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CARBON CAPTURE THROUGH FORESTS & VEGETATION – AN ENVIRONMENTAL INKLING

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ABSTRACT

Forest envelop is one of many factors which affect climate at the global, regional and local scales. Throughout the globe, forests have been a source of inspiration for people who live in them or near them and have often identified forests, forest groves or even individual trees as sacred places or objects. Many environmental and ecological 'services' are derived from forests. In most cases, the forest ecosystem is one element in a complex interaction in which factors such as geographical location, size of the forested area, geology, human and animal activities all play a role. Different interpretations of the significance of forests in issues such as global climate change, flows of water in rivers, soil erosion, and more recently the carbon storage/sequestration and its dynamics are often related to the complexity of measuring the role of forest ecosystems as fact full questions. The existence and cycling of carbon in forest ecosystems is neither well understood nor recognized. Accordingly, its dynamics and recent portrait under climate change scenario is emerging as one of the biggest challenges for mankind, which needs to be sensibly tackled across the globe at all scales of time and space. As a tree grows, it will continue to tie up more and more carbon. In fact, trees will continue to store more carbon than they give off until maturity or old age at which time a homeostasis is reached. Present chapter is focused on certain basics of carbon capture & storage (CCS) by including role of forests in this regard. Essentials of technologies and conceptual ingredients of CCS are described followed by emerging key issues and potentials at global and national scale. Carbon dynamics across forests, soils and in particular in Agro-Forestry systems for Indian conditions is reviewed and presented to visualize the prevailing scenario in this regard.

INTRODUCTION

Forest cover affects the absorption, reflection and transmission of light and heat from the surface of the earth, and of water from the forest canopy due to processes of evaporation and transpiration. The International Panel on Climate Change (IPCC) considers that water cycling as well as carbon cycling use to be most important environmental services provided by forests. Looking into the present day's burning issues like, 'climate change' forests remains at the heart of the transition towards two specific elements namely (1) cycles of water flows, and (2) cycles of carbon flows. Not only forests, but any kind of other vegetation on the land surface has equally huge influences towards regulation and overall environmental impacts on net storage as well as dynamics of these two vital environmental elements, being ultimate keys for prevailing climatic architecture at any place or at any time. Present paper is focused more towards carbon related aspects.

About one third of world's land area is covered by forest being home to 80% of the world's terrestrial biodiversity. It remains as a means to reduce carbon dioxide (CO_2) emissions as well as enhancing carbon sinks. It is truer for tropical locations like India, where each and every kind of forest based intervention (agro-forestry, social & community forests, agro-horti-silvopastoral activities etc) is emerging as an equally vital facet for people and society, where on other side the processes like deforestation frequently release substantial amounts of carbon. International efforts through Reducing Emissions from Deforestation and Degradation (REDD+), Kyoto-based Clean Development Mechanism (CDM) & voluntary carbon markets are offering ample efforts/solutions with confidence towards matching activities of forest preservation/reforestation/afforestation.

Most often the cycling of carbon in forest ecosystems is neither well understood nor recognized. Its dynamics and recent portrait under climate change scenario is emerging as one of the biggest challenge for mankind, which needs to be sensibly tackled across the globe at all scales of time and space. As a tree grows, it will continue to tie up more and more carbon. In fact, trees will continue to store more carbon than they give off until maturity or old age at which time a homeostasis is reached. The time between the initial trapping of the atmospheric carbon through photosynthesis and its eventual release back into the atmosphere varies depending on enormous factors, which are poorly understood as on today.

Forest as Carbon Sink

Public awareness of the significance of CO_2 sinks has grown since passage of the Kyoto Protocol, which promotes their use as a form of carbon offset. Forests remain one of the biggest carbon stores, acting as carbon dioxide (CO_2) sinks. In some part of the globe, like in Canada as much as 80% of total carbon is stored in forest soils as dead organic matter, while another study for African, Asian, and South American tropical forests, revealed the fact that on an average these forests absorb about 18% of all carbon dioxide added by fossil fuels. Any carbon sink could be considered as a natural or artificial reservoir that accumulates and stores some carbon-containing chemical compound for an indefinite period. Moreover, process by which carbon sinks remove CO_2 from atmosphere is termed as carbon sequestration. Based on various studies (FAO, 2016) it has been estimated that Asian forests absorb about 5 tonnes of CO2/ha/year. Carbon sequestered and stored in trees or forests is eventually emitted back to atmosphere after trees are harvested or lost to natural mortality or disturbances such as pest outbreaks and fires. After harvesting, carbon is stored in harvested wood products throughout the lifetime of the product but is eventually lost to decay. Findings have well revealed interesting facts that the global cooling effect of carbon sequestration by forests is partially counterbalanced and reforestation can sizably decrease the reflection of sunlight (albedo).

