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RESEARCH ARTICLE

FOREST MANAGEMENT SOLUTIONS FOR MITIGATING CLIMATE CHANGE: THE CONTRIBUTION OF ETHIOPIAN FORESTS AS CARBON SINK AND CLIMATE CHANGE MITIGATION

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ABSTRACT

Forest and climate are interrelated and the relationship between them is very interesting. The effect of one on the other is very important and decisive. Climate change will affect the environmental conditions to which forest trees are adapted and expose them to new pests and diseases; thus, create additional challenges for forest management and threats the biological diversity in forest ecosystems. In addition to soils, aspect and elevation; climate dictates what will grow when, where and how well. Therefore, changes in temperature, precipitation and other climatic factors have the potential to dramatically affect forests at national level and similarly worldwide. On the reverse, climate is also shaped and strongly influenced by forests. Global warming and climate change largely depends on both the CO_2 and other Green House Gases (GHGs) source from human emissions and the CO_2 sink from natural sinks in the terrestrial biosphere which is mainly forests. Therefore, forests affect the situation both as a source and sink of CO_2. On the top of the efforts being undertaking to reduce the emissions of GHGs into the atmosphere; forest management solutions such as: reduced deforestation and forest degradation, wildfire management, increased afforestation and reforestation, maintained or increased forest carbon density and others; not only reduce the CO_2 emission but also increase the carbon sequestration capacity of forests. In 2010 the overall Ethiopia's GHGs emission level was estimated to be around 150 Mt CO_2e represent less than 0.3% of the global emissions. However, by 2030 it will be more than double (from 150 Mt CO_2e to400 Mt CO_2e) if current practices are continued. Since more than 87% of GHGs emissions in Ethiopia come from forestry and agriculture sectors and according to IPCC definition of "forest", the county has a total of 61.62 million ha of "forest" which can sink 2.7 million tons of carbon and can mitigate the impacts of climate change to certain extent. So, Ethiopia can be benefited from the carbon trade and can achieve the zero-emission target of the Climate Resilience Green Economy (CRGE) plan of the country, if a proper forest management practice implemented effectively.

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INTRODUCTION

Forest and climate are interrelated and the relationship between them is very interesting. One affects the other and the effect of one on the other is very important and decisive. Climate change will affect the environmental conditions to which forest trees are adapted and expose them to new pests and diseases; thus, create additional challenges for forest management and threats the biological diversity in forest ecosystems. In addition to soils, aspect and elevation; climate dictates what will grow when, where and how well. Therefore, changes in temperature, precipitation and other climatic factors have the potential to dramatically affect forests at national level and similarly worldwide. On the reverse, climate is also shaped and strongly influenced by forests. In recent years, climate change is becoming a hot issue and as well as a global number one agenda, since its effect is being clearly seen in different parts of the globe in different magnitudes. Human activities including industry, transportation and change in land uses are significant causes of climate change. So, mitigating climate change through the conservation and sequestration of carbon dioxide which is the major Green House Gases (GHGs) and contributes a lot to climate change is important. Forest management, therefore will improve sequestration of the atmospheric carbon dioxide and increases forest carbon stocks which have many additional benefits including the improved capacity of forestlands to provide other ecosystem services, support biodiversity, and contribute to social welfare which is socially and environmentally acceptable, and economically cost-effective. This paper is therefore, presented with the objective to review the contribution of forest management for mitigating the effects of climate change.

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What is climate change?

Climate includes the long-term patterns of temperature, precipitation, humidity, wind and seasons. Therefore, climate change can be defined as a significant and long-lasting change in the statistical distribution of weather patterns over periods ranging from decades, millennia or even more. It may be a change in average weather conditions or in the distribution of weather around the average conditions. The most important climate change related provocations or aggravations includes: accelerated glaciers melting, melting of permafrost, sea level rise, increased temperature with seasonal changes, more intensive and frequent storms, more heat waves, more cold spells, more droughts, more flooding or frequent flooding more extreme rain (including seasonal changes), and change in water availability (annual and seasonal availability). These climate patterns play a fundamental role in shaping natural ecosystems, economies and the human cultures that depend on them. Because so many natural, economic and social systems are strongly related with climate, a change in climate can affect many related aspects of where and how people, plants and animals live, such as food production, availability and use of water, and health risks. For example, a change in the usual pattern and timing of rains or temperatures can affect when farmers sow their crops and the types of crops to grow, when plants flower and set fruit, when insects hatch or when rivers and streams are at their full-flow. This can affect pollination of crops, drinking and irrigation water supplies, food for animals, crop and forest health etc.

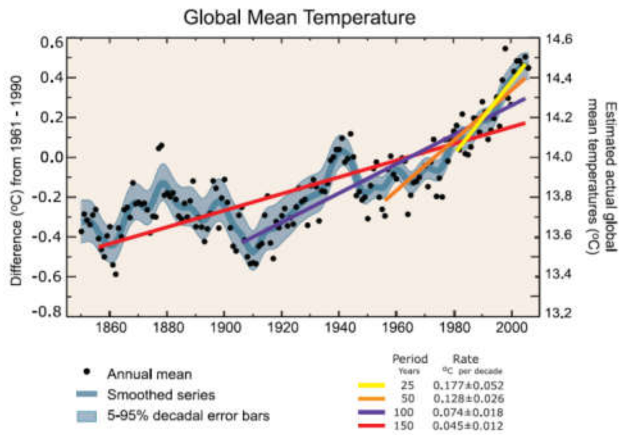
Some short-term climate variation is normal, a year or two of an extreme change in temperature or other condition doesn't mean a climate change. But long-term trends globally now indicate a changing climate. The working group of the Intergovernmental Panel on Climate Change (IPCC) (IPCC, 2007), states that "evidence from all continents and most oceans shows that many natural systems are being affected by regional climate changes, particularly temperature increases." The observation of the working group indicates that climate change has resulted in:

- More and larger glacial lakes.
- Increasing ground instability in permafrost regions.
- Increasing rock avalanches in mountain regions.
- Changes in some Arctic and Antarctic ecosystems.
- Increased run-off and earlier spring peak discharge in many glacier and snow-fed rivers.
- Changes affecting algae, plankton, fish and zooplankton because rising water temperatures and changes in:
  - ice cover
  - salinity
  - oxygen levels
  - water circulation

On fresh water, it is projected that:

- Dry regions are projected to get drier, and wet regions are projected to get wetter: "By mid-century, annual average river runoff and water availability are projected to increase by 10-40% at high latitudes and in some wet tropical areas, and decrease by 10-30% over some dry regions at mid-latitudes and in the dry tropics"
- Drought-affected areas will become larger.
- Heavy precipitation events are very likely to become more common and will increase flood risk.
- Water supplies stored in glaciers and snow cover will be reduced over the course of the century.

