Environment & Ecology 29 (2A) : 822—830, 2011
 ISSN 0970-0420

Carbon Economics and Small Holders Livelihood in India

ANUJ KUMAR SINGH AND A. K. SAHOO

College of Forestry, Orissa University of Agriculture & Technology
Bhubaneswar 751003, India
E-mail : drashokkumars@yahoo.com

Abstract

The potential of Indian forests for carbon sequestration is intriguing. In Indian context, the Kyoto protocol may provide an opportunity for rural community to uplift their livelihood by carbon forestry and by linking to carbon trading markets. Small holders, who do sequester carbon and also reduce emissions through their plantations, individually and collectively, and qualify for the minimum tradable carbon, should be benefited by clean development mechanism (CDM) projects. Incentives and plans for adoption of sound technical practices are needed for farmers, foresters and other land managers. Implementation of such plans will require better understanding of rural society and the market incentives needed for adopting changes in farming, grazing, and forestry practices that benefit all sectors of society. The economic value of forestry carbon needs to be assessed with consideration for both onsite and offsite effects and policies need to be established that provide incentives for net carbon sequestration at the local scale. Such policies can provide financial incentives to the plantation growers especially small holders in India. Enhancing the soil organic carbon pool through local, national and global policy incentives may be especially beneficial to improve agronomic productivity, enhancing food security and most importantly reducing poverty in developing countries, thus the goals of Kyoto protocol will be accomplishing and this global treaty will be able to provide benefits to the society. Review of available information on growing forest productivity, increment in forest soil carbon stock and growing forest cover of the country concludes a tremendous scope for carbon storage in the forest cover and soil.
Key words : Kyoto protocol, Small holders, CDM, Carbon economics, Livelihood.

There is much concern that the increasing concentration of greenhouse gases (GHGs) in general, and carbon dioxide in particular, in the atmosphere contributes to global warming by trapping long-wave radiation reflected from the earth's surface (1). The accumulation of carbon dioxide and other greenhouse gases in the atmosphere is expected to cause observable climatic changes in the coming century. Approximately 22% of the annual global carbon dioxide emission results from human activities such as deforestation. Major cause is supposed to be burning of fossil fuels for various purposes, which is releasing great volumes of carbon dioxide in the atmosphere. The problem of increasing atmospheric carbon dioxide can be addressed in a number of ways. One practicable and realistic approach for climate change mitigation is forests and forestry based interventions. The forestry sector plays a vital role in the global balance of GHGs. Deforestation alone accounts for approximately 20% of anthropogenic emissions (2, 3) and the forestry sector represents upwards of 50% of global greenhouse gas mitigation potential. Climate change mitigation involves reducing the greenhouse gas emissions from energy and biological sources or enhancing the sink of greenhouse gases. A forest not only provides different ecological and environmental services but also renders livelihoods support to the rural community. Forests play an important role in global environmental management and sustainable development. Forests are one of the major carbon sinks well known for long-term carbon storage in the form biomass. The process of carbon assimilation and long-term biological storage is called to be as carbon sequestration. The ability of forests to sequester carbon has been recognized as an additional livelihood support for the community and carbon sequestered in the plant biomass has now recognized as a tradable commodity. The emerging trend of carbon trading is being considered as a potential mechanism to provide a sustainable additional livelihood support to the community. Trading in carbon credits from afforestation and reforestation is foreshadowed by the

Table 1. Estimates of total forestry carbon pool and CO_2 emission in Indian forests.

Years	Forest area (Mha)	Biomass (Mt)	Carbon pool (Mt)	Net release (TgC/yr)
1980	63.2	NA	NA	41.3
1984	64.2	2398	1085.16	NA
1985	64.2	4432	1994.40	42.5
1986	64.0	8358	3761.1	-5.00
1988	63.9	7742	3484.08	32.75
1993	64.0	8683	3907.67	NA
1995	63.9	4503.8	2026.71	-12.5

Kyoto protocol. Human-induced sinks can compensate for human-induced emissions. Forests are sinks only when they are expanding in area or carbon density, and because there is a limit to the quantity of growing stock per unit area, afforestation must be continuous. Forest sinks are important in the current decade because they are seen as being a relatively low-cost first step for reduction of net greenhouse gas emissions. Thus, forests are not only a natural resource for timber and fuel wood but also potential sink for carbon sequestration and a sustainable source of livelihood for a sizeable group of community. This article discusses potential of Indian forest cover for carbon sequestration, points out several aspects of carbon forestry, carbon economics and also deals prospects of livelihood upliftment through carbon forestry.