Present paper is focused on certain basics of carbon capture & storage (CCS) by including role of forests in this regard. Essentials of technologies and conceptual ingredients of CCS are described followed by emerging key issues and potentials at global and national scale. Carbon dynamics across forests, soils and in particular in Agro-Forestry systems for Indian conditions is reviewed and presented to visualize the prevailing scenario in this regard. The ultimate aspire of this chapter is to provide an accessible overview for advanced students, research professionals, land and water managers, and policy makers to acquaint themselves with the established science, management practices and policies that facilitate carbon sequestration and allow for the storage of carbon in forests. It is focused to offer a basic understanding on carbon capture and management in forests and associated sectors/mechanisms encompassing Indian status in regards to prevailing prospects & potential to formulate a cohesive strategy for understanding and tackling forest carbon domain.

ESSENTIALS OF CARBON CAPTURE AND STORAGE (CCS)

Above fundamental description, remains the base for generation of idea towards carbon capture and storage, which in fact looks to be very simple but remains most imperative under present days climatic scenarios. As we continue to rely on fossil fuels for our energy, we mitigate the emission of CO_2 by capturing it at the point of combustion and subsequently storing it in geological formations (Fig. 1). Say for example the CO_2 is separated from the flue gas emitted by a power plant ("capture") and subsequently compressed and transported through pipelines. At a nearby site, the CO_2 is injected through a deep well into a geological formation ("sequestration" or "storage"). CCS is thus a working low carbon technology which captures carbon dioxide (CO_2) from the burning of coal and gas for power generation, and from the manufacturing of steel, cement and other industrial facilities, and transports it by either pipeline or ship, for safe and permanent underground storage, preventing it from entering the atmosphere and contributing to anthropogenic climate change.

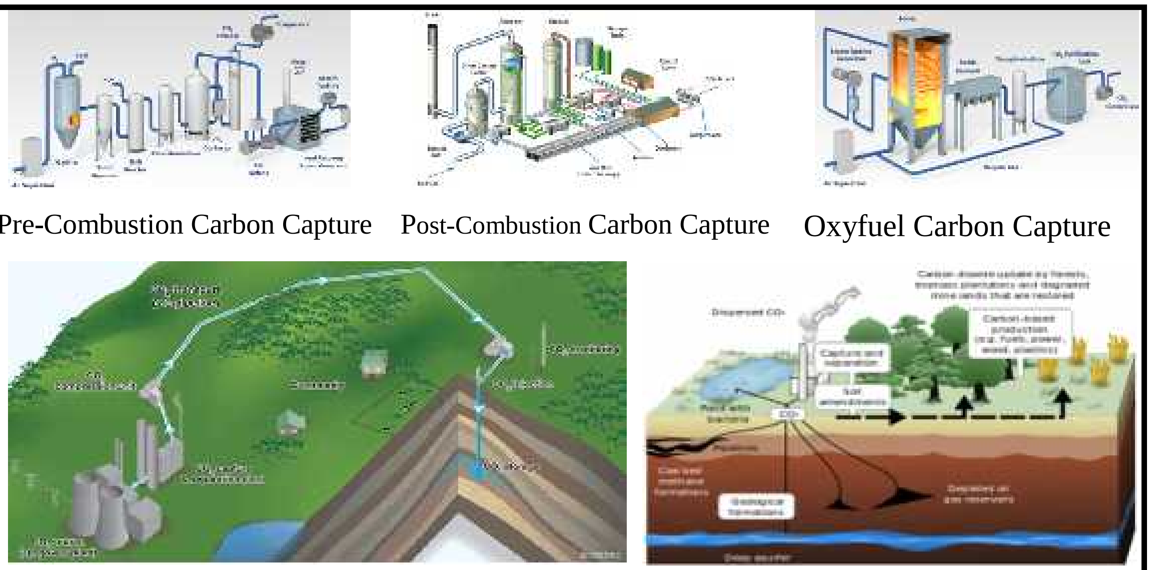
CCS technologies are proved as a vital option to meet the climate goals and can capture up to 90 % of CO_2 emissions from various sources and then storing them in underground geologic formations. By now globally there are more than 15 active commercial-scale CCS projects at industrial facilities around the world, with a growing market for utilizing captured CO_2, primarily in enhanced oil recovery (CO_2-EOR) and selling captured CO_2 offering a valuable revenue source to overcome high costs & financial risks of initial CCS projects. International Energy Agency (IEA) estimates that CCS can achieve 14 % of global greenhouse gas emissions reductions needed by 2050 to limit global warming to 2 degrees Celsius. When we look into its technological architecture, there remain 3 stages as narrated below in brief,

CO_2 Capture : Good candidates for early commercial CCS adoption are certain industrial processes, where it is relatively easy to capture CO_2. As a part of normal operations, these processes remove CO_2 in high-purity, concentrated streams. There are three available primary methods for CO_2 capture from these other industrial processes and electricity generation; (i) Pre-Combustion Carbon Capture, where fuel is gasified (rather than combusted) to produce a synthesis gas, or syngas, consisting mainly of carbon monoxide (CO) and hydrogen (H2) and later a subsequent shift reaction converts the CO to CO_2, and then a physical solvent typically separates CO_2 from H2, (ii) Post-Combustion Carbon Capture, which typically uses chemical solvents to separate CO_2 out of flue gas from fossil fuel combustion, and (iii) Oxyfuel Carbon Capture, which requires fossil fuel combustion in pure oxygen (rather than air) so that exhaust gas is CO_2-rich, which facilitates capture.