The projection also showed that, there will be change on spring events such as the unfolding of leaves, laying of eggs, and migration are happening earlier. There will be pole-ward and upward (to higher altitude) shifts in ranges of plant and animal species. According to IPCC the long-term global data also supports this argument. The following figures (Figure 1, 2,3 and 4) are the long-term trend in global annual mean temperature, seasonal temperature, annual precipitation and sea level rise respectively, which shows the global climate change.



Source: IPCC, 2007

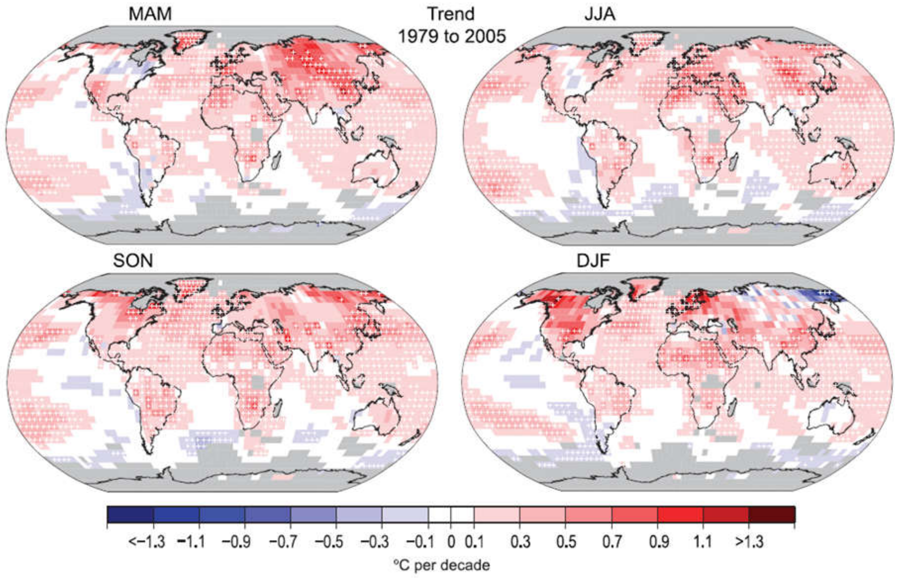
Figure 1. Trend of Global Annual Mean Temperature for 1860 to 2000

Causes of Climate Change

Climate change is caused by natural and human-induced factors. Natural factors which include oceanic processes (such as oceanic circulation), variations in solar radiation received by the Earth, plate tectonics movements and volcanic eruptions and on the top of these human-induced alterations of the natural world aggravates the situations. Since the natural processes are always there, when we say climate change, we often used to describe human-specific impacts as opposed to changes in climate that may have resulted as part of Earth's natural processes. Especially the consequences of human-induces alteration of the natural environment are currently causing global warming. These human-induced factors which are contributing to climate change rang from fossil fuel use to the burning and clearing of forests. Therefore, we need a comprehensive approach to reduce the impacts of climate change. This is an approach that decreases emissions of GHGs across all sectors. So, apart from their other uses, forests can play a great role in mitigating climate change by reducing and fixing GHGs which plays a great role for climate change.

What is mean by greenhouse gases and greenhouse effect?

As described by Hadley Centre (2005), two streams of energy determine what the average surface temperature of the Earth is. Firstly, energy coming in from the Sun as sunlight, which we can see with our eyes and it act to warm the surface of the Earth and the atmosphere. Secondly, because the surface of the Earth is warmer than outer Space, infrared radiation is everywhere being emitted from the surface of the Earth. This acts to cool the Earth's surface. We cannot see infrared with our eyes, but it is straightforward to measure with instruments.



Linear trend of seasonal MAM, JJA, SON and DJF temperature for 1979 to 2005 (°C per decade). Areas in grey have insufficient data to produce reliable trends. The minimum number of years required to calculate a trend value is 18. A seasonal value is available if there are two valid monthly temperature anomaly values. The dataset used was produced by NCDC from Smith and Reynolds (2005). Trends significant at the 5% level are indicated by white + marks.