Carbon Dynamics and Sequestration in Forests

Carbon is held in the terrestrial system in vegetation and soils. Oceans also hold large volumes of carbon, as does the atmosphere. Additionally, fossil fuels, e.g., coal, petroleum, and natural gas, contain large amounts of carbon, which are released upon burning. The problem being faced by human society is that large volumes of carbon previously held captive in fossil fuels are being released into the atmosphere due to intensive fossil fuel burning to meet energy demands. Additionally, rocks hold carbon that is generally captured and released only slowly, through the processes of weathering and rock formation. These processes are supplemented by volcanic action and the venting of gases from the earth.

Table 2. Status of forest covers of India in 2007. Forest Survey of India (2009).

Class	Area (km^2)	Percent of geographical area
Forest Cover		
Very dense forest	83,510	2.54
Moderately dense forest	319,012	9.71
Open forest	288,377	8.77
Total Forest Cover	690,899	21.02
Non Forest		
Scrub	41,525	1.26
Non-forest	1554,839	77.71
Total Geographical Area	3287,263	100.00

Such releases of carbon occur on a much longer time scale than the others and are ignored in this discussion. The global carbon cycle involves carbon flows among the various systems—terrestrial, atmospheric, and oceanic. Biological growth captures carbon from the atmosphere and distributes it within the terrestrial system. Decomposing vegetation and respiration releases carbon back into the atmosphere. The process of photosynthesis combines atmospheric carbon dioxide with water, subsequently releasing oxygen into the atmosphere and incorporating the carbon atoms into the cells of plants. Additionally, forest soils capture carbon. Trees, unlike annual plants that die and decompose yearly, are long-lived plants that develop a large biomass, thereby capturing large amounts of carbon over a growth cycle of many decades. Thus, a forest ecosystem can capture and retain large volumes of carbon over long periods. Forests operate both as vehicles for capturing additional carbon and as carbon reservoirs.

A young forest, when growing rapidly can sequester relatively large volumes of additional carbon. An old-growth forest acts as a reservoir, holding large volumes of carbon even if it is not experiencing net growth. Thus, a young forest holds less carbon, but it is sequestering additional carbon over time. An old forest may not be capturing any new carbon but can continue to hold large volumes of carbon as biomass over long periods of time. Managed forests offer the opportunity for influencing forest growth rates and providing for full stocking, both of which allow for more carbon sequestration. Forest systems operate

Table 3. Soil organic carbon pool of different forest groups in India for 1995 and 2005. (area in 000 ha). Source : Kishwan et al. (22).

Forest type (group)	Area 1995	Area 2005	Mean soil carbon	Total SOC 1995	Total SOC 2005
Himalayan dry temperate forest	31	32	36.198	1122.144	1158.343
Himalayan moist temperate forest	2230	2447	71.577	159616.937	175149.168
Littoral and swamp forest	383	481	71.062	27216.904	34181.021
Montane wet temperate forest	2583	2593	115.460	298233.293	299387.893
Sub-alpine and alpine forest	2021	2067	74.071	149698.375	153105.661
Sub-tropical broad leaved hill forest	260	303	86.611	22518.833	26243.102
Sub-tropical dry evergreen forest	1223	1248	65.279	79836.780	81468.766
Sub-tropical pine forest	4556	4743	50.270	229031.601	238432.151
Tropical dry deciduous forest	18223	19156	34.195	623475.447	655037.332
Tropical dry evergreen forest	134	165	52.398	7021.463	8645.709
Tropical moist deciduous forest	23091	24284	55.009	1270222.177	1335848.398
Tropical semi-evergreen forest	2573	2946	54.625	140549.907	160925.000
Tropical thorn forest	1604	1827	20.375	32681.741	37225.399
Tropical wet evergreen forest	5040	5414	101.404	511078.124	549003.366
Total	63962	67706		3552303.628	3755811.310