CO_2 Transportation : Once captured, CO_2 is transported from its source to a storage site. Pipelines like those used for natural gas present best option for terrestrial CO_2 transport.

CO_2 Storage : The primary option for storing captured CO_2 is injecting it into geological formations deep underground, with options like deep saline formations. CO_2 storage technologies for measurement, monitoring, verification, accounting, and risk assessment can minimize or mitigate the potential of stored CO_2 to pose risks to humans and the environment. Oil and Gas Reservoirs (Enhanced Oil Recovery with Carbon Dioxide, CO_2-

EOR) offers geologic storage potential as well as economic opportunity which injects CO_2 into oil wells to extract the oil remaining after primary production methods. As a second option, the coal beds that are too deep or too thin to be economically mined could offer ample CO_2 storage potential. Captured CO_2 can also be used in enhanced coalbed methane recovery (ECBM) to extract methane gas. Basalt formations and shale basins are also considered potential future geologic storage locations.



Pre-Combustion Carbon Capture Post-Combustion Carbon Capture Oxyfuel Carbon Capture

Conceptual Flow Sketch Depicting Effective CCS Accomplishment

Fig.1 Schematic Drawing of the Carbon Capture and Primary Methods/Processes on CCS

Key Challenges for Accounting Carbon in Forest- Mitigation

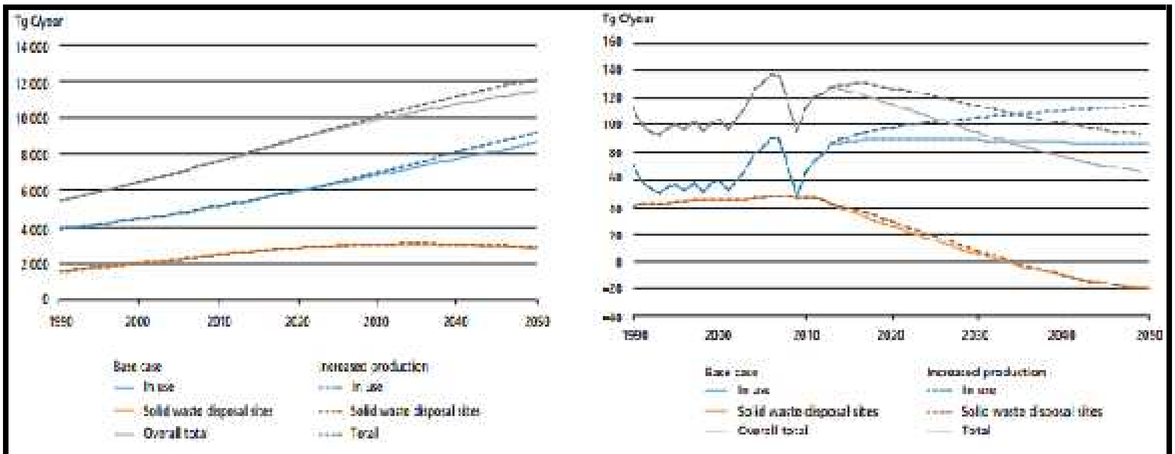
Carbon sequestered and stored in trees or forests is eventually emitted back to the atmosphere after trees are harvested or lost to natural mortality or disturbances such as pest outbreaks and fires. After harvesting, carbon is stored in harvested wood products throughout the lifetime of the product but is eventually lost to decay. This intrinsic characteristic of mitigation in the forest sector, referred to as non-permanence, is critical to address. Mitigation projects necessarily entail a long-term land-use commitment, which makes some options less financially attractive (e.g. afforestation or reforestation projects where land may be converted back to non-forest uses). Leakage remains another important factor that by which changes in land use for the purpose of carbon sequestration may result in carbon releases elsewhere, i.e. a displacement of the emissions. Such leakages to the tune of 43 to 85% have been documented, and a failure to account for leakage can underestimate the costs of CO_2 uptake even by one-third (van Kooten, 2013). Most of the nations have actively considered forests in their climate change plans. Of the 197 Parties to UNFCCC, 175 (174 countries plus the EU) signed the agreement by May 2016, where more than 40 developing countries highlighted their mitigation actions in the forest sector, and in REDD+ in particular.

Salient Elements in Forest Sequestration : The rate of accumulation of carbon in trees has long been a subject of physical study, modelling and economic analysis (Olschewski and Benitez, 2010). Scientists tell us that climate change is upon us and the physical world is changing quickly with important implications for biodiversity and human well-being. Forests cover vast regions of the globe and serve as a first line of defense against the worst effects of climate change, but only if we keep them healthy and resilient. In addition to this, the wood volume and woody biomass levels happens to be another important indicators to quantify or establish the true potential of forests to provide wood on one hand and to sequester carbon on other hand. Wood is needed as a construction material, for pulp and paper manufacture, for fuel and energy, and for a wide variety of other uses. Because living forests trap and hold large amounts of carbon in their woody biomass they have been often indentified as potentially important regulators of the global and local climate. Conversely, forests also may be a source of emissions when forests are burned or when wood from trees and other organic matter decomposes, releasing carbon dioxide back into the atmosphere.