Source: IPCC, 2007

Figure 2. Trend of Seasonal Temperature for 1979 to 2005

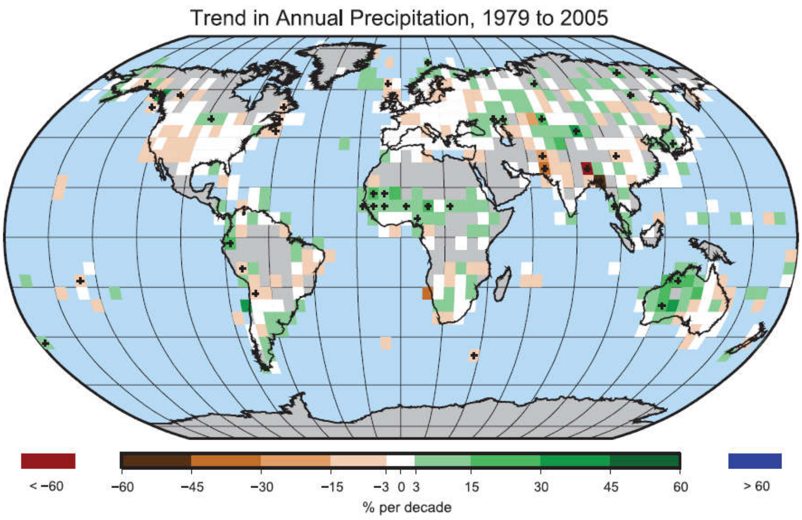
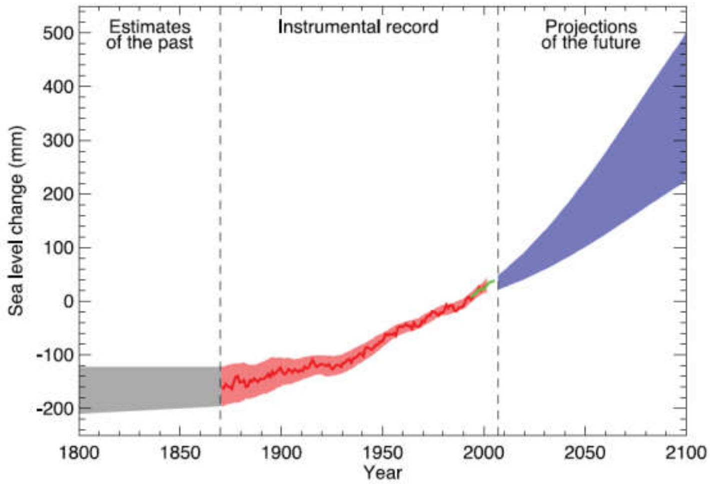
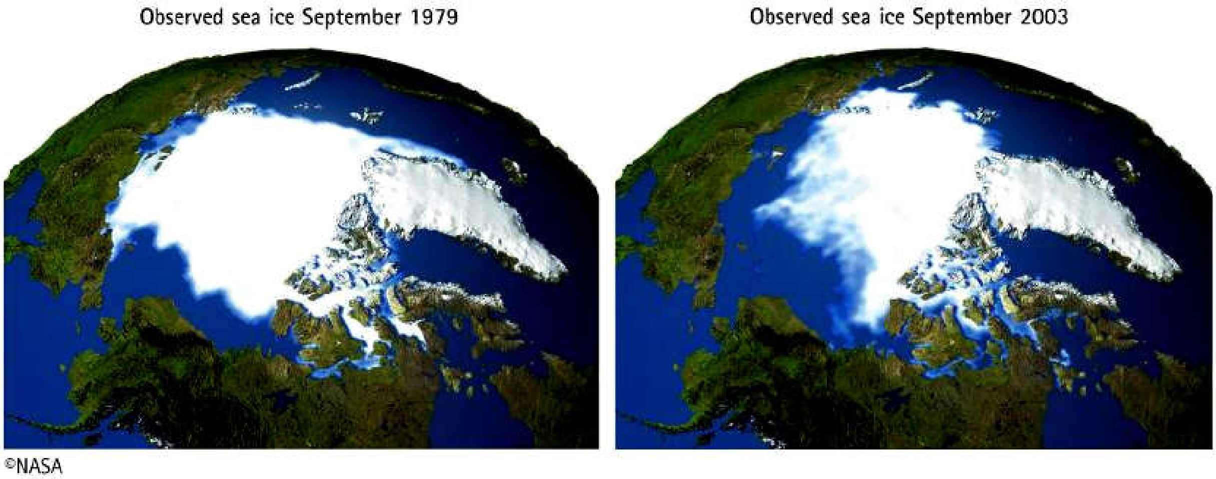


Figure 3. Trend in Annual Precipitation for 1979 to 2005



Sea level rise
Figure 4. Estimate, trends and projection of Sea level rise for the years 1800 to 2100

Changes in ice cover over the Arctic Ocean and Mount Kilimanjaro (Figure 5 and 6) respectively, are also few clear visible examples of the effect of climate change on the glacial regions.



Source: NASA

Figure 5. Changes in ice cover over the Arctic Ocean

Ice cover over Mount Kilimanjaro, Africa

Source: springer- Verlag Berlin Heidelbeg 2005

Figure 6. Ice cover over the Mount Kilimanjaro (A- in 1900and B-in 2005)

Linear projection of the ice cover of Mount Kilimanjaro (Figure 7) also shows that the ice cover is decreasing drastically since 1900, which was 12 km^{2}and reduced to around 2 km^2 in 2000. According to the projection, if the situation continues it may be nil by the year 2020

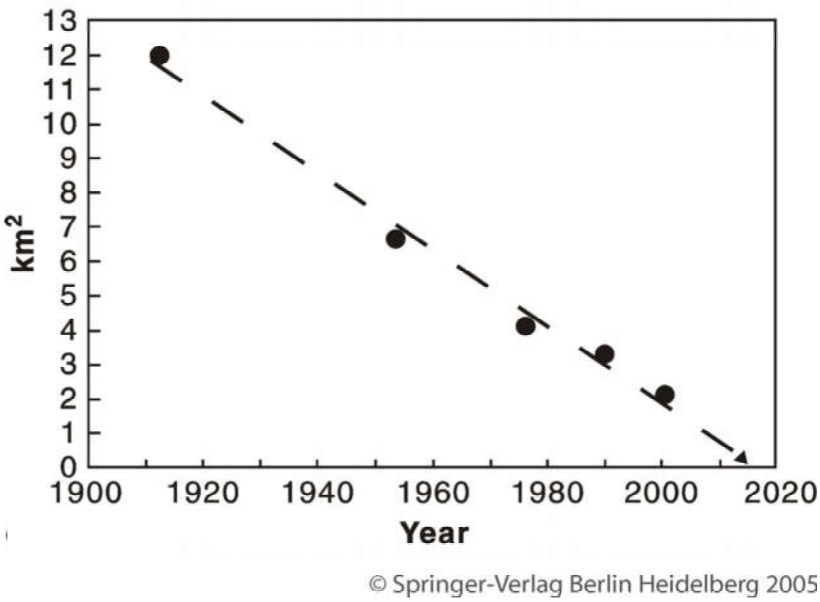
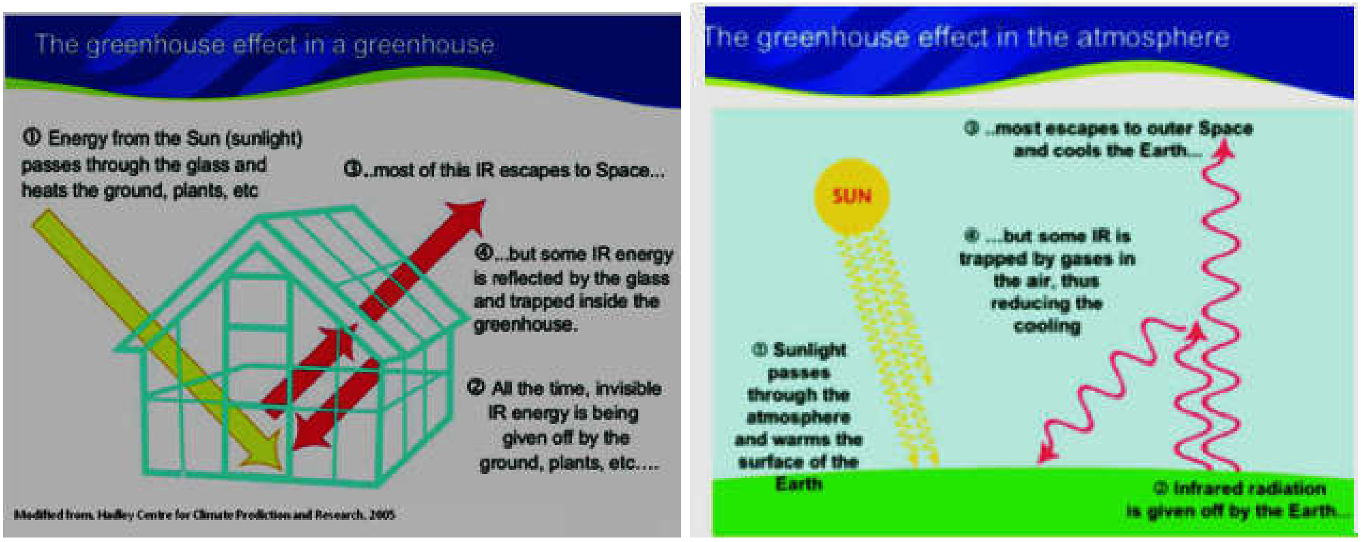


