

Mitigation Potential of Carbon Sequestration through Forestry Activities: An Overview

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Abstract: This article explores the potential of forestry practices to mitigate climate change. Emission of greenhouse gases has become a matter of great concern because of the future projection of the global warming and related effects on biological life. Forests not only sustain its own carbon but also have the potential to absorb carbon from the atmosphere. Forest covers more than 4 billion hectares of the earth's land surface area and contains huge reservoirs of carbon in their biomass and soils. Understanding the role of forests in carbon cycles and predicting whether they will be carbon sinks or sources in the future are important in the ongoing international dialogue on climate change. Long term storage of carbon on land provides a solution by which humans can modify the dynamics of the carbon cycle. Methods include reducing land disturbance, reforestation, afforestation, altered forest management practices, altered land use patterns and consumption and fossil fuel substitution. Mitigation options by the forestry sector include extending carbon retention in harvested wood products, product substitution and producing biomass for bioenergy. Aggressive adoption of these forest management options are necessary to prevent forests from becoming a significant net source of CO₂ to the atmosphere in the future and contributing to climate change. There is a need to improve forest management and its economic implications with respect to improving carbon sequestration.

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1. Introduction

Carbon management in forests is the global concern to mitigate the increased concentration of green house gases in the atmosphere. It is estimated that the world's forests store 283 Gt of carbon in their biomass alone (FRA, 2005). Carbon dioxide (CO₂) is an important green house gas that influence global climate. Since the beginning of industrial revolution, carbon dioxide concentration in the atmosphere has been rising alarmingly. Prior to the industrial revolution carbon concentration in the atmosphere was around 372 ppm (Sage, 1995). If the pace of increase in carbon concentration remains constant, carbon concentration in the atmosphere would go up to 800-1000 ppm by the turn of this century (Whipps, 1990). Trees can contribute to mitigate green house effect and global warming. Terrestrial vegetation and soil currently absorb 40% of global carbon dioxide emission from human activities (Adam, 2001). Forests are the largest terrestrial reservoir of atmospheric carbon. They remove CO₂ from the atmosphere and store it in the organic matter of soil and biomass. The current carbon stock in tree biomass comprises half of the atmospheric storage and is continuing to grow deforestation the rate of which is decreasing but still high (Watson et al., 2000). The amount of carbon stored in a forest stand depends on its age and

productivity. The terrestrial carbon sink, inferred from changes in the concentrations of atmospheric gases and their isotopic composition is normally attributed to the global increase in productivity. The reduction in concentration of CO₂ in atmosphere can be achieved either by reducing the demand for energy or by altering the way the energy is used and by increasing the rates of removal of CO₂ from atmosphere through growth of terrestrial biomass (Bhadwal and Singh, 2002). The most promising management practices for CO₂ mitigation are afforestation and reforestation of blank areas.

Forests have traditionally been used for many products including timber, fuel-wood and fodder. Determining the biomass of forests is a useful way of providing estimates on the quantity of these components. The word biomass generally refers to a renewable resource of plant or animal origin. Forest biomass in contrast with agricultural or ocean biomass includes all renewable goods produced in the forests. The more important ones are the principal forest products derived from wood such as timber, pulpwood and fuel-wood. In addition, wood in other forms (residue from logging and sawmilling operations such as branches, tops, dead or diseased trees, saw dust, bark chips) and leaves constitute a substantial proportion of the potentially usable forest biomass

(Rawat and Nautiyal, 1988). The total above ground biomass of forests is defined as biomass density when assessed, may be expressed as dry weight per unit area usually in tonnes/hectare and is a useful way of quantifying the amount of resource available for all traditional uses. It either gives the quantity of total biomass directly or the quantity of each component (e.g. leaves, branches and bole) because their biomass tends to vary systematically with the total biomass. However, the biomass of each forest component depends on the forest type such as natural or planted forests. The quantity of biomass in a forest is the result of the difference between production through photosynthesis and consumption by respiration and harvest processes. Thus, it is a useful measure for assessing changes in forest structure. Changes in forest biomass density are brought about by natural succession. Biomass density is also a useful variable for comparing structural and functional attributes of forest ecosystems across a wide range of environmental conditions. Biomass of forests is also very relevant for issues related to global climate changes because forest can be a carbon source and sink. Therefore, the management of the forests can affect the global carbon cycle and climate change. Approximately 50 per cent of the biomass is carbon. This represents the potential amount of carbon that can be added to the atmosphere as CO₂ when the forest is cleared (Brown, 1997). Tipper (1998) estimated that deforestation contributes about 1.8 Gigatonne carbon (GtC) per year. However, forests can also remove CO₂ from the atmosphere through photosynthesis. It is estimated that 1.1 to 1.8 GtC per year can be sequestered in 50 years through forests (Makundi et al., 1998).

