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An analysis of forest management practices as a carbon mitigation strategy

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Abstract
Rising population, unlimited energy consumption and huge pressure on natural resources have caused climate to change. Global temperature is rising uncontrollably which impact is not limited to a region or country and it will hit harder those who are already living in food insecurity and poverty. Climate change is a grave challenge before current and future generations. Recognizing the worldwide need of immediate action against climate change, 195 Parties agreed to Paris Agreement to limit the global temperature. A lot of studies suggest that the global mitigation goals of reducing carbon emissions cannot be achieved without the involvement of forests along with the improved forest management practices. Forests provide a fast and cost-effective medium of removing emitted carbon. The practice of forest management aims to maintain or enhance forest carbon stocks while fulfilling the society's needs of energy, fibre and timber. A good forest management practice contributes significantly to a global cost-effective carbon mitigation portfolio which renders synergies with adaptation and sustainable development.

Keywords: forest management; climate change; carbon emission; carbon sequestration

Introduction

Many scientific evidences prove that, since industrial revolution, the fossil fuel combustion and degradation of forests have caused a significant rise in the concentrations of heat trapping GHGs (greenhouse gases) in the atmosphere. According to FAO (2020), global annual emissions through deforestation was about 3 billion tonnes CO_2, in the period 2016-2020. The net CO_2 flux of global forests was less in 2020 (0.5 Gt CO_2/year) and had continuously reduced over the period 1990-2020. The current level of rise in temperature due to carbon (C) emissions from various sources has not been observed in the last 800,000 years (Lindsey, 2020). If the GHG concentrations kept on rising in the atmosphere, the average surface temperature of the globe could hike from 1.8 to 4^0C above pre-industrial levels by this century's end (IPCC, 2007). As per the current INDCs (Intended Nationally Determined Contributions) of different countries, global temperature is estimated to cross the 1.5^0C limit, even if nations would dominantly increase the scale of mitigation strategies after 2030 (Goor and Snoep, 2019). According to IPCC (2018) assessment, the remaining carbon budget for a >66% chance of keeping temperature below 1.5^0C is about 550 Gt CO_2, and about 750 Gt CO_2 for a >50% probability. Before these carbon budget gets exhausted, we definitely need to find some effective solutions to curb the emissions. Forests have been recognized as an effective solution to mitigate climate change. Incentives for protecting, conserving and better managing the forests can offer a very cost-effective and near-term option to easily move towards a low carbon economy (Stern, 2006). Forest carbon activities have the potential for triple advantages- climate change mitigation, biodiversity conservation and community development- and a most robust forest management projects aims to capture all three (Virgilio and Marshall, 2009). Mitigation options through forestry include product substitution, storing carbon in harvested wood products and producing bio-energy from biomass. In this way carbon is captured from the atmosphere and available for fulfilling the society's needs of fibre, timbre and energy (Nabuurs et al., 2007). A forest-based mitigation strategy needs institutional capacity, finance, technology as well as suitable incentives, policies and international cooperation. All needs can be fulfilled through an improved forest management policy and practice when efficiently planned and effectively implemented. This paper analyses the importance of forests and its management as a cost-effective option for carbon reduction and also discusses some relevant forest management practices and global initiatives that are significant for low-carbon future.

Global emissions and forests contribution to climate change mitigation

Global emissions

Global GHG emissions have increased 41% annually since 1990 that is still growing. The major source of anthropogenic GHG emissions is energy consumption, responsible for a huge 73% of emissions worldwide. The energy sector comprises of electricity and heat (30% of total GHG emissions- 15 Gt CO_2 eq), transportation (15% of total emissions- 7.9 Gt CO_2 eq) and construction and manufacturing (12% of total emissions- 6.1 Gt CO_2 eq) in 2016 (Ge and Friedrich, 2020). The other key sectors are crop cultivation and livestock (12%); land use, land use cover (LULUC) change and forestry, such as deforestation (6.5%); chemicals, cement and other industrial productions (5.6%) and waste (3.2%) (Ge and Friedrich, 2020). There are only few countries contributing tremendously in carbon emissions, covering over 2/3rd of annual GHG emissions globally. Most of them have huge population and growing economies, together responsible for over 50% of the total global populations and about

60% of the world's GDP. China solely contributes 26% of global GHG emissions followed by the US (13%), the EU (7.8%) and India (6.7%) (Ge and Friedrich, 2020).