Figure 7. Linear projection of the ice covers of Mount Kilimanjaro, Africa

So that, the balance between these two streams of energy; that emitted by the Sun and that emitted by the Earth determine the global average surface temperature of the Earth. Therefore, if the amount of solar radiation reaching the Earth, or the amount of infrared radiation leaves the ground changes, then the Earth's temperature will change. Greenhouse (Glass House) is a good example to understand with analogy the greenhouse effect on Earth. As shown in figure 8 below a greenhouse is kept warm because energy coming in from the Sun (in the form of visible sunlight) can pass easily through the glass of the greenhouse and heat the soil and plants inside. But energy which is emitted from the soil and plants is in the form of invisible infrared (IR) radiation; this is not able to pass as easily through the glass of the greenhouse. Some of the infrared heat energy is trapped inside; this is the main reason why a greenhouse is warmer than the garden outside. However, this is a rather crude analogy to the way the greenhouse effect works on Earth.



A B

Figure 8. Analogy of the greenhouse effect in green house (A) and in the atmosphere/earth (B) Source: Hadley Centre (2005)

The existence of the greenhouse effect has been known about for a long time. As described by Hadley Centre (2005), in 1896 a paper was published by the Swedish scientist Arrhenius, which discusses the mean temperature of the ground being influenced by the presence of heat-absorbing gases in the atmosphere. Indeed, the notion of heat absorption by gases was put forward even earlier than Arrhenius' time, by scientists such as Tyndall and Fourier. So, the greenhouse effect may be relatively new to policy makers and the media, but in the scientific community it has been known about, and investigated, for well over 100 years.

At a global scale the earth's climate system is determined by many processes, factors and interactions. The earth's atmosphere is an important phenomenon which act as a "blanket" for the earth by creating a well-known phenomenon known as the greenhouse effect (Figure 9).

This natural effect of the atmosphere warms the planet to a temperature comfortable living conditions on earth with a mean global temperature of 15 °C which would be -15 °C, which is less than 30°C without the greenhouse effect of the atmosphere.

However, in recent years, the warming effects of these GHGs are rapidly increasing and putting life at risk (figure 10, below). Human activities such as the burning of fossil fuels result in the emissions of several GHGs, principally carbon dioxide (CO2), methane (CH4), and nitrous oxide (N2O). Table 1 below presents the type of GHGs, their warming power and contribution to global warming.

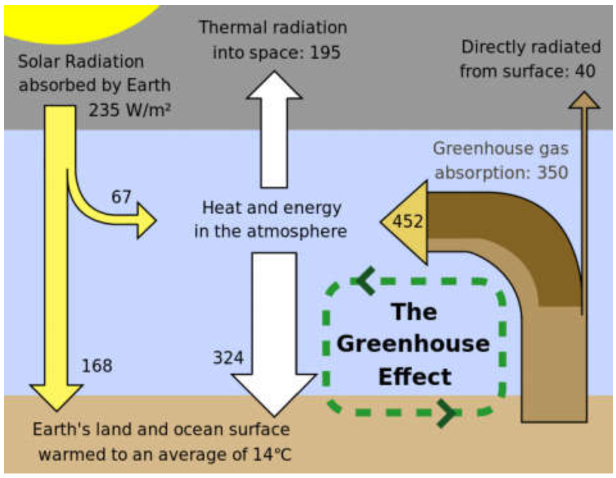


Figure 9. Diagram illustrates the solar radiation absorbed by the earth and the greenhouse effects of GHGs

The contribution of each of these gases to global warming in the next century is estimated to be 63% by CO_2, 24% by CH4, 10% by N2O, and 3% by other GHGs(Hadley Centre 2005). This shows that, CO_2 is the major GHG which is responsible for almost two□thirds of the expected future global warming. The Global Warming Potential (GWP) depends on both the efficiency of the molecule as a greenhouse gas and its atmospheric lifetime. It is measured relative to the same mass of CO2 and evaluated for a specific timescale. Therefore, if a gas has a high (positive) radiative forcing but also a short lifetime, it will have a large GWP on a 20 year scale but a small one on a 100 year scale. Conversely, if a molecule has a longer atmospheric lifetime than CO2 its GWP will increase with the timescale considered.