CARBON DYNAMICS

Carbon stocks & variability in wood or wood products have their own significances. Carbon may exists in natural as well as artificial sinks. More often the natural sinks remains typically much bigger than artificial sinks. It includes the absorption of carbon dioxide by the oceans via physicochemical and biological processes and photosynthesis by terrestrial plants. If we look into the main artificial sinks they remain either the landfills or any other kind of carbon capture and storage proposals. Two broad categories of carbon sources includes (i) combustion of fossil fuels (coal, natural gas, and oil) by humans for energy and transportation, and (ii) farmland (by animal respiration). Oceans are an active CO_2 sinks, and represent the largest active carbon sink on Earth, absorbing more than a quarter of the carbon dioxide that humans put into the air. Afterward, it is the soils that represent a short to long-term carbon storage medium, and contain more carbon than all terrestrial vegetation and the atmosphere. Current agricultural practices lead to carbon loss from soils. It has been suggested that improved/effective farming practices could return soils back as a carbon sink.

Recent assessments have clearly established the dominant role of harvested woods (i.e. forest) as well as their end products. If we analysis it globally, it is very much evident that it varied drastically from year to year. A gist of trends of variability in this regards are illustrated in Fig. 2, which is self explanatory to reflect the prevailing dynamics of carbon.



(a) Global Carbon Stock (b) Annual change in Carbon Stock

Fig. 2 Variability of Carbon Stock & Annual Change in Carbon Stock in Harvested Wood Products from Forests at Global Scale (*Source: FAO, 2016; Miner and Gaudreault, 2016*)

Area under Forests Influences Carbon Cycle

Forests in most of the situations plays an extremely important and dominant role towards dynamics of carbon, maybe it is over the ground, under the ground or even above the ground. At present forests cover just over 4 billion hectares or roughly 31% of the earth's surface and sequester (absorb or remove from the atmosphere) and store large quantities of carbon. The trend of forest depletion in past 25 years is of utter distressing as illustrated in Fig.4, where it is self explanatory to visualize consistent sharp declines of varied quantum and intensities. Forest ecosystems are estimated to store about 650 billion tonnes of carbon (44% in biomass, 11% in necromass and 45% in soils) and absorb 8.5 billion tonnes of CO_2 per year from the atmosphere. The UN's Intergovernmental Panel on Climate Change (IPCC, 2007), using 1980s and 1990s-era forest surveys and satellite data, estimated that deforestation was responsible for around 17% of total annual global GHG emissions.