CO_2 is the main heat trapping GHG, containing 74% part of it which drives global warming by trapping the heat in the lower atmosphere. Other GHGs such as CH_4 (Methane) and N_2O (Nitrous oxide) comprise 17% and 6.2% respectively, of the total GHG emissions. These gases last long in the atmosphere and deteriorate the quality of the environment.

Forests contribution to climate change mitigation

Forests play a significant role in regulating the Earth's ecosystems and mitigating the global climate change by storing the atmospheric C into the terrestrial carbon sinks. Followings are few points highlighting the forests contribution in curbing the global climate change-

- Forests balance the Earth's climate functioning in several ways, particularly, they absorb carbon from the air and transform it into living biomass such as: leaves, branches, trunks, and roots through photosynthesis.
- Trees and forests are the biggest grasper of carbon after oceans that uptake almost 30% of current levels of carbon emissions from energy and fuel consumption into their biomass, wood items and soils and possess potential to sequester much more.
- Forests provide cooling effect by influencing the local temperatures through shade and transpiration. This is important particularly in urban areas, where trees help to counteract the urban heat inland effect.
- Forests play a double role as a crucial mitigation option- they perform as a net carbon sink but also as a source which are responsible for almost 10-12% of global C emissions.
- Wood energy from forests provides high potential for climate change mitigation. Much opportunities lie with the efficient use of wood residues, modifying the wood fuel conversion efficiently and improving the heating capacity of end-use devices and facilities.
- Increased use of wood products is very significant to mitigation potential when fossil-fuel based produces are displaced by it. Wood-based products and materials help in reducing the GHG emissions and it works more effectively when end-of-life wood products are managed efficiently along with the other biomass residues.
- The potential of various mitigation strategies differs considerably among regions and countries and their priorities highly depend upon local considerations. Use of harvested wood options seem very promising in those countries where a proper processing sector is available and industrial forestry works under sustainability guidelines as well as chain-of-custody is also certified.
- Forests contribute to key policy objectives such as climate change adaptation and mitigation, water regulation, biodiversity conservation and improvement of livelihoods. Although these multiple benefits have not been given significant importance in the accounting of the cost-effectiveness of forestry mitigation options, it should necessarily be considered in the analysis of forest mitigation strategies for emission reduction and climate change mitigation.
- Recognizing the forests' role for sustainable environment, more than 70% of INDCs committed to UNFCCC enforce countries to adopt forest-based mitigation strategies.

Managing forests for emission reduction

Forest sector activities are very prominent in potentially reducing the substantial amount of global GHG emissions which maintains natural ecosystem through carbon sequestration and storage functions (Austin et al., 2020). The IPCC (Intergovernmental Panel on Climate Change) suggests that the strategies such as improved forest management including reforestation, afforestation and avoidance of forest conversion, play a crucial role (Austin et al., 2020) in achieving the global goal of Paris Climate Agreement. Managing forests by enhancing and conserving carbon sinks, while substituting wood products for more carbon induced heat and energy sources are very essential to balance the atmospheric temperature. The FAO (2010) has prescribed some forest management mitigation and adaptation strategies to tackle the adverse impact of climate change and reducing the global carbon emissions that is presented below-