on a cycle of many decades and centuries, rather than annually or over a few years as would be the case with most crops and non-tree vegetation. As forest biomass expands, the amount of carbon contained in plant increases. As the biomass contract, the forest holds less carbon. In an unmanaged state, forests recede and flow in response to disturbances in the natural system. Forest disturbance regimes are part of the natural ecological system, with wind, disease, fire and other natural, i.e., non-anthropogenic, events causing forest destruction and death. These events result in the release of carbon into the atmosphere but also are typically followed by the regrowth of the forest, which, in turn, begins a new process of carbon buildup in the forest. In some cases, these disturbances are catastrophic in that large areas of the forest landscape are disturbed, as with large wildfires such as are common in many pine and boreal forests.

In other cases, the disturbances are highly localized, as with an occasional tree death due to disease or old age such as is common in many tropical forests. Carbon release is occasioned by the disturbance and often in the decay and decomposition of dead matter that follows. However, most natural forests have provisions for natural regeneration and regrowth, which, once again, captures carbon. Thus carbon is recycled in the forest ecosystem. There are three basic approaches for using forests as a means of mitigating climatic change (4) : (a) Maintaining or increasing existing stocks of carbon in forests that are currently threatened, (b) creating new stocks in growing trees (e.g. agroforests and forest plantations), and (c) substitution of energy demand materials by renewable natural resources (fuel wood crops). While the existing carbon stocks can be maintained through forest conservation (e.g. the rainforest trees will accumulate carbon in their wood for more than a century (5), new plantations should be established on non-forest lands as a means to enhance the sink potential. Carbon sequestration in terrestrial ecosystems can be defined as the net removal of CO_2 from the atmosphere into long-lived pools of carbon. The pools can be living, above ground biomass (e.g., trees), wood products with a long, useful life created from biomass (e.g., lumber), living biomass in soils (e.g., roots and microorganisms), or recalcitrant organic and inorganic carbon in soils and deeper subsurface environments. It is important to emphasize that increasing photosynthetic carbon fixation alone is not enough. This carbon must be fixed into long-lived pools. Otherwise, one may be simply altering the size of fluxes in the carbon cycle, not increasing carbon sequestration. Plants capture CO_2 during photosynthesis and transform it to sugar and subsequently to dead organic matter. As the trees grow, they sequester carbon in their tissues, and as the amount of tree biomass increases, the increase in atmospheric CO_2 is mitigated (6).

Forests have always sequestered carbon, but this ecosystem service went unnoticed. carbon Sequestration refers to storage of carbon in a stable solid form, it occurs through direct and indirect fixation of atmospheric CO_2. Indirect carbon sequestration occurs by inorganic chemical reactions that convert CO_2 into soil organic carbon compounds such as calcium and magnesium carbonates. Direct plant carbon sequestration occurs as plants synthesize atmospheric CO_2 into plant biomass. Subsequently, some of this plant biomass is indirectly sequestered as soil organic carbon during decomposition process. Carbon sequestered directly by plants can be stored for a considerable period of time (7). These sinks can be above ground biomass (trees) or living biomass below the ground in soil (roots and micro organisms) or in the deeper sub-surface environments. Sequestration, which is relatively a new term, can be described as storage of all forms of carbon, including storage in terrestrial, geological and oceanic ecosystem. Through practices and technologies of sequestration seek to quantify and enhance the storage ability of all potential sinks and expand the number and type of sinks in which carbon storage is possible. Enhancing the natural processes that remove CO_2 from the atmosphere is thought to be one of the most useful methods of mitigating the atmospheric levels of CO_2. There are three basic approaches to sequester carbon in terrestrial ecosystems, which are (i) increasing the inputs of carbon (carbon productivity) to an ecosystem, (ii) partitioning carbon to longer lived pools, and (iii) maintaining and increasing the capacity of existing carbon pools. The general goal of sequestration activities is to maintain ecosystem in the sink phase. However, if the system is disturbed (a forest burns or is harvested or land is cultivated), a large fraction of previously accumulated carbon may be released into the atmosphere through combustion or decomposition. Currently, emissions of CO_2 are increasing globally and are projected to double over the next century. This excess CO_2 enters the global carbon cycle where part remains in the atmosphere, part is taken up by oceans and the terrestrial biosphere. But significant uncertainty still surrounds the quantitative description of the natural carbon cycle. A major challenge of the greenhouse gas and climate change issue is to understand what happens to the excess CO_2 generated from the burning of fossil fuels. In particular, the rate and magnitude by which excess carbon is assimilated into terrestrial and oceanic sinks will determine the balance that remains in the atmosphere. While research in this challenging area continues, there are new efforts to begin research that might help mitigate increasing CO_2 emissions through special efforts to sequester CO_2. Carbon sequestration in terrestrial ecosystems can be defined as the net removal of CO_2 from the atmosphere into long-lived pools of carbon. The pools can be living, above ground biomass (e.g., trees), wood products with a long, useful life created from biomass (e.g., lumber), living biomass in soils (e.g., roots and microorganisms), or recalcitrant organic and inorganic carbon in soils and deeper subsurface environments.

