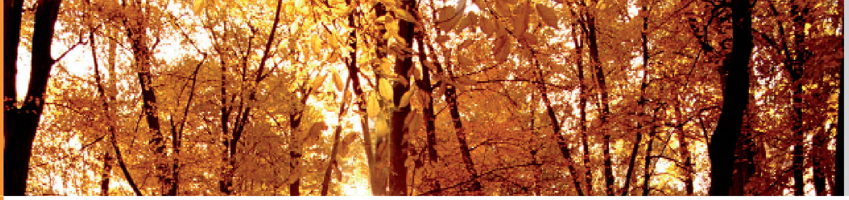

Forests and climate change. A venomous or amorous embrace?

The paper examines the multifaceted relationships between climate change and forests. On one side, climate change is altering forest distribution, composition, structure and functions and phenology of forest species. On the other side, forests and forestry offer significant climate change mitigation options, including measures that reduce greenhouse-gas emissions, especially through reducing deforestation and forest degradation in developing countries; increase the rate of greenhouse-gas removals from the atmosphere (e.g, through afforestation, reforestation, forest restoration and changes to forest management practices); and substitute forest products for fossil fuels or products requiring fossil fuels in their production. Climate change adaptation measures in the forestry sector are essential both to climate change mitigation and for underpinning sustainable development

Because of this, forests feature prominently in the climate change past and ongoing negotiations on commitments of countries under the United Nations agreements to combat climate change.
The forestry sector has much to gain by using existing political support and emerging financial opportunities from the climate change policies to take appropriate action. Nevertheless, the use of forests for climate change mitigation and adaptation also poses a number of unique problems, such as long-term climate benefits, and ownership and fair allocation of these benefits, that need to be confronted

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Introduction

Human activities have enhanced the natural greenhouse effect by adding carbon dioxide (CO_2) and other greenhouse gases (GHGs) to the atmosphere[1] and this is very likely causing the Earth's average temperature to rise. These additional GHGs come primarily from burning fossil fuels. In 2010 the combustion of fossil fuel released 30.6 billion tons (Gt) of CO_2 equivalent into the atmosphere (3.2 $GtCO_2$ in the EU-15), 9% more than the previous year. Scientists have high confidence that global temperatures will continue to rise for decades to come, largely due to GHGs produced by human activities. Temperature projections depend on specific emissions scenarios and the fact that they integrate climate-carbon cycle feedbacks. The 2007 Fourth Assessment Report by the Intergovernmental Panel on Climate Change (IPCC, 2007) in-

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dicates that during the 21st century the global surface temperature is likely to rise a further 1.5 to 1.9 °C for their lowest emissions scenario and 3.4 to 6.1 °C for their highest (Solomon *et al*., 2007)[2].

Forests and the global carbon cycle

Terrestrial biosphere has major role in the global carbon cycle and in climate change. This is because it stores large amount carbon (C) in vegetation (550±100 Gt)[3] and soils (two to three times this amount in the top meter and as much as 2300 Gt in the top 3 meters) (Houghton, 2007). Forests are particularly important as a C reservoir because they hold much more C per unit area (up 250 tC/ha) than other types of ecosystem and they cover about 4 billion hectares, or about 30 percent of the world's land area. In addition, terrestrial biosphere exchanges massive amounts of CO_2 and other gases with the atmosphere through natural processes and biotic and abiotic disturbances. Forests act as *carbon sources*, adding CO_2 to the atmosphere, when total respiration or oxidation of plants, soil, and dead organic matter exceed net primary productivity; they act as *carbon sinks*, removing CO_2 from the atmosphere, when agricultural land and pasture are abandoned and revert naturally to forests, or are restored to native forests or plantations through new forest planting. Aggrading forests also fix more C than they respire.

Deforestation and forest degradation in the tropics and forest regrowth in the temperate zone and parts of the boreal zone are the major factors responsible for emissions and removals, respectively. In the period 2000-2009, deforestation (about 13 Mha/yr) and forest degradation resulted in an estimated release to the atmosphere of about 1.26 GtC, or about 12% of total anthropogenic GHG emissions. However, the extent to which the C loss due to tropical deforestation and forest degradation is offset by expanding forest areas and accumulating woody biomass in the boreal and temperate zones is an area of disagreement between field observations and estimates by top-down model (Houghton, 2007; Reich, 2011).