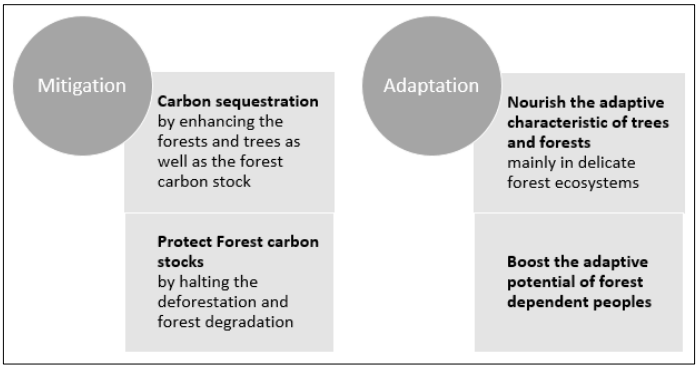

Fig 1: Strategic framework for forest management

Mitigation Strategies

Enhance carbon sequestration through forests and trees increment

Enhancing and maintaining carbon storage in ecosystem is increasingly attracting much interest as forest mitigation approach (Ontl et al., 2020) because it is relatively cost-effective way of addressing impending climate change issues with immediate response. Forest ecosystems have greater than 90% of land sector sequestration capacity (EPA, 2016). Due to the strong mitigation capacity of forest ecosystems, the future proposed natural climate solutions consider carbon management a necessary action (Ontl et al., 2020).

Forest management activities for carbon sequestration include (FAO, 2010)-

- Reforestation, afforestation and forest restoration
- Increase of tree cover outside the forests
- Enhancement of forest carbon stocks in both soils and biomass through management practices

Conserve forest carbon stocks

Forest loss and degradation due to anthropogenic activities cause GHG emissions, carbon stock reductions, impairment of forest good and services and several other environmental losses (FAO, 2010). Conserving and managing carbon stocks in forests is

essential for mitigating these deteriorating impacts that result in increasing CO_2 in the atmosphere (Ontl et al., 2020).

Forest management activities for carbon stock conservation contain (FAO, 2010)-

- Sustainable forest management activities
- Integrated fire management practices
- Management of forest vitality and health
- Management of threatened areas and wildlife
- Management of forest biological-diversity

Adaptation Strategies

Manage fragile forest ecosystems to strengthen the forest adaptive capacity

Forest ecosystems have very unique resources and features that fight against climate change at a global scale at the same time provide numerous socio-economic, cultural and environmental benefits but they are also very vulnerable to the negative impacts of climate change for which their careful management is very important, few management activities are pointed out below (FAO, 2010)-

- Mountain forests and watersheds management
- Dryland forests management
- Coastal forest management

Strengthen adaptive capacity of forest dependent communities

FAO (2010) has suggested following adaptive practices for forest dependent communities-

- Adaptive land use management
- Strengthening coping strategies
- Diversification of employment and livelihoods opportunities related to forests.

REDD+ contribution in managing forests for emission reduction

REDD+ (Reducing Emissions from Deforestation and Forest Degradation) under UNFCCC, designed for developing countries, proposes climate change mitigation and adaptation mechanism that reduces GHG emissions and increases forest carbon stocks by directing developing countries to slow, halt and reverse the forest loss and degradation by appropriately expanding, conserving and managing them (Rhett, 2012, and FAO, 2021). Under REDD+, interested countries are required to progress through three phases (UNFCCC Decision 1/CP.16, paragraph 73)- *readiness phase*, includes national strategies or action plans and capacity building; *implementation phase*, enacting national strategies and results-based activities; *results-based undertakings* must be measured, reported and verified (MRV) properly. These phases are linked with each other closely (FAO, 2021).

Forests can be both a sink or source of carbon, depending on their health, age and susceptibility to various forest disturbances like wildfire and also how are they manages (FAO, 2010). Forest management system could potentially increase the forest carbon sequestration capacity hence curbs the substantial carbon emission. Therefore, improved forest management practices and planning is required for the successful implementation of REDD+.

