 3,336,000 hectares of forest land estimated for 2007 remains protected until 2030. The protection intervention starts in 2007.

6.2.1 Carbon sequestration

In order to determine the carbon pool and sequestration under the forest protection option, biomass density, soil carbon density and carbon content of biomass were used. In the baseline scenario, we started with a biomass density of 95 tonnes /hectare for the year 2005 (FAO, 2007). We assume that the biomass density declines at a rate of 2% per annum under the baseline scenario but that it increases at a rate of 2% per annum under the mitigation scenario. Thus, under the baseline scenario, biomass density declines to 57 tonnes per hectare in 2030 while under the mitigation scenario it rises to 144 tonnes per hectare.

Carbon density in living biomass is obtained by multiplying the biomass density by a carbon ratio for each scenario. The carbon ratio varies between 0.45 and 0.55 for most vegetation. In this analysis, we assume that the carbon ratio is 0.5 and that it is the same for both baseline and mitigation scenarios. Thus, biomass carbon declines from 52 tC/ha in 2000 to 29 tC/ha in 2030 in the baseline scenario but increases to 72tC/ha in the mitigation scenario. This represents an average annual net uptake of carbon by forests of about 1 tC/ha per year, which is comparable to the average uptake used in other similar studies (Nijnik, 2005). We also assume that the soil carbon density remains unchanged at 100tC/ha in the baseline scenario but that it increases at a rate of 1% per year in the mitigation scenario, thereby reaching a level of 126 tC/ha in 2030. Adding the biomass and soil carbon density gives the total carbon density for each year under each scenario. Total carbon density deceases from 152 tC/ha in 2000 to 129 tC/ha in 2030 for the baseline scenario but increases to 198 tC/ha in the mitigation scenario.

Multiplying the total carbon density (tC/ha) by the land area (ha) under each scenario gives the pool (tC) of carbon for each year. Since the carbon density and the land area decline in the baseline scenario, the carbon pool declines from 544 MtC in 2000 to 332 MtC in 2030. In the mitigation scenario it increases to 659 MtC by 2030 (Figure 1).

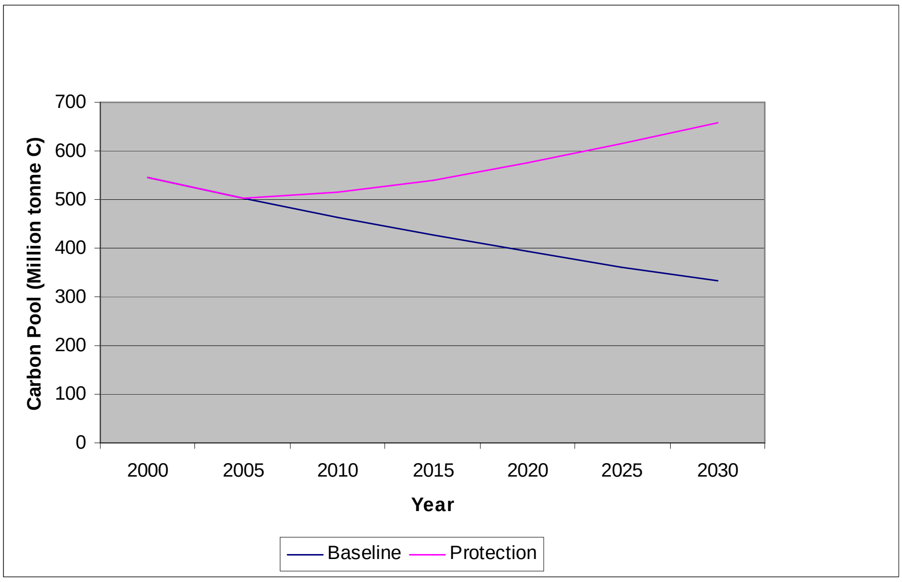

Figure 1: Total carbon pool under forest protection

6.2.2 Monetary costs and benefits

In the baseline scenario, the cost of forest protection is set to be $1.5/ha/year. This has been estimated based on the actual budget expenditure of Viphya Plantations (DOF, 2001). It has been used on the assumption that forest areas in Malawi are poorly protected due to the insufficient funds actually spent for forest protection and management. In the mitigation scenario, the cost of forest protection increases to $5/ha/year. This is based on the approved budget estimates for the Viphya Plantations (DOF, 2002) which we assume that if actually disbursed could provide adequate protection to the areas.