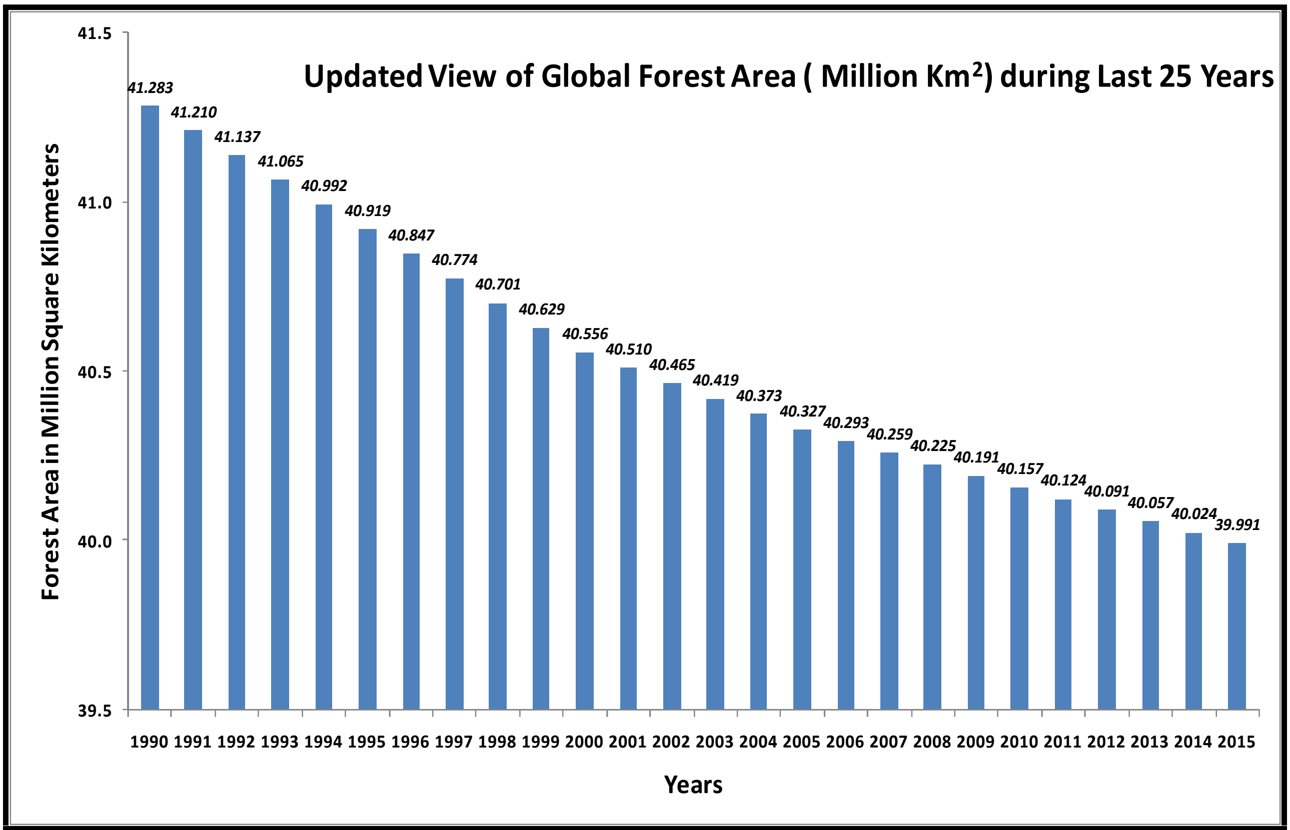


Fig.3 Sharp & Consistent Declines in Global Forest Areas (Source: WorldBank Group, 2016)

MANAGING SOIL CARBON POOL

Soils remain the base for creation, growing and survival of any kind of forests or vegetation on land surfaces. Accordingly, the soil carbon has vast importance because of its role in the global carbon cycle and the function it plays in the mitigation of atmosphere levels of green house gases(GHGs), with special reference to CO_2. To reduce the emission of CO_2, carbon capture and storage (CCS) is an important option. Among the other known sources that enhance CCS, the role of soil in capturing and storing carbon has not been adequately covered. Globally, soil organic carbon (SOC) at the 0 to 30 cm surface level comprises around 66.5 Gt CO_2e (Jobbágy and Jackson, 2000), which use to be the largest terrestrial carbon pool being 2 to 3 times more carbon than what is held in the atmosphere (Davidson et al. 2000). Ample Interest in the contribution of such soil carbon pool to mitigation strategies has been growing, with a well established indications that even a 5 % increase in the size of SOC pool with modified land management techniques could result in up to a 16 % reduction in the amount of atmospheric carbon (Paustian et al., 2000). Preventing deforestation and forest degradation has an important role in maintaining soil carbon stocks, and better functional relationship between biodiversity/carbon sequestration. Table 1 illustrates prevailing situation in regards to carbon pools for major soil orders of India.

Table 1 Carbon Stock (in Pg = 10^{15}g) Distribution by Soil Order in India

Soil Orders	Soil Organic Carbon (Pg) under varied range of Soil Depths		Total Carbon (Pg) under varied range of Soil Depths	
	0–30 cm	0-150 cm	0–30 cm	0-150 cm
Entisols	0.62	2.56	1.51	5.42
Vertisols	2.59	8.77	3.66	14.90
Inceptisols	2.17	5.81	2.79	12.85
Aridisols	0.74	2.02	2.14	15.42
Mollisols	0.09	0.49	0.09	0.56
Alfisols	3.14	9.72	3.30	14.20
Ultisols	0.20	0.55	0.20	0.55
Total SOC (Pg)	9.55	29.92	13..69	63..90
Source : Bhattacharyya et al. 2009				

POTENTIAL OF AGRO-FORESTRY TOWARDS CARBON SEQUESTRATION

Trees on farms have the potential to improve productivity in two ways. Tree-crop combination can increase the amount of water that is used on farm and can also increase the productivity of water that is used by increasing biomass of trees or crops produced per unit of water. Supportive evidences are well established at global scale (Table 2) including similar facts from semi-arid India (murthy et al, 2013). Land use management measures such as conservation of existing tree cover, promotion of agroforestry, etc. will not only have positive impacts on biodiversity but also promote the use of biomass fuels, replacing the fossil fuels, thereby contributing to net reduction in CO_2 emissions. Tree cultivation on agricultural land improves biomass productivity per unit area and also uses nutrients from different soil layers. Further, land such as bund and avenues that are hitherto not cultivated would increase the tree cover of the landscape (MoEF, 2011).

For regions like India, the Agroforestry has always offered a vital scope to deal with carbon management in & around the agrarian & forest landscapes. Carbon sequestration through agroforestry offers several distinct advantages like, improved soil fertility, controls and prevention of soil erosion/water logging, and acidification/eutrophication of streams & rivers, increase in local biodiversity, decrease in pressure on natural forests for fuel and provides fodder for livestock. It also has the ability to enhance the resilience of the system for coping with the adverse impacts of climate change. The effectiveness of agroforestry systems in storing carbon often depends both on environmental as well as socio-economic factors. The carbon storage capacity in agroforestry varies across species and geography. Further, the amount of carbon in any agroforestry system depends on the structure and function of different components within the systems put into practice (Newaj and Dhyani, 2008).