Global interests in climate change led to the establishment of the United Nations Framework Convention on Climate Change (UNFCCC) at the 1992 UN Conference on Environment and Development at Rio-de Janeiro. The objective of the convention was to stabilize atmospheric greenhouse gas concentration at the level that would prevent dangerous anthropogenic interference with the climate system. Changes in the cover, use and management of forests produce sources and sinks of CO₂ to and from the biosphere. To estimate the magnitude of these sources and sinks, requires, reliable estimates of the biomass density of forests undergoing change. Biomass density estimate also provides the means for calculating the amount of CO₂ that can be removed from the atmosphere by rejuvenating forests or by plantations because they establish the rates of biomass production and the upper bounds for carbon sequestration. This issue is receiving more attention because forests act as a means of mitigating greenhouse gas emissions, particularly CO₂, a major greenhouse gas and the one

fixed during photosynthesis. Practices such as sustainable forest management slow down deforestation and low impact logging decrease CO₂ emissions and conserve it. Other practices such as afforestation programmes on the exposed and barren lands sequester CO₂ (Brown et al., 1996). Furthermore, biomass density estimates of forests are extremely relevant for studying other global biogeochemical cycles such as nitrogen because the amount of other nutrient elements in forests is also related to the quantity of biomass present.

On the global scale, deforestation results in the release of approximately 1000 million tons of carbon to the atmosphere each year in the form of CO₂, an important greenhouse gas. This is about 15 per cent of the total human caused emission and is a significant portion of the global carbon cycle that could contribute to global climate change. The earth's terrestrial vegetation plays a pivotal role in the global carbon cycle. Tremendous amounts are actively exchanged between vegetation and atmosphere. Any land use practices that increase vegetation cover or reduce its removal, could have an influence on the global carbon budget by increasing the terrestrial carbon sink. Carbon sequestration is emerging as a major international policy goal in the context of increasing concerns about global climate change. The idea about mitigating it through forest conservation and management was initiated and in 1992 several countries agreed to the United Nations Framework Convention on Climate Change, with the major objectives of developing national inventories of greenhouse gas emission and sinks, and reducing the emission of greenhouse gases (FAO, 2001). At the third meeting of the United Nations Framework Convention on Climate Change (UNFCCC) in 1997 in the Kyoto, Japan, the participating countries through what would later become known as the Kyoto protocol, to reduce greenhouse gas emissions to 5 per cent or more below 1990 levels by 2012, which was extended up to 2017 in a recently held Climate Conference in Durban (COP-17) from November 28 to December 11, 2011 to establish a new treaty to limit carbon emissions. Finally forests are one of the alternatives to increase forest cover which will widen the area of carbon sink.

2. Causes of Climate Change

2.1 Natural Causes

The Earth's climate can be affected by natural factors that are external to the climate system, such as changes in volcanic activity, solar output, and the Earth's orbit around the Sun. Of these, the two factors relevant on timescales of contemporary climate change are changes in volcanic activity and changes in solar radiation. In terms of the Earth's energy balance,

these factors primarily influence the amount of incoming energy. Volcanic eruptions are episodic and have relatively short-term effects on climate. Changes in solar irradiance have contributed to climate trends over the past century but since the Industrial Revolution, the effect of additions of greenhouse gases to the atmosphere has been about ten times that of changes in the Sun's output.