Forest Management Practices

Forests capture huge carbon within their living above and below ground biomass, in dead organic matter such as litter and dead wood and most importantly in soil. Improved mitigation activities include enhancing forest carbon stocks, adopting good forest management techniques, and reducing deforestation as well as increasing reforestation and afforestation (EGR, 2015). In both developed and developing countries, forest related mitigation actions provide significant potential for climate change mitigation. This is the reason that enhancing or managing ecosystem carbon storage has become an essential goal of forest management worldwide. There are a range of forest management practices such as harvesting, rotation modification, wildfire management and reforestation which help forests to adapt the changing climate, increase the carbon sequestration capacity, and sustain the future productivity of forest ecosystems by improving the forest health (FAO, 2016). Some forest management practices which enhance or improve the productivity and health of forest ecosystems are discussed below-

Tree Harvesting

Forest harvesting is an effective practice for reducing the build-up anthropogenic carbon dioxide in the atmosphere. The harvested material is used to substitute C emissions from fossil fuel combustion or to hold carbon for a long-period in wood products. When the forests are harvested, the quality and health of forests improve. The regrowth of forests after better managed harvesting has high capacity to absorb carbon.

Thinning harvest

Thinning treatments have great impact on carbon capture, in addition to improving the quality and quantity of forests. This technique improves forest health by clearing insect/disease-susceptible and unwanted phenotypes of trees that reduces tree mortality and promotes the volume growth of forest which provides more biomass for carbon capture.

Single-tree selection harvest

Single-tree selection method removes single trees which are mature and have lower carbon uptake capacity. The other benefit of single-tree selection is that it continuously fulfils the need for timber and gives space for the growth of new plants with high carbon uptake capacity at the place of harvested trees. Single-tree selection ensures late succession of forest which benefits various wildlife species as well as provides a balanced carbon capture mechanism.

Shelterwood tree harvest

In this technique, the mature trees are harvested in two to three phases over 10-15 years of time period. This technique allows regrowth of low to medium shade- tolerant species as they require a “shelter” to protect them. Such regeneration of more species creates more carbon stocks.

Clear-cut harvest

Clear-cutting is a system which removes a whole stand of trees in a single harvesting operation and this is considered an effective method to transform unhealthy tree stands into productive and healthy forests. However, clear-cutting method for carbon storage purposes is not well supported because when forests are

cleared at once there are high chances of losing carbon in the atmosphere. That is why selective harvest of mature trees is more preferred than clear-cut harvest.

Prescribed burning

One of the potential practices of curbing carbon emissions from the spread of wildfire is the application of prescribed burning. The method reduces the amount of leaves, accumulated dead trees and branches on the forest floor which could fuel a fire in the forests. The removal of "litter layer" from the forest floor gives space for the growth of new forage and succulent plants which develop as a potential carbon sink.

Integrated pest management

The practice of integrated pest management (IPM) comprises of three measures- prevention, observation and suppression which are economically and ecologically efficient for forest health protection. Prevention through natural regeneration, variety and site selection, thinning and planting practices control pest populations sustainably by reducing natural enemies. Careful observation of pest populations through trapping systems or visual inspections figures out when preventive actions are required. For suppression, biological control by bio-pesticides or other sustainable preventive techniques are promoted over synthetic pesticides. IPM mechanism lies on the understanding of forest and pest biology along with the biology of natural control instruments that regulates the health of forests for ecological functions.

Reforestation and afforestation

Forests are a renewable natural resource. So, they can be planted, harvested, regrown and harvested again and again – this process is called reforestation while afforestation is the process of growing trees where earlier was no forest. These activities are a part of cost-effective emission reduction program which offset the atmospheric carbon as well as provides many forests related benefits.

There are various other ways of managing and protecting forests (Ontl et al., 2020)-

- Maintain or enhance the extent of forest ecosystem
- Sustain fundamental ecological functions
- Reduce carbon emissions from natural disturbances
- Improve forest recovery after disturbances
- Prioritize management locations which have high potential for C reduction across the landscape
- Maintain or increase the forest carbon stocks while retaining forest quality.
- Maintain or increase the sequestration potential by necessary forest alterations.