The role of forests in the climate change mitigation strategies

The significance of both emissions and removals and the potential of humans to alter the magnitude of terrestrial C stocks and the direction of C fluxes explain why the United Nations Framework Convention on Climate Change (UNFCCC, 1992) and the Kyoto Protocol[4] (KP, 1997) include forestry and land-based activities — dubbed land use, land-use change and forestry (LULUCF) — in the international climate change contest.

There are five fundamental approaches to sequestering C in terrestrial ecosystems and reducing net GHG emissions: supplying of renewable energy; replacement for more fossil carbon-intensive products; decrease of emissions of non-CO_2 gases (e.g., from agriculture); sequestration of C through the enhancement of terrestrial C stocks; and conservation of existing C stocks.

Nabuurs *et al*. 2007, quoting bottom-up regional studies, proved that forestry mitigation options have the 'economic' potential at costs up to 100 US$/tCO2-eq to contribute 1.3-4.2 $GtCO_2$ eq/yr (average 2.7 $GtCO_2$ eq/yr) in 2030. Global top-down models predict far higher mitigation potentials of 13.8 $GtCO_2$ eq/yr in 2030 at prices less than or equal to 100 US$/$tCO_2$-eq, depending on a multitude of factors, such as the changes in other economic sectors, political and social changes, the cost-competitiveness of forestry mitigation versus other sector options in achieving climate mitigation goals and the future impacts of climate change itself on growth and decomposition rates, on the frequency and intensity of natural disturbances, on land-use patterns, and on other ecological processes of forests.

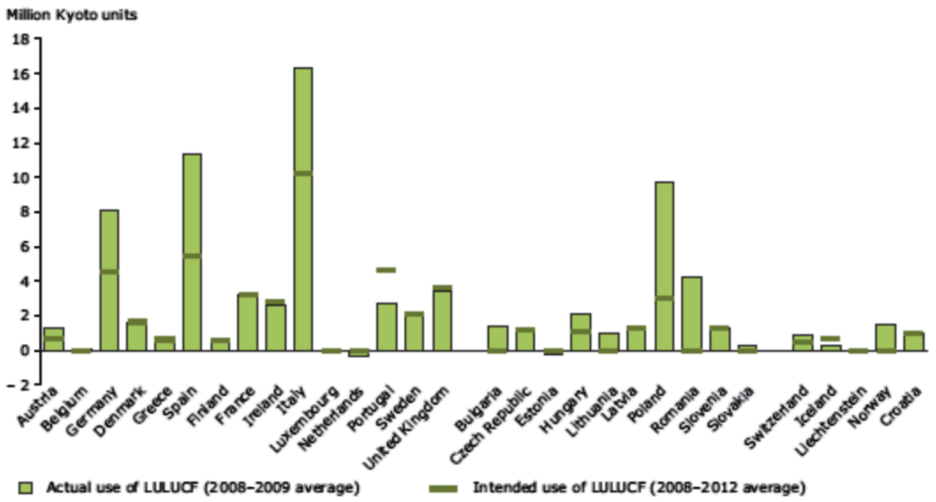
In the negotiation process subsequent to the KP several rules specifically related to LULUCF have been agreed upon for the first commitment period 2008-2012, some of which are quite restrictive for forestry projects. Specifically, C stock changes and non-CO_2 emissions between 2008 and 2012 on new forest areas (afforestation and reforestation) created or deforested since 1990 *must* be included in the commitments of industrialised countries (KP's Article 3.3). In addition, industrialised countries *may* also elect to include C stock changes and non-CO_2 emissions between 2008 and 2012 on areas subject to forest management, up to a cap that is, in most cases, a fraction of the anticipated uptake; on areas subject to cropland management, grazing land management and revegetation relative to carbon stock changes and associated greenhouse gas emissions from these activities in 1990 (KP's Article 3.4); on new forest areas created due to projects in developing countries, agreed under the terms of the Clean Development Mechanism (CDM), up to a limit of 1% of the industrialised country's total emissions in 1990 (KP's Article 12).