2.2 Human Causes

Climate change can also be caused by human activities, such as the burning of fossil fuels and the conversion of land for forestry and agriculture. Since the beginning of the Industrial Revolution, these human influences on the climate system have increased substantially. In addition to other environmental impacts, these activities change the land surface and emit various substances to the atmosphere. These in turn can influence both the amount of incoming energy and the amount of outgoing energy and can have both warming and cooling effects on the climate. The dominant product of fossil fuel combustion is carbon dioxide, a greenhouse gas. The overall effect of human activities since the Industrial Revolution has been a warming effect, driven primarily by emissions of carbon dioxide and enhanced by emissions of other greenhouse gases. The build-up of greenhouse gases in the atmosphere has led to an enhancement of the natural greenhouse effect. It is this human-induced enhancement of the greenhouse effect that is of concern because ongoing emissions of greenhouse gases have the potential to warm the planet to levels that have never been experienced in the history of human civilization. Such climate change could have far-reaching and or unpredictable environmental, social, and economic consequences.

2.3 Short-lived and long-lived climate forcers

Carbon dioxide is the main cause of human-induced climate change. It has been emitted in vast quantities from the burning of fossil fuels and it is a very long-lived gas, which means it continues to affect the climate system during its long residence time in the atmosphere. However, fossil fuel combustion, industrial processes, agriculture, and forestry-related activities emit other substances that also act as climate forcers. Some, such as nitrous oxide, are long-lived greenhouse gases like carbon dioxide, and so contribute to long-term climate change. Other substances have shorter atmospheric lifetimes because they are removed fairly quickly from the atmosphere. Therefore, their effect on the climate system is similarly short-lived. Together, these short-lived climate forcers are responsible for a significant amount of current climate forcing from anthropogenic substances. Some short-lived climate forcers have a climate warming effect ('positive climate forcers)

while others have a cooling effect ('negative climate forcers). If atmospheric levels of short-lived climate forcers are continually replenished by ongoing emissions, these continue to exert a climate forcing. However, reducing emissions will quite quickly lead to reduced atmospheric levels of such substances. A number of short-lived climate forcers have climate warming effects and together are the most important contributors to the human enhancement of the greenhouse effect after carbon dioxide. This includes methane and tropospheric ozone, both greenhouse gases and black carbon, a small solid particle formed from the incomplete combustion of carbon-based fuels (coal, oil and wood). Other short-lived climate forcers have climate cooling effects, most notably sulphate aerosols. Fossil fuel combustion emits sulphur dioxide into the atmosphere in addition to carbon dioxide which then combines with water vapour to form tiny droplets (aerosols) which reflect sunlight. Sulphate aerosols remain in the atmosphere for only a few days (washing out in what is referred to as acid rain), and so do not have the same long-term effect as greenhouse gases. The cooling from sulphate aerosols in the atmosphere has, however, offset some of the warming from other substances. That is, the warming we have experienced to date would have been even larger had it not been for elevated levels of sulphate aerosols in the atmosphere.

3. Forests as an effective option for Carbon Storage

Global carbon is held in a variety of different stocks. Natural stocks include oceans, fossil fuel deposits, the terrestrial system and the atmosphere. About two-thirds of the globe's terrestrial carbon, exclusive of that sequestered in rocks and sediments is stored in the standing forests including forest debris and in forest soils. In addition, there are some non-natural man made stocks like long lived wood products and waste dumps. Five pools of carbon are involved in a forest ecosystem. These are aboveground biomass, belowground biomass, litter, dead wood and soil organic carbon. As the forest floor experiences growth, the carbon held captive in the forest stock increases. Simultaneously, plants grow on the forest floor and add to the carbon store (Kauppi and Sedjo, 2001). Over time, branches, leaves and other materials fall to the forest floor and may store carbon until they decompose. Forest soils too may sequester some of the decomposing plant litter through root/soil interactions. In addition carbon may be sequestered for long periods in long lived wood products resulting from forest harvests. Current literature shows ample evidence that forests could sequester carbon and reduce the potential impacts of climate change (Metz et al., 2001).

4. Forest management options for potential carbon sequestration

Forests have the potential to be managed to reduce atmospheric concentrations of CO₂ and thus mitigate climatic change. Mainly the management activities revolve around carbon conservation, carbon storage and carbon substitution (Brown et al., 1996).