Table 1. Major GHGs, their warming potential and current contribution to global warming. Source: Hadley Centre, 2005

Parameters	Carbondioxide (CO_2)	Methane (CH_4)	Nitrous oxide (N_2O)	Ozone (O_3)	Chlorofluoro-carbons (CFCS)
Concentration(1993)	362 µl l □1	1,75 µl l □1	313 nl l-1	20 nl l□1	0.6 nl l□1
Concentration(1765)	280 µl l □1	0.8 µl l □1	288 nl l□1	15 nl l□1	□□□□□□□
Current % yearly increase	0.45	0.95	0.25	0.5	5
Life time (years)	100	10	150	0.1	100
Warming potential per molecule	1x	21x	310x	2000x	15 500x
Current contribution to global warming	63	24	10	□	□

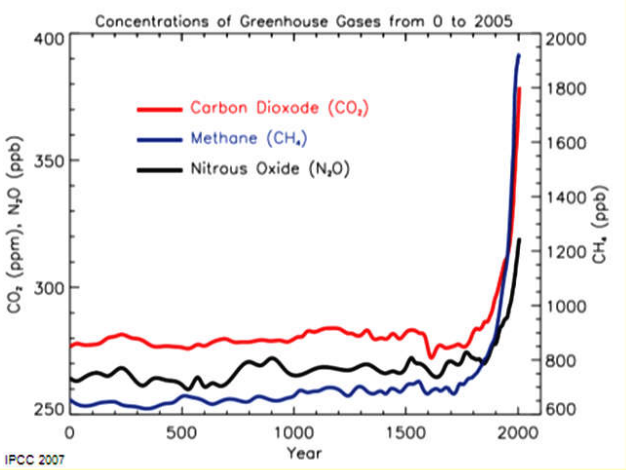


Figure 10. Concentration of GHGs from 0 to 2005. (Source: IPCC, 2007)

For example, Methane has an atmospheric lifetime of 12 ± 3 years and a GWP of 72 over 20 years, 25 over 100 years and 7.6 over 500 years. The decrease in GWP at longer times is because methane is degraded to water and CO2 through chemical reactions in the atmosphere. Carbon dioxide is defined to have a GWP of 1 over all time periods (IPCC, 2007). IPCC uses CO2 as a reference gas with a GWP of 1. Table 2 below shows the GWP of different GHGs relative to CO2 for different time horizons.

Table 2. Global warming potential of major GHGs relative to CO_2 for different time horizons

GWP relative to CO_2 for different time horizons				
	Lifetime (years)	GWP (Time Horizon in Years)		
		20	100	500
CO_2	12	1	1	1
CH_4	114	62	23	7
N_2O	55	275	296	156
N_2O	260	9400	12000	10000
CF-4	>50,000	3900	5700	8900
SF-6	3200	151000	22200	32400

Source: Climate Change, 2001

Current level of the GHGs emissions in Ethiopia

According to FDRE (2011), the Ethiopia's Climate-Resilient Green Economy (CRGE) states that on the global scale, Ethiopia's contribution to GHGs emissions is very low. In 2010 the overall Ethiopia's GHGs emission level was estimated to be around 150 Mt CO_2e represent less than 0.3% of the global emissions.However, by 2030 it will be more than double (from 150 Mt CO_2e to400 Mt CO_2e) if current practices are continued. More than 87% of GHGs emissions in Ethiopia come fromforestry and agriculture sectors and followed by power, transport, industry and buildings, which contributed 3% each (Figure 11 shows the total GHGs emissions in Ethiopia in the year 2010).

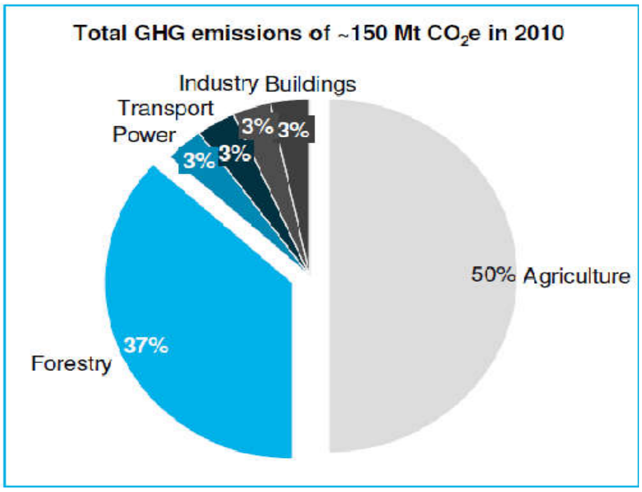


Figure 11. Ethiopia's total GHG emissions and sectoral breakdown of the year 2010 Source: FDRE (2011), (The Ethiopia's Climate-Resilient Green Economy)

Overview of the Carbon Cycle

Carbon is an important element which is found in all living things and it plays an indispensable role. It is an abundant element on Earth. Most of the Earth's carbon is stored in rocks, but this carbon is essentially inert. Whereas the rest of the carbon is stored as CO_2 in the atmosphere (2%), as biomass in land plants and soils (5%), as fossil fuels in a variety of geologic reservoirs (8%) and as a collection of ions in the ocean (85%). These three reservoirs are the "active" reservoirs of carbon (Figure 12, below shows the different carbon pools and fluxes).

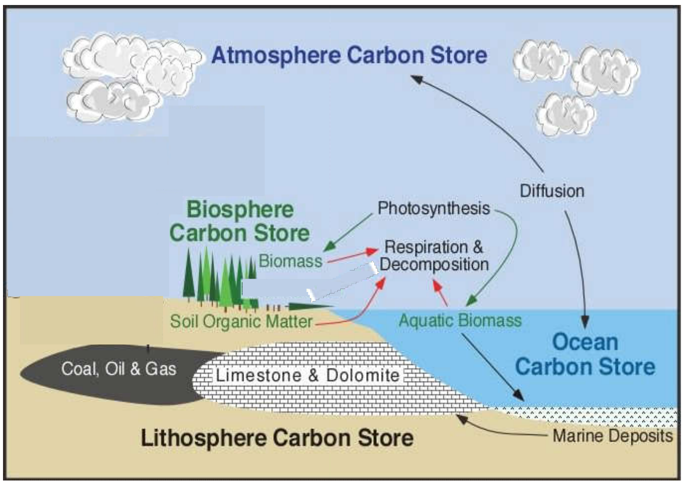


Figure 12. Main carbon pools and fluxes of the 'fast' global carbon cycle

There is a natural exchange of carbon compounds between various reservoirs which can be generalized as the atmosphere, the oceans and terrestrial ecosystems. Therefore, in short, carbon cycle is the circulation of carbon between living organisms and their surroundings. It is the continuous process by which carbon dioxide is absorbed from the atmosphere by plants and algae and converted to carbohydrates by photosynthesis. Carbon is then passed into the food chain and returned to the atmosphere by the respiration and decay of animals, plants, and other organisms. Regrettably, in recent years this natural process is being modified by human activities and the release of $CO_2$is increasing from time to time as a result of inappropriate use of fossilized organic compounds, burning and clearing of tropical forests, change in land uses and other activates which releases CO_2 and other GHGs which aggravate the climate change. Therefore, there is a need to employ a comprehensive approach to reduce the impacts of climate change. Hence, being one of the components of such holistic approach forest can play a great role in mitigating climate change by reducing and fixing GHGs (CO_2) which plays a great role in global warming and climate change.