An average figure of $50/ha/year has been used in the baseline scenario as the opportunity cost of land or the benefits from land conversion. This is based on the fact that some of the land is converted to commercial farming such as tobacco growing while some of it is used for subsistence farming. Thus, the land that is used for commercial farming will have conversion benefits that will be greater than \$50/ha/year while those used for subsistence farming will have conversion benefits which will be less than \$50/ha/year. There is no opportunity cost of land under the mitigation scenario since no land conversion occurs under the forest protection option.

For benefits of protection a default value of \$2/ha/year has been used in the baseline scenario. A higher value should be used in the mitigation scenario since mitigation reduces degradation of the vegetation in the protected areas.

Total costs and benefits are determined by aggregating the costs and benefits for the baseline and mitigation scenarios. Thus, the net benefit for the baseline scenario for each year is obtained by subtracting the total cost of protection from the sum of all benefits of land conversion and the benefits from forests. The net benefit for the baseline scenario declines from about \$3,417,000 in 2001 to about \$2,938,000 by 2030. The net benefit for the mitigation scenario for each year is obtained by subtracting the sum of all costs of protection including the opportunity cost of land from the total benefits of protection. However, the net benefit of forest protection as a mitigation option is very sensitive to changes in the value of benefits obtained from protection. For benefit values of less than \$29/ha/year, the net benefit of protection is negative. Higher values can be justified by including indirect benefits of forest protection such as watershed protection and soil erosion control, though their computation is usually controversial. The mitigation option uses a benefit value of \$40/ha/year which is less than the benefit from land conversion of \$50/ha/year. This justifies the need for continued protection.

6.2.3 Cost-effectiveness Indicators

Table 3 presents cost-effectiveness indicators generated by COMAP for two discount rates: 3 per cent and 10 per cent. The results show that the cost-effectiveness indictors are very sensitive to changes in the discount rate. For instance the net present value of benefits is positive at 10 per cent discount rate and negative at 3 per cent discount rate. Negative net benefits have been recorded up to 7 per cent discount rate.

Table 3: Cost-effectiveness indicators under protection option

Discount Rate	Indictor						
	NPV of benefits		Initial cost of Protection		Present value of costs		BRAC
	$/tC	$/ha	$/tC	$/ha	$/tC	$/ha	$/tC
3%	-5.69	-523.32	0.05	5	11.20	1029	-0.43
10 %	0.52	47.50	0.05	5	1.43	131	0.04

6.3. Reforestation/afforestation Option

Under this mitigation option, 4,825 hectares of land is to be reforested each year starting from 2007 to 2011 bringing in a total of 24,125 hectares of additional forest land by 2011. The carbon gains, costs and benefits and the cost-effectiveness indicators of this project are presented below.

6.3.1 Carbon sequestration

The information needed to estimate carbon pools for the reforestation option include biomass density, soil carbon density, and carbon content of biomass. In the baseline scenario, we assume that the biomass density remains fixed at 20 t/ha until 2030. We also assume a carbon ratio of 45 per cent since these are degraded lands. Thus, multiplying the biomass density by the carbon ratio gives the carbon density of 9 tC/ha per year. The soil carbon density is assumed to be 70 tC/ha, again since this is degraded land which has undergone a lot of human disturbances like cultivation. Thus, in the baseline scenario, the carbon pool is estimated at 79 tC/ha.