4.1 Conservation Management: The goal of conservation management is to prevent carbon emissions to the atmosphere by conserving existing carbon pools in forests as much as possible through options such as controlled deforestation, protecting forest in reserves, lengthening rotation times, reducing damage to residual stand during harvesting etc. The most significant carbon conservation practice clearly would occur in the tropics where deforestation and degradation is currently estimated to emit about 100 million tonnes of carbon annually.

4.2 Storage Management: The goal of storage management is to increase the amount of carbon in vegetation and soil of forests by increasing the area and or biomass carbon of natural and plantation forests and to increase storage in durable wood product. Sequestering carbon by storage management is only a short term option producing a finite carbon sequestration potential beyond which little additional carbon can be accumulated.

4.3 Substitution Management: It aims at increasing the transfer of forest biomass carbon into products rather than using fossil fuel based energy and products and cement based products. Substitution management has the greatest potential in the long run i.e more than 50 years (Marland and Marland, 1992). This approach involves expanding the use of forests for wood products and fuels obtained either from establishing new forest or plantations or increasing the growth of existing forests through silvicultural treatments (Brown et al., 1996).

The above mitigation techniques can also be grouped into four categories (Nabuurs et al., 2007).

- Maintaining or increasing the forest area through reduction of deforestation and degradation and through afforestation/reforestation.
- Maintaining or increasing the stand level carbon density through the reduction of forest degradation and through planting, site preparation, tree improvement, fertilization, uneven-aged stand management or other appropriate silvicultural techniques.
- Maintaining or increasing the landscape level carbon density using forest conservation, longer forest rotations, fire management, and protection against insects.
- Increasing off-site carbon stocks in wood products and enhancing product and fuel substitution using forest derived biomass to substitute products

with high fossil fuel requirements and increasing the use of biomass derived energy to substitute fossil fuels.

5. Policy needed to achieve Carbon Sequestration

Policy makers could attempt to produce or induce increases in forest carbon sequestration in a variety of ways. The government could provide subsidies in the form of payments, tax credits or cost sharing to private land owners for adopting practices that are known to increase carbon stocks. Alternatively the government could tax undesirable land use changes or practices, establish a tradable carbon rights system or otherwise regulate activities on private lands. In addition the government could expand its own forest plantations on public lands.

6. Challenges

Although this is an overestimate of the feasible sequestration potential, it does suggest that there is substantial sequestration potential using forestry. The potentials of forestry are intriguing. Although sequestration through forestry does have limitations, it is generally agreed that large amounts of carbon could be sequestered utilizing existing technology (IPCC, 2001). Additionally, these activities could be undertaken over the next couple of decades. Although not the complete answer of the carbon problem, carbon sequestration through forestry does have the potential of stabilizing or at least contributing to the stabilization of atmospheric carbon in the near term (20-50 years) and thereby allowing time for the development of a more fundamental technological solution in the form of reduced carbon emission energy sources.

7. Conclusion

Forests are the major terrestrial sink for carbon in the world. They are also a potential source of biomass. Besides forests there are large areas of degraded lands that are available for re-vegetation and restoration of these lands must be given a high priority for economic and environmental reasons. To mitigate climate change, there should be policy reforms such as to encourage environmental sustainability, improve infrastructure and planning related to carbon sequestration research, long term monitoring and large financial commitment. Mitigation measures are required to reduce global greenhouse gas emissions with the intention of eventually stabilizing atmospheric concentrations at some level at which an acceptable dynamic equilibrium could be sustained between climate, ecosystems and human society. Anthropogenic activities such as deforestation, combustion, emission of greenhouse gases which are frequently released in the atmosphere should be

strictly prohibited. In addition to this alternatives of the fossil fuel should be found and invented. The temperate forests will probably continue to be net carbon sinks favoured by enhanced forest growth due to climate change. Aggressive adoption of forest management options that conserve sequester carbon are not only necessary for sustainable development but also for preventing forests from becoming a significant net source of CO₂ to the atmosphere in the future and contributing to climate change.

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