In point of fact, these provisions restraint the mitigation potential of LULUCF activities. Firstly, they do not address deforestation and forest degradation in developing countries, the major source of anthropogenic emissions. In addition, they do not allow countries to make ample use of the options offered by LULUCF activities to sequestering carbon in terrestrial ecosystems and reduce net GHG emissions to fulfill the GHG reductions commitments. At EU scale, for example, a new report from the European Environmental Agency shows that the «projected» use of carbon sink under Articles 3.3 and 3.4 during the 2008-2012 period by the EU-15 —which include 'forestry' countries such as Finland, Sweden and Germany — is relatively small: about 40 Mt CO_2 per year of the commitment period (1.0% of EU-15 base-year emissions) (EEA, 2011). Italy, Spain and Poland reported the highest removals from LULUCF activities (Figure 1).

Effects of climate change on forests

Climate change is altering forest plant processes, biodiversity, the structure and function of ecosystems, disturbance interactions through higher mean global temperatures, combined with higher atmospheric CO_2 levels, changed precipitation patterns, more extreme weather events such as hurricanes, heat waves and wind storms.

In terrestrial ecosystems, the earlier timing of spring events and poleward and upward shifts in plant and animal ranges (Kellomaki *et al*. 2008; Lenoir *et al*. 2008; Malhi *et al*. 2009) have been linked with high



Note: A positive value indicates that the country has/expects net removals from LULUCF activities, taking into account the caps for forest management. It does not necessarily mean that the country intends to actually use RMUs to achieve its Kyoto commitment. The estimate of the actual effects of LULUCF activities might change in future years if better data becomes available.

FIGURE 1 Actual (2008 and 2009) and expected (2008-2012) average annual emissions and removals from LULUCF activities
Fonte: EEA, 2011

confidence to recent warming. Scientists assume that each 1 °C of temperature increase in the northern emisphere moves ecological zones by about 125 km northward, 125 m higher in altitude, to find a suitable climatic regime. Mediterranean-type ecosystems, such as maquis and garigue, are especially sensitive, as increased temperature and drought favour development of desert and grassland.

The extension of the growing season has contributed to an observed increase in forest productivity in boreal and temperate regions, while warmer and drier conditions are partly responsible for reduced forest productivity, increased forest fires and pests and pathogens in the Mediterranean Basin. However, Zhao and Running (2010) reported a reduction of 0.55 GtC in global terrestrial net primary production (NPP) of 535.21 Gt C over the period 2000 to 2009. They attributed this decline to a drying trend in the Southern Hemisphere that decreased NPP by 1.83 Gt C (0.34%) and that was counteracted by increased NPP in the Northern Hemisphere by 1.28 Gt C (0.24%).

Projections for the 21st century suggest that the climate will change faster than at any other time in at least the past 10 thousand years. The projections for the European climate predict mean temperatures are likely to increase more than the global mean in the 21st century (Christensen *et al*., 2007). The largest warming is likely to be in northern Europe in winter and in the Mediterranean area in summer. Annual precipitation is very likely to increase in most of northern Europe and decrease in most of the Mediterranean area. In central Europe, precipitation is likely to increase in winter but decrease in summer. Risk of summer drought is likely to increase in central Europe and in the Mediterranean area, where summer rainfall could decline by as much as 80 percent. The duration of the snow season is very likely to shorten, and snow depth is likely to decrease in most of Europe.

A multitude of studies based on field experimental research, combination of ecological modelling with different climate change scenarios and process modelling affirm that the responses of forests to climate change trends across Europe described above may be considerable (Lindner *et al*., 2010).

Forest area is assumed to contract in the South. Native coniferous forests are likely to be replaced by broadleaved forests in western and central Europe. Distribution of archetypal European species, as common oak (*Quercus robur*.) and sessile oak (*Quercus petraea*), will be relatively unaffected by climate change. Other species' distribution will be significantly affected, such as Scots pine (*Pinus sylvestris*), Norway spruce (*Picea abies*) and many other temperate and boreal trees. These species' distributions should contract substantially with climate change, with migration northward being limited by the sea. A third category of species' distribution will be very much affected by climate change and this is mainly Mediterranean and temperate native coniferous species, such as European larch (*Larix decidua*) and silver fir (*Abies alba*), European black pine (*Pinus nigra*) and maritime pine (*Pinus pinaster*). These species should disappear from most of their present distributions. In Europ, for some species the new colonisable areas may be disconnected from the present ones (*Pinus nigra*, *P. pinaster*). The distribution of a number of typical tree species is likely to decrease in the Mediterranean.