Conservation and Sequestration of Carbon for Climate Change Mitigation

About 30% of the global land area is covered by forests, which provide a wide range of important products such as timber, fuel wood, paper, food and fodder as well as environmental and social services including the protection of soil and water resources, the conservation of biological diversity and the provision of livelihoods for an estimated 1.6 billion people (World Bank, 2004). Forests, like other ecosystems, are affected by climate change, but also influence climate and the climate change process. They absorb carbon in wood, leaves and soil, and release it into the atmosphere, for example when burned or when forest land is cleared. At the global level it is estimated that during the 1990s deforestation and forest degradation released around 1-2 PgC/year(Houghton, 2005); which represents around 17% of total annual anthropogenic GHG emissions and the majority of deforestation and forest degradation takes place in developing countries (Gullison *et al*., 2007). Le Quéré *et al.*(2009), also indicated that, in the 1990's, humans added $8.0x10^{15}$ grams of carbon (10^{15} grams of carbon = 1 PgC) to the atmosphere each year, primarily by burning fossil fuels (6.4 PgC/yr) and clearing land in the tropics (1.6 PgC/yr). Among this amount of carbon, the ocean took up 28%, and the land absorbed 32%. The remaining 40% stay in the atmosphere to cause global warming. LeQuerealso presented that, from 2000-2008 humans added 9.1 PgC to the atmosphere each year, 7.7 PgC/yr from fossil fuels and 1.4 PgC/yr from land use change. A larger fraction of these recent emissions (45%,) has remained in the atmosphere (LeQuere, 2009). Therefore, future global warming depends on both the CO_2 source from human emissions and the CO_2 sink from natural sinks in the ocean and the terrestrial biosphere which is mainly forests.

In order to improve this situation (increase in the amount of CO_2 in the atmosphere) there are two alternatives:

1. Reduce the emissions of greenhouse gases into the atmosphere; and
2. Remove these gases from the atmosphere once it is in place.

The term 'carbon sequestration' is the most commonly used term to talk about the removal of GHGs from the atmosphere in which forests play a significant role in fixing the atmospheric CO_2.

To achieve climate change mitigation through forest management, it requires that forests to be managedin such a ways that, it fundamentally reduce carbon emissions due to forest degradation and deforestation in addition to the removal of CO_2 gas from the atmosphere. To do so, several forest-related options are available, such as:

- Maintained or increased forest land area;
- Reduced deforestation and forest degradation;
- Increased afforestation and reforestation (by planting and natural regeneration Approaches);
- Maintained or increased forest carbon density;
- Forest restoration and conservation;
- Wildfire management;
- Increased use of wood products from sustainably managed forests; and
- Increased long-term carbon storage in timber products.

The definition of forest is changing from time to time and which as well may affect and changes the estimation of the potential of forests as carbon sink. FAO (2001) defines forest as "land with a tree crown cover (or equivalent stocking level) of more than 10% and an area of more than 0.5 hectare; the trees shouldbe able to reach a minimum height of 5 meter at maturity *in situ*". On the other hand the more recent definition of FAO (2006) defines forest as a minimum land area of 0.05□1 ha with tree crown cover more than 10□30% and tree height of 2□5m at maturity. So that, in 2010 the World Food and Agriculture Organization of the United Nations (FAO) estimated the global forest cover to be over 4 billion hectares (table 3 below), which is 31% of total land area of the world (GFRA, 2010).

Table 3. Forest cover of the world by region and sub-region in 2010

Region/sub region	Forest area	
	1 000 ha	% of land area
Eastern and Southern Africa	267 517	27
Northern Africa	78 814	8
Western and Central Africa	328 088	32
TotalAfrica	674 419	23
East Asia	254 626	22
South and Southeast Asia	294 373	35
Western and Central Asia	43 513	4
TotalAsia	592 512	19
Russian Federation	809 090	49
Europe excl. Russian Federation	195 911	34
TotalEurope	1 005 001	45
Caribbean	6 933	30
Central America	19 499	38
North America	678 961	33
TotalNorthandCentralAmerica	705 393	33
TotalOceania	191 384	23
TotalSouthAmerica	864 351	49
World	4 033 060	31

Source:GFAR, 2010

As described by IPCC (2007), tropical forests are the richest in carbon density per unit area as compared to other biomes and other terrestrial carbon stocks (Figure 13, below). Moreover, tropical forests support much of the Earth's biological diversity and contribute substantially to the global economy and to local human welfare, in addition to the contribution to the global carbon budget. Based on 109 case studies from across the tropics, the TEEB Climate Issues Update 2009 described that, if all the ecosystem services provided by tropical forests were paid for, they would generate about $11.1 trillion per year ($6,120 ha-1 *1807 million ha), nearly equivalent to the European Union's GDP in 2009 (Sukhudev, 2010).