According to the IPCC (2007) even globally, the Agroforestry systems offer important opportunities of creating synergies between both adaptation and mitigation actions with a technical mitigation potential of 1.1-2.2 PgC in terrestrial ecosystems over the next 50 years. Additionally, 630 Mha of unproductive croplands and grasslands could be converted to agroforestry representing a carbon sequestration potential of 391,000 MgC/yr by 2010 and 586,000 MgC/yr by 2040 (Jose, 2009). The carbon in the aboveground and belowground biomass in an agroforestry system is generally much higher than the equivalent land use without trees (i.e. crop land without any trees).

Carbon Stocks in Agroforestry Systems in India

Carbon sequestration in different agroforestry systems occurs both belowground, in the form of enhancement of soil carbon plus root biomass and aboveground as carbon stored in standing biomass. Some of the earliest studies of potential carbon storage in agroforestry systems and alternative land use systems for India had estimated a sequestration potential of 68-228 MgC/ha, and 25tC/ha over 96 Mha of land (Dixen et al., 1994) . But these estimates varies in different regions depending on the biomass production (Pandey, 2007). Studies done by Jha et al. (2001) showed that agroforestry could store nearly 83.6 tC/ha up to 30 cm soil depth, 26% more carbon compared to cultivation in Haryana plains. However, the magnitude of carbon sequestration from forestry activities would depend on the scale of operation and the final use of wood.

Carbon stored in block and boundary plantations too have ample scope and contributions. In a study done by Kumar [67] on four different agroforestry systems (*Populus deltoides* block plantation+wheat, *Eucalyptu*s hybrid boundary plantation+wheat, *Populus deltoides* boundary plantation+wheat and *Populus deltoides* block plantation+lemon grass), all 9-year old block and boundary plantations, it was observed that total carbon sequestration [in trees] was 70.59, 21.38, 116.29 and 18.53 tCha−1 in system *Populus deltoides*+wheat followed by 68.53, 20.63, 113.03 and 17.60 tCha−1 in system *Populus deltoides*+Lemon grass, respectively, with a greater potential for carbon sequestration in boundary plantations of *Populus deltoides* and *Eucalyptus* hybrid. In another study on mitigation potential of block plantations in farm forestry, Hooda et al. (2007) estimated a mitigation potential of 48.5, 62.7, 61.7, 60.8, 37.6 tC/ha/yr respectively for Khair, Chir pine, mixed plantations, Mango/Kinoo farm forestry systems in Uttaranchal.

TECHNOLOGICAL & POLICY BASED CORRIDOR FOR INDIA

India use to be world's 2nd most populous country with a rapidly growing economy and increasing emissions having looming threat of anthropogenic climate change in coming decades, where CCS based interventions could play a pivotal role to overcome the problems. Looking into the prevailing demands many technological and policy based decisions/efforts are being undertaken in India to set right targets with right pace of desired actions.

Table 2: Carbon Storage Potential of Agroforestry Systems Across World's Eco-Regions

Continent	Eco region	System	Potential (Mg C ha^{-1})
Africa	Humid tropical high	Agrosilvicultural	29-53
South America	Humid tropical low dry lowlands	….. do …….	39-102 39-195
Southeast Asia	Humid tropical dry lowlands	….. do …….	12-228 68-81
Australia	Humid tropical low	Silvipastoral	28-51
North America	Humid tropical high humid tropical low dry lowlands	….. do …….	133-154 104-198 90-175
Northern Asia	Humid tropical low	….. do …….	15-18

Emerging Portrait of CCS Research in India

As per India's Integrated Energy Policy India's CO_2 generation in 2031-32 is expected to be in the range of 3.9 and 5.5 billion tones, which when combined with its estimated population of 1468 million in that year, gives per capita CO_2 emissions in 2031-32 as 2.6 and 3.6 tonnes/capita (Holloway et al., 2009*)*. Under Indian conditions many CO_2 capture pilot projects are making their focus towards some of the regionally emerging issues which remains closely associated with agrarian, forest and bio mass based interventions. Most Indian R&D activities related to CCS occur under the Department of Science and Technology (DST), where already a national program on carbon sequestration (NPCS) research is commissioned in 2007, with a view to compete with other countries in this area. Four important thrust areas of research use to be (i) CO_2 Sequestration through Micro algae Bio-fixation Techniques; (ii) Carbon Capture Process Development; (iii) Policy development Studies; and (iv) Network Terrestrial Agro-forestry Sequestration Modeling. Salient researchable issues and later some of the preliminary efforts towards them are ,

- Advanced pre-combustion & post combustion technologies (membrane reforming etc)
- Feasibility studies of CO_2 storage in India
- Bio-sequestration, ie carbon management in forests
- A 'biomimetic' approach, i.e. the identification of a biological process to utilise CO_2
- Potential of enhanced oil recovery and enhanced methane recovery
- Micro algae growth for the extraction of biodiesel