Thuiller *et al*. (2005), in projecting late 21st century distributions for 1,350 European plant species under seven climate change scenarios, showed that many European plant species could become severely threatened and more than half of the species studied could be vulnerable or threatened by 2080. Despite the coarse scale of the analysis, mountain species could be seen to be disproportionably sensitive to climate change (60% species loss) due to the narrow habitat tolerances of the mountain flora, in conjunction with marginal habitats for many species. The boreal region was projected to lose few species, although gaining many others from immigration. The southern Mediterranean and part of the Pannonian regions have a negative residual for species loss. Both regions are characterized by hot and dry summers and are occupied by species that tolerate strong heat and drought.

Under the scenarios used here, these species are likely to continue to be well adapted to future conditions.

Water use efficiency in forest trees may increase due to the fertilisation effect of increased atmospheric CO_2 concentrations, but in some parts of Europe, leaf area and associated evapotranspiration from forests may increase, resulting in decreased water flow from forests. Negative impacts of drought on deciduous forests are also likely. Water stress in the south may be partially compensated by increased water-use efficiency, elevated CO_2 and increased leaf area index, although this is currently under debate. Plant physiological responses, including growth responses to increased atmospheric CO_2 and changes in water use efficiency, are expected to ameliorate the response of some plant functional types to climate change. On the other hand, nitrogen deposition, the enhanced potential for invasion by exotic species (that may benefit more than slower growers in more productive environments) or the promotion of more competitive native species may change competitive interactions in plant communities, yielding novel patterns of dominance and ecosystem function.

Abiotic disturbances for forests are likely to increase, although expected impacts are regionally specific and will be substantially dependent on the forest management system used. A substantial increase in wind damage is not predicted. In northern Europe, snow cover will decrease, and soil frost-free periods and winter rainfall increase, leading to increased soil waterlogging and winter floods. Warming will prevent chilling requirements from being met, reduce cold-hardiness during autumn and spring, and increase needle loss and limit seed reproductive success.

Frost damage is expected to be reduced in winter, unchanged in spring and more severe in autumn due to later hardening, although this may vary among regions and species. The risk of frost damage to trees may even increase after possible dehardening and growth onset during mild spells in winter and early spring. Increased temperatures and reduced precipitation, combined with abandonment of forest management, appear to be increasing fire frequency and severity, duration and intensity of the wildfire season in the Mediterranean. Climate-induced shifts in vegetation, associated with changes in fuel characteristics, such as dominance of shrubs over trees (Lindner *et al.*, 2007) can amplify fire spread. Nonetheless, CO_2 fertilization might diminish fire risk due to increased water use efficiencies of plants, thereby reducing the demand for water uptake from the soil and increasing litter moisture.

Fire danger is likely to also increase in central, eastern and northern Europe. This, however, does not translate directly into increased fire occurrence or changes in vegetation. In the forest-tundra ecotone, increased frequency of fire and other anthropogenic impacts are likely to lead to a long-term (over several hundred years) replacement of forest by low productivity grassy glades or wetlands over large areas. The range of important forest pests may expand northward.

Finally, as the biosphere and the atmosphere are a coupled system, changes in the structure and function of terrestrial ecosystems, as expected under a changing climate, may in turn feed back to climete, both positively and negatively. These feedbacks are mediated through changes to albedo (Euskirchen *et al.* 2010), altered carbon cycle dynamics (Phillips *et al.* 2009), energy fluxes and moisture exchange, resulting in increased fires.