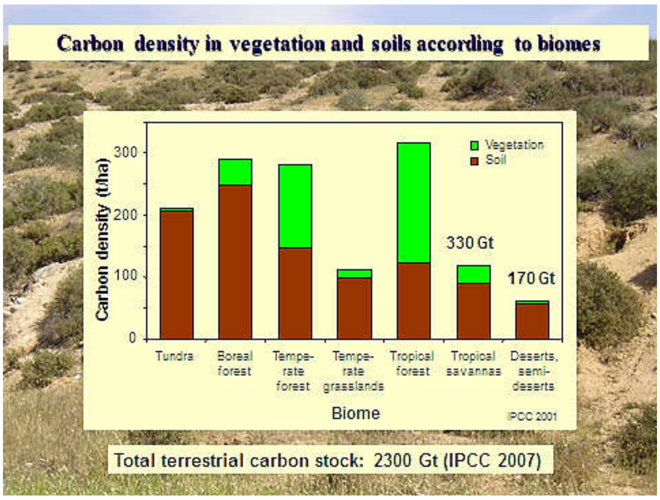


Figure13. Terrestrial carbon density in vegetation and soils according to bioms

Unfortunately, the capacity of tropical forest to provide these services is reduced each year by deforestation as well as by forest degradation principally due to uncontrolled logging (Lambin *et al*., 2003; FAO 2010). Concerning degradation, at least 392 million ha, or 20% of the total area of humid tropical forests, were logged during 2000–2005, and about 50% of standing humid tropical forests retained 50% or less cover as of 2005 (FAO 2010).

The Kyoto Protocol and Carbon Finance

The Kyoto Protocol was adopted in Kyoto, Japan, on 11 December 1997, and entered into force on 16 February 2005. The rules for the implementation of the Protocol were adopted at COP7 in Marrakesh in 2001, referred to as the 'Marrakesh Accords'. The main feature of the Kyoto Protocol is that it sets a legally binding target for 37 industrialized countries, as well as for the European Community, to reduce GHG emissions by an average of 5 % against 1990 levels over the five-year period 2008 to 2012 (UN-REDD Program, 2012).According to the UN-REDD Program (2012), developed countries are primarily responsible for the current atmospheric GHG levels as a result of over 150 years of industrial activity. Recognizing that, the Kyoto Protocol places a heavier burden for action on developed countries under the principle of 'common but differentiated responsibilities'. In addition to targeting national measures for reducing GHG emissions, the Kyoto Protocol provides countries with an additional tool for achieving their objectives through three flexibility mechanisms:

- **Trading of Assigned Amount Units (AAUs),** allowing Annex I country Parties to exchange emission allowances among themselves;
- **Clean Development Mechanism (CDM)** through which developed countries can fund emissions reductions projects in developing countries, while contributing to technology transfer;
- **Joint Implementation (JI)** which is similar to that of CDM but the emission reduction projects are implemented in Annex B countries. (Annex B countries are Parties to the UNFCCC that have committed to limitation or reductions of emissions under the Kyoto Protocol).
-

REDD$^+$ Activities as mitigation options and carbon finance

As part of international efforts to mitigate climate change, REDD$^+$ aims to provide positive incentives to developing countries for reducing GHG emissions from forestry activities and conserving, sustainably managing and/or increasing the carbon stocks in their forests. As described by UN-REDD Program (2012), the decision 1/CP.16, paragraph 70 encourages developing country Parties to contribute to mitigation actions in the forest sector by undertaking the following five activities, as deemed appropriate by each Party and in accordance with their respective capabilities and national circumstances:

(1) Reducing emissions from deforestation;
(2) Reducing emissions from forest degradation;
(3) Conservation of forest carbon stocks;
(4) Sustainable management of forests;
(5) Enhancement of forest carbon stocks.

Figure 14 below shows the simplified REED$^+$ activities, potential source of GHGs and the potential removal of GHGs as described by UN-REDD Program (2012)

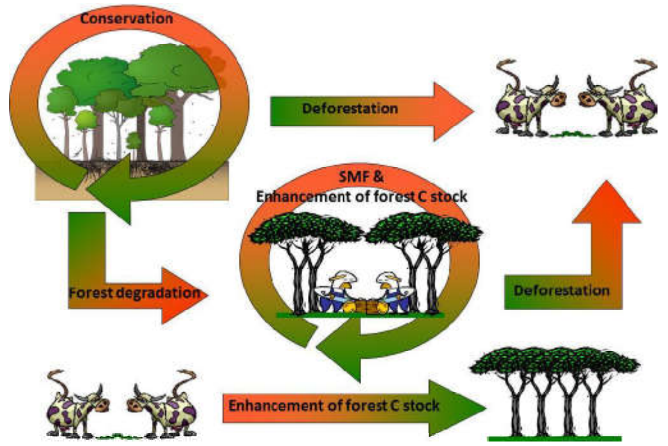


Figure 14. The REDD$^+$ activities. Arrows show how carbon stocks are affected by the potential activities: a gradient from green to red represents a potential source of GHGs, while the arrow with a gradient from red to green represents a potential removal of GHGs. Circular arrows represent no expected change resulting of potential positive (removal) and negative (source) GHG changes

In general, global model results indicate annual amount sequestered or emissions avoided, above business as usual, in 2030 for carbon prices 100 US$/t$CO_2$ and less to be 13,775 MtCO_2/yr at Potential costs equal or less than 100 US$/t CO_2 (Nabuurs *et al*., 2007) (table 4 below). Among these, 5,780 MtCO_2will be from forest management, 3,950 from reduced deforestation and the rest 4,045 from afforestation. Out of the estimated 3,950 MtCO_2/yr emission reduction from reduced deforestation, around 30% (1,160 MtCO_2/yr) is expected from Africa while its reduction of emission from forest management and afforestation is only 1.73 and 16.44 % respectively. This shows that, more is expected from Africa to reduce deforestation to mitigate the climate change and to contribute what is expected from the continent.

Table 4. Potential of mitigation measures of global forestry activities

Global model results indicate annual amount sequestered or emissions avoided, above business as usual, in 2030 for carbon prices 100 US$/t$CO_2$ and less. (Source: Nabuurs *et al*., 2007)

Region	Activity	Potential at costs equal or less than 100 US$/t CO_2, in Mt CO_2/yr in 2030 *
USA	Afforestation	445
	Reduced deforestation	10
	Forest management	1,590
	TOTAL	2,045
Europe	Afforestation	115
	Reduced deforestation	10
	Forest management	170
	TOTAL	295
OECD Pacific	Afforestation	115
	Reduced deforestation	30
	Forest management	110
	TOTAL	255
Non-annex I East Asia	Afforestation	605
	Afforestation	110
	Forest management	1,200
	TOTAL	1,915
Countries in transition	Afforestation	545
	Reduced deforestation	85
	Forest management	1,055
	TOTAL	1,685
Central and South America	Afforestation	750
	Reduced deforestation	1,845
	Forest management	550
	TOTAL	3,145
Africa	Afforestation	665
	Reduced deforestation	1,160
	Forest management	100
	TOTAL	1,925
Other Asia	Afforestation	745
	Reduced deforestation	670
	Forest management	960
	TOTAL	2,375
Middle East	Afforestation	60
	Reduced deforestation	30
	Forest management	45
	TOTAL	135
TOTAL	Afforestation	4,045
	Reduced deforestation	3,950
	Forest management	5,780
	TOTAL	13,775