Reforestation in the mitigation scenario has the potential to increase carbon density through increased carbon in vegetation, soil, decomposing matter and wood products. For vegetation carbon, we assume that the planted species has a rotation period of 15 years, a yield (mean annual increment) of 12 tonnes of biomass per hectare per year, and a carbon ratio of 0.5 (since this is under forestry). We also assume that soil carbon increases at 2 tC/ha over the rotation period of 15 years, and then remains fixed in the soil in perpetuity. Decomposition is equivalent to storing carbon. Thus, the decomposition of biomass on land also creates a stock of carbon. In this analysis we assume that the decomposition period is 6 years, and that the amount of decomposing carbon left behind is 6 tC/ha/year. If the forest products are renewed continually, they store a stock of carbon over an infinite period. The amount of carbon stored in the form of products will depend on the product life. The longer the product life the more carbon will be stored away. In this assessment, we assume that the average product life is 30 years, and the amount of carbon in the product is 30 tC/ha.

The total stored carbon by the mitigation option is the sum of carbon in vegetation, soil, decomposing matter and wood (forest) products. This amounts to 128 tC/ha. The pool of carbon for the reforestation scenario is the sum of carbon stored by the mitigation scenario and the baseline soil carbon. This gives a pool of 198 tC/ha.

Multiplying the total carbon density (tC/ha) by the land area (ha) under each scenario gives the total pool (tC) of carbon for each year. For the baseline scenario, this is fixed at about 2 MtC per year. However, for the mitigation scenario, this increases to about 2.5 MtC in 2007, 4 MtC in 2010, and stabilizes at about 4.8 MtC per year from 2011 to 2030 (Figure 2).

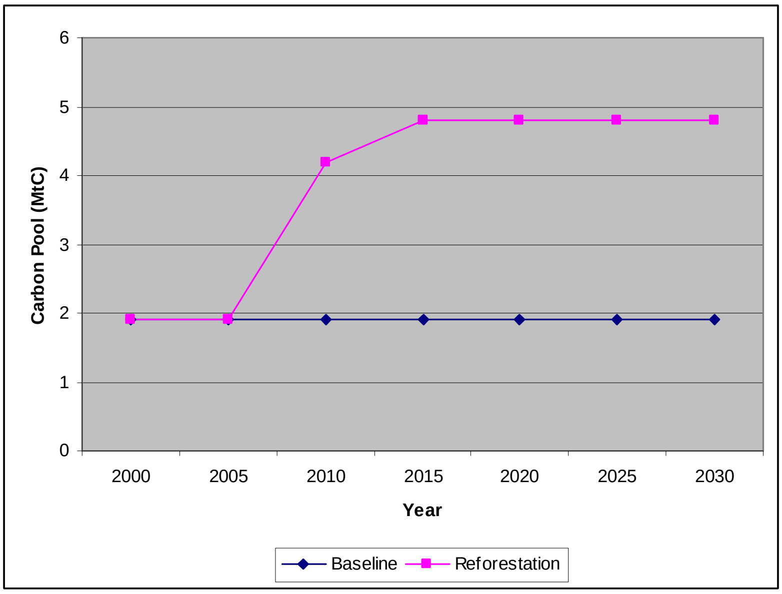

Figure 2: Total carbon pool under reforestation programme

6.3.2 Monetary costs and benefits

In the baseline scenario, the cost of reforestation has been assumed to be $5/ha/year. In the mitigation scenario, reforestation incurs initial (establishment), recurrent, and monitoring costs. These costs have been estimated from the Tree Planting for Carbon Sequestration and other Ecosystem Services Programme budget. According to the programme budget, the average establishment cost is about US$616/ha, recurrent cost is 4US$/ha, and monitoring cost is US$8/ha (Malawi Government, 2006).

In the baseline scenario, the annual benefits obtained from working the degraded lands have been assumed to amount to $10 /ha. For the mitigation scenario the benefits are derived from the sale and utilisation of timber, non-timber forest products such as firewood, honey, mushrooms, orchids, etc, and carbon offsets. It is assumed that timber production will contribute $150/ha during the harvest years. A non-timber benefit of $5/ha is assumed for 2007, and this increases overtime to a modest maximum of $15/ha in 2015. According to the programme document, the government is also to provide incentives to the participants of this programme. The incentives include a payment of U$234 per hectare in the first and second year for successful planting, managing and protecting the trees, and U$117 per hectare in years 3 to 5 for effective protection and management of the trees. It has been assumed that the sale of carbon offsets will take place in the year 2012 after the establishment phase.