Carbon Sequestration in India's Forest : Present Status and Future Projections

The forest inventories and ecosystem models are widely used for broad scale quantification of forest carbon pools and fluxes (8). In India, biomass carbon stock and carbon budget estimation has been done by various workers on the basis of growing stock volume data (Table 1). The studies used standard conversion and expansion factors (or, IPCC default factors) to make an overall estimate of biomass pools and total C stock. The estimated Indian forest phytomass carbon densities for the recent period are mostly in the range of 50—68 t/ha. Using field inventory of growing stock volume and biomass expansion factors relating wood volume to biomass, forest phytomass C pool was estimated in the range of 2.5—4.1 Pg C estimated the total carbon pool of Indian forests to be 1.9 Pg C for 1985, and 1995 to be 2027 Mt, 4503.82 Mt respectively (9—11). The carbon storage estimate (2,027 Mt) for 1995 is higher than reported by Dadhwal and Nayak (12). By Chhabra and Dadhwal (13) the total forest phytomass pool was estimated as 3.871 and 3.874 Pg C in 1988 and 1994, respectively. In a more recent study using the forest inventories, thematic maps and vegetation maps of FSI, Manhas and co-workers (14) calculated growing stock for each forest types pertaining to 1984 and 1995 that incorporated wood density of dominant species for each stratum estimated the biomass of India's forest to be 5,995.48 Mt and 5,987 Mt for 1984 and 1995 respectively. According to their estimate

Table 4. Component-wise carbon in India's forests in 1995 and 2005 (million tonnes). Source : Kishwan et al. (22).

Carbon	1995	2005	Incremental change
In biomass	2692.474	2865.739	173.265
In soil	3552.304	3755.811	203.507
Total	6244.778	6621.55	376.772

the C stock of ABG biomass would be 1,085 Mt for 1984 and 1,083 Mt for 1995.

Wide differences in estimate of carbon flux made for Indian forest was also observed. The earlier estimate of carbon emission was in the range of 63×10^6t (15). A study estimated annual carbon uptake which was 27.8 Mt, 32.1 Mt and 34.1 Mt for the year 1985, 1990 and 1995 respectively, and computing the carbon released for the corresponding period, the net CO_2 uptake in the forests to be 0.02 Gt, 0.03 Gt and 0.04 Gt for the periods (16). Decay of products or soil carbon flux was not considered in the estimate. With respect to CO_2 emissions, Indian forestry sector was estimated to be net CO_2 sink for 1986, a marginal source in 1990 and 1994 and it is projected to be a significant source of 76 Mt of CO_2 by 2020. Chhabra and Dadhwal (13) reviewed various estimates of carbon release from Indian forests which reveals no uniformity in findings between studies.

India is a large developing country well known for its diverse forest ecosystems, diverse climatic patterns and vast biological diversity. Due to its extended forest and tree cover it has registered a place in the list of most forested countries of the world with 22.28% of its geographical area under forest cover. Conservation and management of existing forests and development of new forests for carbon sequestration has many advantages like production of timber, biodiversity conservation and soil conservation. In addition to ecosystem services, forests provide livelihoods and helps in poverty alleviation. Absorbing CO_2 from atmosphere and converting it into plant biomass and further storage for a substantial period of time could be a cost effective and practical approach for removal of large volumes of green house gases. This approach could be realistic and fruitful in order to mitigate global warming and climate change effects. The carbon sequestration potential of forests is substantial and has been established in several studies (17—19). In India, CO_2 emissions from forest degradation or loss are largely offset by carbon uptake due to forest increment and afforestation. The improved quantification of pools and fluxes related to the forest carbon cycle is important for understanding the contribution of India's forests to net carbon emissions as well as their potential for carbon sequestration in the context of the Kyoto protocol (20).