Global initiatives for protecting and managing the world's forests

The world is confronting great challenges due to deforestation, global warming and climate change. Threats to the world's forests are increasing because of expanding agriculture, illegal and unsustainable logging, shifts in diet and increased population which is responsible for high deforestation and carbon emission (WWF, 2021). As per the IPCC special report on climate change and land (2019), saving the remaining forests and creating more forests are necessary to all pathways for having the global warming lower than 1.5^0C or well below 2^0C rise as forests act as a critical carbon sink to mitigate the climate change (The World Bank, 2020). These climate goals can be attained through sustainable forest management which relies on two hypotheses; first, forests have the ability to renew themselves and second, the economic activities and social values which define human interaction and behaviour with natural resources are 'choices' which can be upgraded to improve the health and productivity of the ecosystem in the long run (Macdicken, 2015). There is an immediate need for international cooperation for saving the world's forest by sustainably managing them to combat climate change and sustain nature's biodiversity and human well-being. There are a range of global initiatives and programmes working for enhancing and preserving the forests as a climate change solution.

UN strategic plan for forests- Global Forests Goals (2017-2030)

This strategic plan of UN presents a global framework regarding the sustainable management of all kinds of forests and separate trees from forests which contribute to the progress of the 2030 Agenda for Sustainable Development, the Aichi biodiversity Targets, the Paris Agreement and other global forest-related commitments and goals (Brack, 2019). It consists of six Global Forest Goals and 26 allied targets that is to be achieved by 2030 (UN, 2017).

1. Reduce the loss of forests all over the world with the help of SFM (Sustainable Forest Management) and raise concern to halt forest degradation so as to control the climate change.
2. Escalate forest-related environmental, social and economic benefits by reforming the income sources of forest dependent communities.
3. Expand significantly the sustainably managed forests and other protected forests all over the world along with the proportion of forest products.
4. Create new and more financial resources and mobilize them significantly for the operation of SFM and to improve the global scientific and technical collaboration and partnerships.
5. Encourage governance frameworks by the means of the UN forest strategic plan and its instruments. In this way, enhance the remarkable role of forests in sustainable development.
6. Increase synergies and coherence on various forest-related matters at all levels, including cooperation and coordination inside the UN system as well as across the relevant stakeholders and Collaborative Partnership on Forests members.

FAO's role in forest management

The Food and Agriculture Organization in the United Nations (FAO) promotes sustainable management of forests by working at the international levels with the help of collaborative partnerships to help, address and resolve the global and regional forest-based issues. FAO provides countries technical support, capacity building and policy instruction through workshops and field projects. The organization promotes innovative and multipurpose forest management techniques that fulfils the need for adapting and mitigating the climate change (FAO, 2020a).

Global Environment Facility (GEF)

GEF's strategy stimulates holistic action and thinking towards SFM. It motivates developing countries to take part and invest in projects which integrate land degradation, biodiversity and climate change. It encourages forest based activities divided into

two pilot initiatives: Taking Deforestation out of Commodity Supply Chains and Sustainable Cities- local actions for Global Commons. It is also linked with three Rio Conventions: The UNFCCC, Convention on Biological Diversity- CBD and UN Convention to combat Desertification- UNCCD which work in collaboration with the UN Forum on Forests- UNFF (GEF, 2020).

The World Bank Group (WBG)

The World Bank Group (WBG) motivates nations to better exploit the capacity of forests to remove poverty, to safeguard and support the environmental role of forests and optimally integrate forests into their economies. The WBG focuses on investments in preservation, nature-based solutions and SFM with a holistic method at terrestrial landscapes i.e., agriculture, transport and energy to generate a friendly ecosystem service outcome (The World Bank, 2020). This integrated approach of WBG is now being raised-up by the Adaptation and Resilience strategies to endorse an integrated landscape management agenda for decreasing deforestation, improving SFM and restoration of 120 million hectares of trees and forests in 50 countries (The World Bank, 2020).