RECENT DEEDS AND FUTURISTIC ROAD

Keeping in view the facts that trees absorb carbon dioxide from the atmosphere, and wood can be a substitute for fossil fuels and carbon-intensive materials such as concrete and steel, the best way to manage forests to store carbon and to mitigate climate change is hotly debated. In the past few decades, the world's forests have absorbed as much as 30% (2 petagrams of carbon per year; Pg C $year^{-1}$) of annual global anthropogenic CO_2 emissions about the same amount as the oceans. Much has been learned about the carbon cycle in forests, but there are still too many gaps in our knowledge. To make good decisions about how to manage forests for climate-change mitigation and whether to harvest or to conserve trees, we must better understand the cause and future behavior of relevant carbon sinks.

Futuristic Attempts towards Climate Change Mitigation via Forest Carbon

Forest carbon stocks could be potentially conserved and enhanced through a wide range of activities like (i) Planting and/or regenerating trees on barren/non-forested land, degraded forests, agricultural and urban landscapes including afforestation, reforestation, forestation, forest rehabilitation, forest restoration, agroforestry, urban forestry and enrichment planting; (ii) Conserving existing forests and avoiding their degradation or conversion to alternative land use by avoiding deforestation, reducing emissions from deforestation and forest degradation (REDD), and conservation of forest carbon stocks; (iii) Improved or sustainable forest management using options such as reduced impact logging (RIL), longer rotations, mixed ages and species; and (iv) Managing harvested wood products, Soils (including peatland) by its conservation/rehabilitation, Use of forestry products for bioenergy to replace fossil fuel use, Tree species improvement to increase biomass and carbon sequestration. Measuring & monitoring of forest carbon is being given high priorities, as it has been made obligatory for any of the forest carbon sink project or program to demonstrate that net carbon gains have been made through the project or program activities and such gains are more than expected under a baseline scenario or reference emission level. Under a normal situation the carbon stocks and its changes are often estimated by considering five basic carbon "pools"/ "reservoirs", namely below-ground biomass (roots), above-ground biomass (tree trunk, branches, stems, leaves), litter (dead leaves and other small fragments), dead wood, and soil organic carbon. To meet the required quality standards, many pioneer forest carbon offset projects are coming out with region specific baseline/monitoring methodologies being in accordance to Kyoto Protocol's Clean Development Mechanism (CDM) and for the voluntary markets as well.

Forest Carbon Market- Where and What ?

The forest carbon market of today is emerging as need of hour, because under prevailing climate change scenario the carbon stored by forests can be valued as part of a national level greenhouse gas inventory or, ever more, credited as a unit of carbon to be sold in the global carbon market. However, the market projects require a methodology for determining carbon stocks, certification by an applicable set of standards, and registration and/or sale under given conditions, which are often shaped by the policy, legal and cultural environment in which they operate. Broadly defined, the sum of transactions of forest carbon credits make up the forest carbon market. The forest carbon market is normally composed of two basic categories, (i) compliance markets and (ii) voluntary markets. Increasingly the voluntary market has been the primary forum for forest carbon trading along with compliance markets that mostly deal in land-based carbon. Some of the leading examples are Australian Carbon Farming Initiative (ACFI) and New Zealand Emissions Trading Scheme.

Recent Initiatives/Policy Approaches in India

The Green India Mission: It use to be a core national mission adopted under the Indian National Action Plan on Climate Change (NAPCC), which is comprehensive in terms of areas covered (from urban to shifting cultivation areas) and addresses both mitigation and adaptation aspects. The intention is to double India's existing greening efforts through scaled up investments and convergence with other related missions (MoEF, 2011). It has an estimated cost nearing US$7 billion, and aimed towards a 5 million hectare increase in forest and tree cover by 2022 with enhancement of tree cover on over 0.2 million hectares of urban and periurban areas by creation of new agroforestry and social forestry assets (Shrivastava, 2014). In recent pasts, the Greening India mission under the National Climate Change Action Plan targets 1.5 Mha of degraded agricultural lands and fallows to be brought under agroforestry; about 0.8 Mha under improved agroforestry practices on existing lands and 0.7 Mha of additional lands under agroforestry. Much of the opportunity to store carbon through afforestation in India were occurred through agroforestry on agricultural lands due to the fact that majority of arable land in India is being cultivated. The total potential for agroforestry has been estimated at 25.36 Mha with almost half of it under tree borne oilseeds, silvipasture and others by 2025 (Puri, 2004; NRCAF, 2007).