India's total forest cover accounts for 22.28 of the total geographical area of the country as of 2007 (21) (Table 2). Over the last two decades, progressive national forestry legislations and policies in India aimed at conservation and sustainable management of forests have reversed deforestation and have transformed India's forests into a significant net sink of CO_2. From 1995 to 2005, the carbon stocks stored in our forests and trees have increased from 6,245 million tonnes (mt) to 6,662 mt, registering an annual increment of 38 mt of carbon or 138 mt of CO_2 equivalent. Soil organic carbon pool for different forest groups and component wise carbon in India's forest was reported (22) for 1995 and 2005 (Table 3) which indicates India's forests as a major sink of CO_2. Thus India's forest and tree cover are serving as major mode of carbon mitigation for India and the world. India is one of the few developing countries in the world that in making a net addition to its forest and tree cover over the last two decades. Based on trends of forest cover increment, three scenarios are predicted for carbon stocks in the forest and tree cover of India. In the first scenario, the carbon stocks in India's forest and tree cover decrease at the rate of the world average. Under this scenario, the total carbon stored in India's forests in 2015 will decrease to 6,504 mt. In the second scenario, the carbon stocks in India's forest and tree cover continue to increase at the historical rate of the last decade (0.6% p.a.). Under this scenario, the total carbon stored in India's forests in 2015 will increase to 6,998 mt. In the third scenario, the carbon stocks in India's forest and tree cover increase at a rate higher than the historical rate of increase. Under this scenario, the total carbon stored in India's forests in 2015 will increase to 7,283 mt (23).

Future projections of C sequestration potential of Indian forests have been attempted based on current rate of plantations, harvesting and deforestation trend in India. Prasad and co-workers (24) have modeled the land use changes and forestry data of India from 1997 to 1999 and suggested that Indian forests would be a potential sink for 0.94 Gt of carbon over a period of time, with an increase in dense forest area of about 76 Mha and decrease of about 3 Mha and 5 Mha in open and scrub forests, if similar land use changes that occurred during 1997–1999 would continue. A study reports by using land use and carbon sequestration (LUCS) model and estimated that 7 billion tones of carbon will be sequestered during 2000—2050 (25). In an earlier study, a comparison of the commercial forestry scenario over the base line scenario (in the period 2000—2012) estimated that an additional carbon stock of 78×10^6 Mg C would be sequestered from meeting all the incremental biomass demands (26) (estimated for 2000—2015). The sequestration potential was projected to be 4.1 Gt in 2020 if the total forest cover remains stable at 64 Mha and plantation covers another 0.5 Mha of forest land per year (27).

Kyoto Framework : Carbon Forestry and Carbon Economics

Carbon sequestration in the context of the Kyoto protocol includes the definition of allowable sinks and the manner in which functioning of the sinks will be allowed. Carbon sequestration is cevered by subsections of Article 3 of the Kyoto protocol : Article 3.3 allows for afforestation, reforestation and deforestation since 1990. Article 3.4 provides for a process for the inclusion of additional sink activities such as soils. Article 3.7 provides for inclusion of emissions from land use change in the 1990 baseline emission.

Carbon sequestered by forests planted since 1990 will be allowed as carbon sinks; these forests are termed 'Kyoto forests'. Trees sequester carbon in their early juvenile stages where net primary productivity (NPP) is high and respiration is only a small proportion of gross primary productivity (GPP). As forests senesce, NPP declines and almost all energy captured by the plants is used in respiration or maintenance; this results in negligible additional carbon sequestration. This means that Kyoto forests must be managed and eventually harvested in order to maintain sequestration of atmospheric carbon. It appears that such harvesting may be allowed without debit if the extent of the balance of carbon in planted, growing and harvested forests are such as to keep a reasonably constant rate of carbon sequestration in the landscape.