World Wildlife Fund (WWF)

To wipe out one of the biggest drivers of deforestation is irresponsible spread of agricultural activities. WWF is intended to ensure that governments, agribusinesses and others fulfil their commitments to support and conserve the world's forests. WWF adopts two approaches to tackle deforestation- First is the ability, through REDD+ programs, to integrate with governments; Second is the ability, through market-based certification schemes, to integrate with agriculture producers (WWF, 2021).

Collaborative Partnership on Forests (CPF)

CPF is a voluntary collaboration comprised of 15 world-wide institutions and secretariates with worthwhile agendas on forests. The motto of CPF is to encourage the sustainable development with advanced conservation and management plans for all kinds of forests and build up a long run and firm political will to this end. Concerned subjects of CPF are, forest landscape restoration, combating deforestation and forest degradation, the livelihoods of forest-dependent communities, social and cultural perspective of forests and international trade (CIFOR, 2020). In this way, the Partnership seeks to support and enhance the global collaboration and cooperation on forest related issues.

The collaborated CPF members are listed below-

Table 1

1.	CIFOR- Center for International Forestry Research
2.	CITES- The Convention on International Trade in Endangered Species of Wild Fauna and Flora
3.	CBD Secretariate- Convention of Biological Diversity
4.	FAO- Food and Agriculture Organization of the United Nations
5.	GEF Secretariate- Global Environment Facility
6.	ITTO- International Tropical Timber Organization
7.	IUCN- International Union for Conservation of Nature
8.	IUFRO- International Union of Forest Research Organizations
9.	UNCCD Secretariate- United Nations Convention to Combat Desertification
10.	UNDP- United Nations Development Programme
11.	UNEP- United Nations Environment Programme
12.	UNFF Secretariate- United Nations Forum on Forest
13.	UNFCCC Secretariate- United Nations Framework Convention on Climate Change
14.	ICRAF- World Agroforestry Centre
15.	World Bank- World Bank

The leading international organizations which are working to manage and protect the world's forests encourage the governments across the globe to increase the involvement of forest dependent communities in decision making on sustainable forest management in order to reduce poverty and combat climate change. Recent data released by GPF and IUCN reveal that about 1.2 billion hectares of degraded and deforested landscape could be restored with the help of efficient, locally-controlled management activities (IUCN, 2011). REDD+, ITTO, UNFF and many other are such international organizations that promotes holistic views of engaging communities by providing them new opportunities and benefits from preservation and sustainable management of forests.

Conclusion

According to the NOAA Global Climate Summary 2019, the global annual temperature combining land and ocean has risen at an average rate of 0.07^0C per decade since 1880 and since 1981, the average temperature has increased over twice of that rate (0.18^0C). Such hike in the temperature of Earth's ecosystem causes climate to change with extreme weathers, sea level rise and other challenges. Deforestation is the dominant factor in global climate change which results in concentration of more than 1.5 billion tonnes CO_2 in the atmosphere mainly due to burning and clearing of forests every year. Forestry sector is the second biggest contributor (18.4%) to the GHG emissions after energy consumption (73.2%).

But, if managed appropriately, there is no other cost-effective, nature-based climate change mitigation strategy than forests which have the potential to sequester $1/3^{rd}$ of global CO_2 emissions required by 2030 to achieve the Paris Agreement Target. Observing such potential of forests, more than 70% of INDCs have been communicated to UNFCCC reflecting positive intentions of countries to adopt forest-based mitigation solutions. SDG 15: "Sustainably manage forests, combat desertification, halt and reverse land degradation, halt biodiversity loss" and SDG 13: "Take urgent action to combat climate change and its impact" signifies the role of forests in global climate change mitigation efforts. Implementation of good forest management practices such as harvesting, thinning, prescribed burning, reforestation, etc, is key for reducing global carbon emissions which protect forests from insect infestation, disease, wildfire and other natural disturbances and also stimulates faster growth rate and productivity of forests. A number of international organisations and secretariate such as FAO, UNFCCC, REDD+, etc. are taking initiatives for the best implementation of forest management practices highlighting the need for involvement of local and indigenous people including women along with the government cooperation and collaboration at both local and global level in achieving sustainable forest management.

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