The total costs and benefits of the degraded lands in the baseline scenario amount to $120,625 and $241,250 per year respectively, giving a net benefit of $120,625 per year. In the mitigation scenario, the net present value of benefits is sensitive to the price of carbon. The price of long term carbon sequestration ranges between $5 and $15 per tonne[12]. For any price less than $7 per tonne, the net present value of benefits is negative. The conservative price of $7 per tonne of carbon has therefore been used.

6.3.3 Cost-effectiveness indicators

Table 4 presents the cost-effectiveness indictors generated by the COMAP model.

[12] These figures are from the Plan Vivo used by the Edinburgh Centre for Carbon Management Ltd (http://www.planvivo.org/fx.planvivo/scheme/buyers.aspx)

The NPV of benefits provided by the reforestation programme is negative both at 3 per cent and 10 per cent discount rate. This is not surprising considering that the programme has very high establishment costs averaging $616/ha. The cost of establishing a forest plantation, excluding the opportunity cost of land was estimated to range from $230 to $1000 per hectare with an average of $400 per hectare (Sathaye and Meyers, 1995 cited from Sedjo and Solomon, 1988).

Table 4: Cost-effectiveness indicators for the reforestation option

Discount Rate	**Indictor**						
	NPV of benefits		Initial cost of Protection		Present value of costs		BRAC
	$/tC	$/ha	$/tC	$/ha	$/tC	$/ha	$/tC
3 %	-244.67	-28993.8	15.6	1848.5	269.81	31972.5	-1.84
10%	-44.96	-5327.7	5	600	50	5977	-0.34

7. Conclusion

The major objective of this paper was to identify carbon mitigation options and analyse their costs, benefits and impact in the forest and land use sector in Malawi. In particular we wanted to identify a number of options that are likely to provide the desired forestry products and services at the least cost and minimum negative environmental and social impacts.

Forest mitigation options include maintaining existing stands of the trees through reduced deforestation, or forest protection; expanding the stand of trees and the pool of carbon in wood products through reforestation programmes; and providing wood fuels as a substitute for fossil fuels. Two mitigation options have been analysed for Malawi namely forest protection and reforestation. In the forest protection option, we assumed that adequate steps are taken to ensure that 3,336,000 hectares of forest land is effectively protected until 2030. The reforestation option takes into account the Tree Planting for Carbon Sequestration and other Ecosystem Services Programme, initiated by the Malawi government in 2007. The programme is to reforest about

24,125 hectares of degraded land within five years at a cost of approximately $14.6 million. These mitigation options have been analysed using the COMAP model.

Results from the analysis show that forest protection can reduce carbon emissions in Malawi at lower cost per tonne (or cost per hectare) than reforestation under the Tree Planting for Carbon Sequestration and other Ecosystem Services Programme. However, our approach assumes that the major factor contributing towards poor forest protection in Malawi is inadequate financial resources provided to protection agencies. Government funding to forestry, national parks and game reserves has been very low in most cases although there are some improvements. Thus, reversing the current trend in forest degradation will require a lot of resources and new commitments from the government, the private sector and non-governmental organisations. The resources will have to be used efficiently in improving human resources and providing the required facilities and equipment. But since resources could be just one factor, we recommend further investigation on non-monetary measures that could be undertaken to unsure that forests are effectively protected.

Although the reforestation option gives higher costs than the protection option, it has greater potential as a mitigation option. What is needed is detailed information on the amount and type of degraded land that is available for forest expansion. Thus, Malawi needs to carry out a comprehensive assessment of degraded land that is available for tee-planting, defined across silvicultural (forestry) zones, because cost per tonne of carbon (or per hectare) varies across land type and tree species. With such information, a new reforestation programme can be analysed.

References

Barbier, E.B., Burgess, J.C. and Folke, C., (1994), Paradise Lost? The Ecological Economics of Biodiversity. Earthscan Publications, London.