Conclusion

Upcoming negotiations on a post-2012 agreement provide an opportunity to reassess and simplify the inclusion of LULUCF mitigation activities in next international climate change regime. Progress is being made on addressing forest management accounting provisions, including a proposal to rationalize and increase transparency in setting possible reference levels for forest management. The treatment of harvested wood products and natural disturbances, particularly extreme events, are also under discussion within the context of forest management, as is the voluntary versus mandatory nature of Article 3.4 additional activities, and the possible inclusion of more activities (e.g., wetland management). Negotiators are also considering broadening the scope of LULUCF activities that are eligible under the CDM. Proposals to expand the scope to include REDD (reducing emissions from deforestation and forest degradation), wetlands, sustainable forest management and reforestation of 'forests in exhaustion' are being debated. Opportunities to implement REDD policies include simplifying procedures, developing certainty over future commitments, reducing transaction costs, building confidence and capacity among potential buyers, investors and project participants; setting harmonized standards for forest-carbon credits, which include rules for profit-sharing with indigenous communities or local landowners, monitoring and verifying credits and protecting biodiversity.

A key factor for encouraging the forestry sector to play a greater role in helping cut atmospheric GHG concentrations is the creation of an institutional framework that values forestry carbon offsets. Though, current policies reveal that the prospects for European forest owners to valorise the carbon sequestration service under current regulations and schemes are limited at the moment.

At EU scale, policy does not seem to be very coherent with regard to the use of forest sinks in climate change policies and measures. Already the diverging attitudes towards the election of forest management according to Art.3.4 of the Kyoto protocol reveal some inconsistency between member states in this regard, which may also be correlated with diverging interests between different EU directorates (specifically those for agriculture and environment), as well as between the respective ministries at national level. While an EU decision to include LULUCF carbon credits in its ETS is still lacking, selling LULUCF credits on the regular Emissions Trading market will not be doable in the near future. Furthermore, under the current institutional framework LULUCF credits appear in the national GHG accounts and serve to help Member States comply with GHG abatement commitments at national level. In this respect, aggregate property rights for carbon sequestration by forests rest implicitly with governments.

Voluntary carbon markets may offer an alternative for marketing the sequestration service of forest enterprises. However, due to the limited prices for carbon units, this alternative may be regarded as an opportunity for additional income rather than an incentive to prioritise carbon sequestration as the main product. Two problems remain to be solved: the high transaction cost associated with the monitoring, verification and certification, and marketing of carbon units; the lack of market transparency with regard to quality and reliability of voluntary carbon certificates, which in the long run could sap the market participants' confidence in this kind of product (Ciccarese *et al.*, 2011).

Even if net global carbon emissions are controlled and reversed by mid-century, it could take centuries for atmospheric carbon levels and temperatures to stabilise. In this regard, adaptation (which refers to efforts to reduce the vulnerability and increase the resilience of natural and human systems to the impacts of climate change) has a new and pressing dimension. Specific adaptation responses might comprise: reducing the impact of stresses that can exacerbate the effects of climate change (wildfire, insects, air pollution, etc.); intensifying measures to prevent and control the expansion of invasive species; avoid or reducing obstructions to species migration; helping forests regenerate after large-scale disturbances (forest restoration); taking historical climate changes into account in planning forest management; considering the future impacts of climate change in selecting genotypes and planting stock types, and choosing planting methods.

Meeting the adaptive forest management challenge needs support from the research sector, called to provide more reliable climate change models at regional scale and to better understand forest vulnerability to multiple stresses and to find ways to enhance forest resilience.

Decision making where and how to allocate scarce funding to conserve plants (and animals) in a changing and uncertain climate is a challenging issue

(Lawler *et al.*, 2011). A key issue is to identify the most effective mix of conservation measures based on the level of available spending.

In the long-term, carbon will only be one of the goals that drive forest management and land-use decisions. Within each region, local solutions have to be found that optimize all goals and provisions of forests goods and services and aim at integrated and sustainable land use.

Notes

1 The 2010 average annual concentration of CO_2 in the atmosphere, 389.78 parts per million (ppm), has risen about 23% since 1958, according to the U.S. National Oceanic and Atmospheric Administration. For the past decade the average annual increase is 2.04 ppm per year.

2 The ranges of these estimates arise from the use of models with differing sensitivity to greenhouse gas concentrations.

3 This amount is on the order of the amount in the atmosphere (800 Gt).

4 Under the Kyoto Protocol 38 industrialised countries (listed in Annex I to the UNFCCC) have committed themselves to reduce national anthropogenic GHG emissions by at least 5.2% below 1990 levels, within the first commitment period (2008-2012).

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