Carbon Finance Prospects for Ethiopia

Clean Development Mechanism (CDM) and REDD are the two climate change funding mechanisms available for the forestry sector especially for developing countries. So that, under CDM, Ethiopia has so far registered only one CDM project which is Humbo (Supported by World Vision Ethiopia), found in South Nations Nationalities and Peoples (SNNP) Regional State and has registered 2,728 ha by UNFCCC on Dec. 2009 (Yitebitu *et al*., 2010). Picture (plate 1) below shows the partial view of the Humbo CDM project site natural forest regeneration on Abela-Longena and Gamo-Saluwa mountains. Regarding REDD, Ethiopia has prepared Readiness Preparation Proposal (R□PP) to the World Bank's Forest Carbon Partnership Facility (FCPF) (Yitebitu *et al*., 2010). In addition to several efforts and beginning of small REDD projects here and there in different parts of the country, recently a national REDD secretariat has been established and the REDD activity is being coordinated by Ministry of Agriculture (MOA) and several organizations are member of the secretariat. In the global carbon balance, forests play an important role as both carbon sources and sinks. They are an important component in the efforts to combat global climate change. The world's forests store 289 Gt of carbon in their biomass alone (GFRA, 2010). On the other hand, deforestation accounts for approximately 20% of global anthropogenic GHGs emissions (FAO, 2006). The situation of deforestation is even more serious in Africa and it contributes about 70% GHGs emissions in the region (Gibbs *et al*., 2007 cited in Yitebitu *et al*., 2010). In Ethiopian case, Woody Biomass Inventory and Strategic Planning Project (WPISPP, 2005), classified the land cover types in Ethiopia into 9 major types (Table 5).

Table 5. The land□cover types of Ethiopia and their magnitude/proportion (WBISPP, 2005)

Land Cover Type	Area in Hectare	Percentage
Cultivated land	21,298,529	18.6
High forests	4,073,213	3.56
Plantations	501,522	0.4
Woodlands	29,549,016	25.8
Shrublands	26,403,048	23.1
Grasslands	14,620,707	12.8
Afro-alpine	245,326	0.21
Highland bamboo	31,003	0.027
Lowland bamboo	1,070,198	0.97
Swamp	810,213	0.70
Water	828,277	0.72
Bare rock, soil, etc	15,359,409	13.4

Source: WBISPP, 2005 (p. 18), cited in Yitebitu *et al*., 2010

As described by Yitebitu *et al*. (2010), according to the definition of FAO (2001) the vegetation of Ethiopia that may qualify as 'forests' are natural high forests, woodlands, plantations and bamboo forests (Table 5), with an estimated area of 35.13 million ha (around 30% cover of the country). If the shrub lands are added to this (considering the definition of IPCC for forest), the estimated cover will be over 50% (61.62 million ha). On the other hand, the recent data on forest resources of Ethiopia reported in FAO (2010) puts Ethiopia among countries with forest cover of 10□30%. According to this report Ethiopia's forest cover (FAO definition) is 12.2 million ha (11%) (Yitebitu *et al*., 2010). It should be clear that, while there is no as such much significant difference in the country's forest cover; the percentage of forest cover of the country is being reported to be 3.5%, 11%, 30% and 50% because of the definition of "forest" and inclusion and exclusion of some land use land cover components such as shrub-lands.

Therefore, for carbon accounting proposes it seems logical to take the IPCC definition of "forest" since the vegetation cover contributes to carbon sequestration whatever the definition is. So that, it can be said that the county has atotal of 61.62 million ha of "forest" (according to IPCC definition) which can contribute to reduce GHGs and which can mitigate the impacts of climate change to certain extent. Though, this estimation seems a little bit exaggerated, because all the shrub-lands of the country may not qualify the FAO definition of forest, it can be taken as a good start for carbon finance purposes and can be refined and verified later while doing actual and latest inventory activities. So that, the national carbon stocks is estimated (Table 6) to be 2.7 billion tons (Yitebitu *et al*., 2010) which is near to the estimation of 2.5 billion tons in 2005 as reported by Sisay *et al*. (2009).

Table 6.
Mean aboveground Carbon density and total C stocks in major forest categories of Ethiopia

Forest Category *	Free-Bole Biomass (Tons Ha^{-1})(A)	BEF (Tons Ha^{-1}) (B)	AGB C (Tons Ha^{-1}) (A*B*0.5**)	Area (Mln Ha)	Total Carbon Stock (Mln Tons)
High forest	131.5	2.74	106.68	4.07	434.19
Woodland	21.0	6.9	42.75	29.55	1,263.13
Plantation	178.8	2.33	123.0	0.50	61.52
Lowland Bamboo	26.0	6.19	47.5	1.07	50.80
Highland Bamboo	83.0	3.44	84.23	0.03	2.53
Shrubland	14.9	8.20	36.04	26.40	951.54
Total Carbon					2,763.70

Source: Yitebitu *et al*., 2010.
* All woody vegetations (referred to as forest category) are included in the estimation of the national carbon stocks.
**Assuming the carbon content of green wood is approximately 50% of the biomass (WBISPP, 2005). Carbon is calculated based on the for

Conclusion

Global warming and climate change largely depends on both the CO_2 and other GHGs source from human emissions and the CO_2 sink from natural sinks in the terrestrial biosphere which is mainly forests. Therefore, forests affect the situation both as a source and sink of CO_2. On the top of the efforts being undertaking to reduce the emissions of GHGs into the atmosphere;forest management solutions such as: reduced deforestation and forest degradation, wildfire management, increased afforestation and reforestation, maintained or increased forest carbon density, increased long-term carbon storage in timber productsand others not only reduce the CO_2 emission, but also increase the carbon sequestration capacity of forests. By doing such forest management solutions, Ethiopia can be benefited from the carbon trade and can achieve the zero-emission target of the CRGE plan of the country.

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