Benítez-Ponce, P.C., I. McCallum, M. Obersteiner, and Y. Yamagata. (2007). Global potential for carbon sequestration: geographical distribution, country risk and policy implications. Ecological Economics, **60**:572-583.

Boer, R.: (2001), Economic assessment of mitigation options for enhancing and maintaining carbon sink capacity in Indonesia, Mitigation and Adaptation Strategies for Global Change. **6**, 313–334.

DOF, (1993), Forest Resource Mapping and Biomass Assessment for Malawi, Ministry of Forestry and Natural Resources: Lilongwe.

DOF, (2002), Department of Forestry Annual Report 2001 – 2002, Ministry of Natural Resources and Environmental Affairs: Lilongwe.

DREA, (1994), Malawi: National Environmental Action Plan, Department of Environmental Affairs: Lilongwe.

EAD, (1998), State of the Environment Report 1998, Environmental Affairs Department: Lilongwe.

EAD, (2001), State of the Environment Report 2001, Environmental Affairs Department: Lilongwe.

FAO, (2001), Global Forest Resource Assessment 2000: main report, FAO Forestry Paper No. 140. Rome. (Also available at www.fao.org/forestry).

FAO, (2003), State of the World's Forests 2003, FAO, Rome (also available at www.fao.org/forestry).

FAO, (2005a), State of the World's Forests 2005, FAO, Rome. (also available at www.fao.org/forestry).

FAO, (2005b), Global Forest Resource Assessment 2005: Malawi Country Report, Country Report 038, FAO, Rome. (Also available at www.fao.org/forestry).

FAO, (2006), Global Forest Resource Assessment 2005: progress towards sustainable forest management (FRA 2005) FAO Forestry Paper 147. Rome. (Also available at www.fao.org/forestry).

FAO, (2007), State of the World's Forests 2007, FAO, Rome. (Also available at www.fao.org/forestry).

Fearnside, P.M., (2001), The potential of Brazil's forest sector for mitigating global warming under the Kyoto Protocol, Mitigation and Adaptation Strategies for Global Change **6**, 355–372.

Halsnaes, K., Painuly, J.P., Turkson, J. Meyer, H.J. Markandya, A. (1999) Economics of Greenhouse Gas Limitations: Summary Guidelines. UNEP Collaborating Centre on Energy and Environment.

Hanley, N., Spash, C., (1993), Cost-Benefit Analysis and the Environment, Edward Elgar, Cheltenham, UK.

Hanley, N. (2007). The economics of climate change policy in Scotland, A paper for the David Hume Institute

Hecht, J. (2006), Valuing the resources of Mulanje Mountain: current and projected use under alternate management scenarios, Occasional Paper No. 14, Community Partnership for Sustainable Resource Management in Malawi (Compass II).

Hepburn, C. and Koundouri, P. (2007), Recent advances in discounting: implications for forest economics, Journal of Forest Economics, **13** (2): 169-189.

Lasco, R.D. and Pulhin, F.B. (2001), Climate change mitigation activities in the Philippine forestry sector: Application of the COMAP model, Mitigation and Adaptation Strategies for Global Change **6**, 313–334.

Makundi, W.R. (2001), Greenhouse gas mitigation potential in the Tanzanian forest sector, Mitigation and Adaptation Strategies for Global Change, **6**, 335–353.

Makundi, W. and J.Sathaye, (1999), Comprehensive Mitigation Assessment Process (COMAP), description and instruction manual, Ernest Orlando Lawrence Berkeley National Laboratory, LBNL/PUB-3163.
(http://unfccc.int/resource/cd_roms/na1/start.htm)

Makundi W. R. and J.A. Sathaye, (2004) GHG Mitigation Potential and Cost in Tropical Forestry – Relative Role for Agroforestry. Environment, Development and Sustainability 6: 235–260, 2004.

Makundi, W. R., Sathaye, J. and Ketoff, A. (1995) COPATH—a spreadsheet model for the estimation of carbon flows associated with the use of forest resources. Biomass and Bioenergy **8: 5**, 369-380

Makundi, W. R., Sathaye, J. and Ketoff, A. (1991) COPATH: Description of a spreadsheet mode for estimation of carbon flows associated with forest use. Lawrence Berkeley Laboratory Report, LBL-30525. Berkeley.