A period between 2008 and 2012 has been set as the first commitment period by the UNFCCC. Allowable sink activities such as carbon sequestration by forests planted since 1990 will be counted towards meeting the emission targets of participating countries. The importance of this period is that a lead time is required to get trees up to their maximum rate of carbon sequestration. Any early loss of soil carbon due to changing land use and establishment of plantations will need to be offset by the forest sink in time for measurement and verification of carbon in sinks for the commitment period. In order for a healthy and rapidly growing forest with an increasing soil carbon sink to be counted towards emission reduction, the forests need to be either in the ground now, or being planned to be planted in the next two years, depending on the fertility, climate and production potential of the intended site.

The Kyoto protocol was adopted at the conference of parties (COP) of the United Nations Framework Convention on Climate Change (UNFCCC) in Kyoto in 1996, where, the developed countries along with some countries falling under "Economies In Transition" (EIT), categorized as Annex-1 countries, were required to reduce their emission by an average of 5% relative to 1990 levels by the year 2012. For this, carbon sequestration is considered as one of the important strategies through sink enhancement. The Kyoto protocol potentially offers an opportunity for capital investment and technology transfer for commercial forestry, under the afforestation / reforestation activities of the clean development mechanism (CDM).

Under the Kyoto protocol, industrialized countries and countries with economies in transition will reduce their combined GHG emissions by at least 5% below their 1990 levels by the first commitment 2008 to 2012. The most important GHG is carbon dioxide (CO_2) whose emissions are mainly related to combustion of fossil fuels. Carbon, in the form of carbon dioxide CO_2 is accumulating in the atmosphere at a rate of about 3.5 billion metric tones per annum as a result of fossil fuel combustion, tropical deforestation and forest fuel combustion. The accumulation of carbon dioxide (CO_2) and other greenhouse gases (GHGs) in the atmosphere is expected to cause observable climatic changes in the coming century. The Kyoto protocol to the United Nations Framework Convention on Climatic Change, if ratified, will require developed nations to reduce their net carbon emission in the period 2008—2012 to less than wheat was emitted in 1990. Approximately 22% of the annual global carbon dioxide emission results from human activities such as deforestation. The six major gases in the earth's lower atmosphere which are responsible for global warming are carbon dioxide (CO_2), hydrofluoro carbons (HFC's), methane (CH_4), nitrous oxide (N_2O), per fluorocarbons (PFCs) and sulfur hexafluoride (SF_6). If the atmospheric concentrations of these green house gases rise and other natural processes do not remove them, the average temperature of the lower atmosphere will progressively amplify which could be hazardous for the entire living organisms in the long run. The preconditions are present in the Kyoto protocol for forestry to play a significant role in addressing the atmospheric carbon issue. That is, the Kyoto protocol recognizes forestry as an acceptable carbon sequestration vehicle, and forestry offers possibilities for significant carbon influence over the time period allowed. In addition, forestry based interventions do not need development of new technologies, as community is well versed with the management of plants and they are aware enough about the role and importance of forests in the environment.