New Forestry Policy **:** The recent efforts by Indian government to conceive, confine, and create new forest policy (2016) have amply considered many of the issues and concerns described above. It has considered some of the chronic issues/points like, integrating climate change concerns in forest management, embedding forest hydrology and hydro-geology in forest education/ planning/management/research/training. Forests sequester carbon and produce wood thereby assisting in climate change mitigation. Policy has well taken care of points like creating a pool of carbon with delayed release, considering that an increase in wood consumption would lock many additional million tonnes of carbon dioxide in wood products. Massive afforestation and reforestation to create an additional carbon sink, intensive agro-forestry and farm forestry, logical dealing (keeping carbon dynamics in focus) of sensitive ecosystems such as coastal/marine/mangroves/temperate/sub-alpine forests/western and eastern Ghats etc. Massive afforestation and reforestation are being taken up to create an additional carbon sink while increasing the forest and tree cover and enhancing ecosystem services. The agro-forestry and farm forestry sector are too being given ample importance to harness its full potential, even by integrating GIS and RS technology.

SUMMARY AND CONCLUSION

Budding at different rates, and with different structures and different species, forest types accumulate carbon at different rates. "More than any other kind of vegetation, forests capture vast amounts of atmospheric carbon dioxide and store it in live and dead woody tissues (especially in stems and roots) and in forest floor and soil organic matter. But diverse forest types and developmental stages accumulate atmospheric carbon in different ways. Forests play an important role to govern and regulate the global carbon balance. They act in both the roles, namely the ‘carbon sources’ and ‘carbon sinks’ they have vast potential to form an important component while planning and implementing any effort to combat adverse climate issue. Accounting for the carbon within any forest ecosystems and changes in carbon stocks resulting from human activities is a necessary first step towards the better representation of forests in climate change policy at regional, national and global scales. Many international and national efforts are already on as a part of REDD+, IPCC, UNDP-UNEP, CDM, etc to promote carbon projects, in the important bio-carbon sector and others. This paper has thrown some light on important constituents of forest carbon and its integrated values and management at various scales, based upon reviews of past workers, with sincere acknowledgement for them.

Some of capacity building efforts, major principles, practices, challenges in regards to carbon accounting in the forestry sector have shown their own importance under present time. In accordance to prevailing conditions, the forest carbon accounting can be divided into three specific forms, (i) Stock accounting to assess the magnitude of carbon stored in forest ecosystems at a single point in time, (ii) Emissions accounting to assess the net greenhouse gas emissions to the atmosphere resulting from forests, and (iii) Emission reductions to assess the decrease in emissions from project or policy activities. Forest carbon accounting could be very much usefull for identifying the carbon-density of areas and thus providing information for low-carbon-impact land use planning. It can vastly facilitate to prepare territories for accounting and reporting of emissions from the forestry sector. Also it could greatly allow comparison of the climate change impact of the forestry sector relative to other sectors, as well as allowing comparison between these territories. Finally, it also contributes to enable trade of project emission reductions on carbon markets and for emission reductions to be included in policy targets.

There remains some of the bottlenecks in Harnessing CCS Potentials, which includes meeting the increasing demand for wood sustainably, difficulties in meeting these demands for wood biomass, externalities involved in supplying the increased demand, higher costs of industrial wood energy compared to alternatives, and absence of competitive cost of biomass power in contrast to other renewable energy power. CCS is well established and accepted for majority of locations in world and accordingly India too have marched ahead to accomplish the due milestones. Country is having ample potential which needs to be still harnessed and its detailed description in preceding segments of this write up are self explanatory to quantify this school of thought. India has shown ample potential for capturing carbon via agro forestry and social forestry means by having a sound synergy among agrarian, forest and grassed lands. Even the hydrological and other land and water based interventions have greater scope to get linked with carbon based strategies and interventions at micro scales. The gist on present and futuristic magnitudes of carbon in soils, forests and other ventures for Indian conditions have made it clear to conceive and execute an integrated approach for tackling the sensitive issue of carbon assessment, management, dynamics, market and management in a location specific manner to harness productive as well as protective benefits out of it. Focus must be kept on the recent findings of Intergovernmental Panel on Climate Change, where it is concluded that "a sustainable forest management strategy aimed at maintaining or increasing forest carbon stocks, while producing an annual sustained yield of timber fibre or energy from the forest, will generate the largest sustained mitigation benefit". Sustainable management practices keep forests growing at a higher rate over a potentially longer period of time, thus providing net sequestration benefits in addition to those of unmanaged forests.

The aim of this paper was to provide an accessible overview for advanced students, research professionals, land and water managers, and policy makers to acquaint themselves with the established science, management practices and policies that facilitate carbon sequestration and allow for the storage of carbon in forests. It is focused to offer a basic understanding on carbon capture and management in forests and associated sectors/mechanisms encompassing Indian status in regards to prevailing prospects & potential to formulate a cohesive strategy for understanding and tackling forest carbon domain. Enormous efforts are already initiated, moreover how much successful are our policy initiatives and what should be done differently to encourage carbon capture? How well can forest carbon stocks and stock-changes be efficiently assessed, and how valid are the estimates provided at a local or global level? What are the modifications to management and harvest planning where carbon storage is a management objective? Where India stands in terms of carbon capture and its sequestration with existing opportunities and potential in this regards? These are some of the basic questions which often crop up among planers, policy makers, researchers, common people and many sectors/societies. Sincere effort is made in this chapter to touché these issues and evolves food for thought seeking best possible answers or at least clues on these questions.

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