Malawi Government, (2006), Tree Planting and Management for Carbon Sequestration and Other Ecosystem Services Programme. Department of Forestry: Lilongwe.

Masera, O.R., Ceron, A.D. and Ordonez, A. (2001), Forestry mitigation options for Mexico: Finding synergies between national sustainable development priorities and global concerns. Mitigation and Adaptation Strategies for Global Change **6**, 291–312.

Nabuurs, G.J., O. Masera, K. Andrasko, P. Benitez-Ponce, R. Boer, M. Dutschke, E. Elsiddig, J. Ford-Robertson, P. Frumhoff, T. Karjalainen, O. Krankina, W.A. Kurz, M. Matsumoto, W. Oyhantcabal, N.H. Ravindranath, M.J. Sanz Sanchez, X. Zhang, (2007). Forestry. In Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

NEC, (2000) Economic Report 2000, National Economic Council, Lilongwe.

Nijnik, M. (2005), Economics of climate change mitigation forest policy scenarios for Ukraine, Climate Policy **4**:319-336.

Ravindranath, N.H., Sundha, P. and Sandhya, R. (2001), Forestry for sustainable biomass production and carbon sequestration in India, Mitigation and Adaptation Strategies for Global Change **6**, 233–256.

Riahi, K., A. Gruebler, and N. Nakicenovic, (2006). Scenarios of longterm socio-economic and environmental development under climate stabilization. Technological Forecasting and Social Change, Special Issue.

J.A. Sathaye, W.R. Makundi, K. Andrasko, R. Boer, N.H. Ravindranath, P. Sudha, S. Rao, R. Lasco, F. Pulhin, O.Masera, A. Ceron, J. Ordonez, X.Deying, X. Zhang and S. Zuomin (2001) Carbon mitigation potential and costs of forestry pptions in Brazil, China, India, Indonesia, Mexico, The Philippines and Tanzania. Mitigation and Adaptation Strategies for Global Change **6:** 185–211, 2001.

Sathaye, J.A., W. Makundi, L. Dale, P. Chan and K. Andrasko, (2007). GHG mitigation potential, costs and benefits in global forests: A dynamic partial equilibrium approach. Energy Journal, Special Issue 3, pp. 127-172.

Sathaye, J. and S. Meyers, (1995). Greenhouse Gas Mitigation Assessment: A Guidebook. Kluwer Academic Publishers: London.

Sohngen, B. and R. Sedjo, (2006). Carbon sequestration costs in global forests. Energy Journal, Special Issue, pp. 109-126.

Strengers, B., J. Van Minnen and B. Eickhout, (2007). (in print): The role of carbon plantations in mitigating climate change: potentials and costs. Climatic change.

UNFCCC, (2006). Background paper for the workshop on reducing emissions from deforestation in developing countries, Working Paper No. 1b, Rome, Italy.

Van Kooten, G.C., Eagle, A.J. Manley, J. Smolak, T., (2004), How costly are carbon offsets? A meta-analysis of carbon forest sinks, Environmental Science & Policy **7**:239–251

Vuuren, D. Van, M. den Elzen, P. Lucas, B. Eickhout, B. Strengers, B van Ruijven, S. Wonink, and R. van Houdt, (2007). Stabilizing greenhouse gas concentrations at low levels: an assessment of reduction strategies and costs. Climatic Change, **81**(2):119-159.

Waterloo, M.J., P.H. Spiertz, H. Diemont, I. Emmer, E. Aalders, R. Wichink-Kruit, and P. Kabat, (2003). Criteria potentials and costs of forestry activities to sequester carbon within the framework of the Clean Development Mechanism. Alterra Rapport 777, Wageningen, 136 pp.

Xu, D., Zhang, X.Q. and Shi, Z. (2001), Mitigation potential for carbon sequestration and emission reduction through forestry activities in southern and eastern China, Mitigation and Adaptation Strategies for Global Change **6**, 213–232.