Among many of the causes which are attributed to contribute to the climate changes, green house gas emissions are noted to be on top of the list. Reducing emissions and sequestering carbon are recognized to be the best approach to this global issue of discussion. The forestry sector has sufficient potential to sequester atmospheric carbon dioxide. However, managing natural forests alone for maximizing carbon sequestration will compromise their other ecological functions. Hence, the need for production forestry, which means any plantation carried out outside the natural forest area for meeting various demands of the country. Production forestry in India can bridge not only the constantly increasing gaps between the demand and supply of industrial timber, but also help the nation enhance carbon sequestration. In addition, it can help conserve bio-diversity by reducing large-scale removals of fuel-wood from natural forests, and also create much needed employment opportunities in rural areas, which can curtail poverty driven forest degradation. In carbon sequestration through sink enhancement by way of growing more trees, the industrialized countries, through CDM options, are allowed to buy carbon credits that are generated by carbon sequestration projects in developing countries. It gives the industries, targeted for emitting GHGs, the flexibility to continue using fossil fuel for some time, which will act as a buffer in the process of switching over to more efficient energy source, if they invest in sequestering carbon. By way of investment from developed countries, the CDM projects could also lead to a large positive impact on programs which are aimed at forest conservation and regeneration, through afforestation / reforestation, reclamation of degraded lands and socio-economic development of rural communities, in addition to the global environmental benefits. Now this is being looked upon as a major benefit with market instruments favoring the active involvement of industry in the mechanism. The potential for CDM related projects is quite high in India. Although it is not mandatory for Indian industries to meet any sort of targets under Kyoto protocol, they prefer to favor this phenomenon as it strengthens their claim for using the wastelands for this purpose in the country. India has the biggest scope for generating certified emission reductions (CERs). Currently; India has the largest number of CDM projects. Government of India has set up a National Designated Authority (NDA) to deal with the CDM projects in the country. The global carbon market has been linearly expanding in recent years. From a meager of about 8 billion Euros in 2005, it has grown to about 92 billion Euros in 2008 (28). Through this opportunity, a number of agencies, corporate houses and some large NGOs have benefited from it. The paid up benefits so far have been for reducing emissions, carbon sequestration, or both. Few such benefits have also accrued in India, but mostly for reducing the emissions. However, only large companies, which could qualify for the minimum tradable amount of carbon, afford to properly write the application, prove the additionality in emission reduction, and/or carbon sequestration and get their efforts/projects validated, mostly by external agencies at usurious costs (some times running to between 100 and 200 thousand dollars per case), have been able to cash on this opportunity.

Most of the carbon market trade involves emission reduction credits but there is also growing interest in the use of trees and forests for absorbing carbon dioxide from the atmosphere. The clean development mechanism (CDM) of the Kyoto protocol and some voluntary carbon markets, such as the Chicago Climate Exchange, allow countries and companies to offset their carbon emissions by carrying out tree planting projects. There is also considerable evidence that forests and agro-forestry (the planting of trees on farms) in developing countries provide substantial benefits to rural dwellers, national economies, and the environment. Trees provide a range of products for home use such as food, timber, firewood, medicines, and fodder and products for sale, boosting farm incomes, rural economies, and national exports. Trees on farms and in forests can also provide a range of environmental services, such as conserving biodiversity, reduced soil erosion and sedimentation in rivers and lakes, and increased soil fertility. Moreover, what is often unrecognized is that while forested area is declining in developing countries, tree cover on farms is rapidly increasing, as farmers substitute for the tree products they formerly accessed from forests and seize market opportunities for selling tree products. Sequestered carbon is now a globally traded commodity. As a commodity with the ability to provide economic returns to land managers, carbon sequestration can serve as a new catalyst for improved forest management practices. Unlike traditional development models based on deferred and diffused benefit streams, the new carbon-market model offers an opportunity to directly link land management and natural resource conservation with specific and immediate market incentives. This market-driven approach will stimulate growth and development of local social and technical infrastructure that is self-sustaining and can be maintained over the long term, with highly valued additional benefits.

References

1. IPCC. 1995. *Climate change : The science of climate change.* Cambridge Univ. Press, Cambridge, UK.
2. FAO. 2006. *Global forest resources assessment 2005 : Progress towards sustainable forest management.* FAO Forestry Paper 147. Food and Agric. Organ., United Nations, Rome.
3. Stern N. 2006. *The economics of climate change.* Cambridge Univ. Press, Cambridge, UK.
4. Schlamadinger B. and G. Marland. 2000. Land use and global climate change : Forests. *Land Sci.* 256 : 70—74.
5. Chambers J. Q., N. Higuchi, E. S. Tribuzy and S. E. Trumbore. 2001. Carbon sink for a century. *Nature* 41 : 429.
6. Dyson F. J. 1977. Can we control the carbon dioxide in the atmosphere ? *Energy* 2 : 287—291.
7. Watson R. T., I. R. Noble, B. Bolin, N. H. Ravindranathan and D. J. Verardo (eds.). 2000. *Land use, land use change and forestry.* Special report of the intergovernmental panel on climate change. Cambridge Univ. Press, Cambridge, UK.
8. Fang J., A. Chen, C. Peng, S. Zhao and L. Chi. 2001. Changes in forest biomass carbon storage in China between 1949 and 1998. *Science* 292 : 2320—2322.
9. Hingane L. S. 1991. Some aspects of carbon dioxide exchange between atmosphere and Indian plant biota. *Climate Change* 18 : 425—435.
10. Ravindranath N. H., B. S. Somashekhar and M. Gadgil. 1997. Carbon flows in Indian forests. *Climate Change* 35 : 297—320.
11. Dadhwal V. K., N. Shukla and A. B. Vora. 1997. Forest litter fall in India : A review and estimate of litter fall C flux. *Ind. Forester* 123 : 45—52.
12. Dadhwal V. K. and S. R. Nayak. 1993. A preliminary estimate of biogeochemical cycle of carbon for India. *Sci. & Cul.* 59 : 9—13.
13. Chhabra A. and V. K. Dadhwal. 2004. Assessment of major pools and fluxes of carbon in Indian forests. *Climatic Change* 64 : 341—360.
14. Manhas R. K., JDS Negi, R. Kumar and P. S. Chauhan. 2006. Temporal assessment of growing stock, biomass and carbon stock of Indian forests. *Climate Change* 74 : 191—221.
15. Ravindranath N. H., R. K. Chaturvedi and I. K. Murthy. 2008. Forest conservation, afforestation and reforestation in India : implications for forest carbon stocks. *Cur. Sci.* 95 : 216—222.
16. Lal M. and R. Singh. 2000. Carbon sequestration potential of Indian forests. *Environm. Monit. and Assess.* 60 : 315—327.
17. Dixon R. K., J. K. Winjum, K. J. Andrasko, J. J. Lee and P. E. Schroeder. 1994. Integrated systems : assessment of promising agroforests and alternative land use practices to enhance carbon conservation and sequestration. *Climate Change* 30 : 1—23.
18. Nilsson S. and W. Schopfhauser. 1995. The carbon sequestration potential of a global afforestation program, *Climatic Change* 30 : 267—293.
19. IPCC. 1997. *Lend use change and forestry. In* J. T. Houghton, L. G. Meira Filho, B. Lim, K. Treanton, I. Mamaty, Y. Bonduki. D. J. Griggs and B. A. Callander (eds). *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories : Reference Manual.* Volume 3. Intergovt. Panel on Climate Change 10th Dec., 2007. http://www.ipccnggip.iges.or.jp/public/gl/invs6d.htm.
20. Chhabra A., S. Palria and V. K. Dadhwal. 2003. Soil organic carbon pool in Indian forests. *Forest Ecol.*

and Manag. 173 : 187—199.

21. FSI. 2009. *State of forest report. Forest survey of India.* Ministry of Environ. and Forests Govt. India, Dehra Dun, India, 226 pp.
22. Kishwan J., R. Pandey and V. K. Dadhwal. 2009. *India's forest and tree cover : Contribution as a carbon sink.* Tech. Paper No 130 ICFRE BI-23.
23. MoEF. 2009. *India's GHG emissions profile : Results of five climate modeling studies.* Climate Modeling Forum. Min. Environ. and Forests. Govt. India report. 60 pp.
24. Prasad V. K., K. V. S. Badrinath, H. Tsuruta, S. Sudo, S. Yonemura, J. Cardina, B. Stinner, R. Moore, D. Stinner and C. Hoy. 2003. Implications of land use changes on carbon dynamics and sequestration-Evaluation from forestry datasets. India. *The Environmentalist* 23 : 175—187.
25. Chhabra A. and V. K. Dadhwal. 2004. Assessment of major pools and fluxes of carbon in Indian forests. *Climatic Change* 64 : 341—360.
26. Ravindranath N. H., R. K. Chaturvedi and I. K. Murthy. 2008. Forest conservation, afforestation and reforestation in India : implications for forest carbon stocks. *Curr. Sci.* 95 : 216—222.
27. Lal M. and R. Singh. 2000. Carbon sequestration potential of Indian forests. *Environm. Mon. and Assess.* 60 : 315—327.
28. Sedjo R. A. 2001. *Forest carbon sequestration : Some issues for forest investments.*Discussion Paper. Resour. for the Future. 1—34. http://www.rff.org.