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GUEST EDITORIAL

Can planting new trees help to reduce global warming?

We often hear that planting trees can help cool the environment. This may work not only at a household level, but also on the planetary scale – large-scale afforestation has been advanced by the United Nations as a means of mitigating global climate change. At the garden level, trees provide shade and relief from the summer heat. On the planetary scale, how do trees help cool the earth? Plants remove CO_2 – a major greenhouse gas (GHG) driving today's global warming[1] – from the atmosphere during photosynthesis. This leaf-level process when scaled up to the global level removes about ~130 billion or giga tonnes of carbon (Gt-C) each year. This is 13 times more than the ~10 Gt-C emitted each year from human activities such as fossil-fuel burning (~9 Gt-C/yr) and deforestation (~1 Gt-C/yr). Annual CO_2 exchange between ocean and atmosphere via gas exchange is of similar magnitude – 90 Gt-C/yr – but we confine this discussion to terrestrial plants and climate change.

Since trees remove massive amounts of CO_2 each year from the atmosphere, are new tress the solution to climate change? Unfortunately, recent research indicates that they can be only a small component of the solution. Though carbon uptake by forests is an important natural process of removing CO_2 from the atmosphere, ecosystems also respire. An amount of CO_2 almost equal to global-scale photosynthesis is released back to the atmosphere each year from plant respiration and by microbial decomposition of soil organic matter. The result is that the net removal of CO_2 is nearly zero each year in steady-state conditions. Unless plant matter is permanently stored away in deep soil/ocean, planting trees cannot be a viable solution to counter climate change in the long term. The temporary nature of carbon storage in terrestrial ecosystem explains why expansion of our croplands can provide no carbon sequestration benefit. By the same logic, biofuels are carbon-neutral sources of energy because the CO_2 removed by biofuel plants is released back when the fuel is burnt. However, on timescales of decades to a century, afforestation can help remove CO_2 from the atmosphere until the trees reach maturity. After attaining maturity, an ecosystem is unlikely to act as a sink for atmospheric CO_2 any further.

What is the maximum potential for climate change mitigation from afforestation? To answer this, we take a look at the historical deforestation. Humans started releasing CO_2 to the atmosphere long before the industrial era by clearing forests for agriculture. Indeed the scale was global and unprecedented. 'Anthropocene', a term that marks the impact of humans on the Earth's global ecosystem, perhaps started 10,000 years ago with the rise of agriculture. By the 1750s, humans had deforested approximately 6–7% of the global land surface area for cultivation, and today croplands and pasture lands make up approximately 35% (~5 billion ha) of the global land area[2]. This large-scale deforestation has contributed nearly 40% to the cumulative anthropogenic CO_2 emissions till now (~180 ± 80 Gt-C out of 545 ± 85 Gt-C)[3]. Suppose we reverse the historical deforestation. Such an assumption is unrealistic, but it provides an upper limit for the mitigation potential of afforestation. This highly optimistic scenario suggests a removal potential of only about 40 ppm of atmospheric CO_2 – it is clear that afforestation can at best help mitigate climate change by 5–10% for 'business-as-usual' scenarios where CO_2 levels could reach 700–800 ppm by 2100. Given the competing demand for land for agriculture and infrastructure development, it is unlikely that afforestation can play a major role in mitigation.

Other than the carbon sequestration and related minor benefits for climate change mitigation, does growing trees have any other effect on climate? Does it matter where on the planet trees are planted? A more fundamental question could be 'Do forests have a net warming or net cooling effect on this planet?' To answer these questions, we need to take a comprehensive look at land conversion. We also need to take the help of Earth system models since it would be undesirable to perform large scale deforestation experiments in the real world. Recently, it has emerged that the effects of deforestation or afforestation on climate can be separated into biochemical and biophysical components, and it is the net effect of these two components that determines climate change from land conversions.

The net CO_2 or other GHG emissions from land cover change are normally derived from biochemical conversions. It is these biochemical processes that are accounted for in the discussion above and in carbon sequestration strategies suggested by the United Nations Framework

Convention on Climate Change (UNFCCC) and its Kyoto Protocol for stabilizing atmospheric concentrations of GHGs. The biochemical effect from land conversions at any location (boreal, temperate or tropical) has a global effect, because CO_2 is well mixed in the atmosphere within weeks. This is an important feature of biochemical effect which is distinct from the biophysical effect – discussed next – which mainly has a strong local effect.

The biophysical effect, not accounted for in the Kyoto Protocol, refers to the climatic changes associated with changes in surface characteristics such as albedo, evapotranspiration and surface friction. Earth system modelling research in the last decade indicates that the net effect from biophysical changes is comparable to the biochemical effect and in some cases larger. Hence, climate benefits of afforestation strategies accounted for in the Kyoto Protocol may not truly reflect the full and actual effect. Hypothetical global deforestation modelling studies have consistently indicated a net cooling from deforestation or warming from afforestation: forests on this planet have a net warming effect[4]. This is mainly because forests are darker: they reflect less and absorb more sunlight than grasslands or bare ground. Crops and pasture lands reflect up to 20% of the solar radiation, while most forests reflect ≤10%; the difference is even larger when highly reflective (90%) snow covers the ground, because it is obscured under forest canopies, yet visible on fields. This 'albedo' effect works well in seasonally snow-covered mountain regions and in the high latitudes.

Decrease in plant transpiration, an important component of the hydrological cycle in the tropics may offset some of the cooling from increase in reflectivity following deforestation. When forests are converted to grasslands, transpiration is reduced because grasses have a smaller leaf area and shallower roots, which partitions the net surface radiation more towards the release of sensible heat and less into evapotranspiration causing surface warming. A drying and heating of the atmosphere also reduces cloud formation and increases the absorption of solar radiation, which can lead to additional warming. Numerous modelling studies indicate that the net effect of biophysical feedbacks depends on the location: albedo dominates in the mid and high latitudes, whereas evapotranspiration has the greatest impact in tropical regions. As a result, the net effect – biochemical plus biophysical – is a cooling if new trees are planted in the tropical areas and warming if afforestation programmes are undertaken in the high latitudes. Contrary to conventional wisdom, afforestation in boreal regions could exacerbate climate change.

This new science that has emerged in the last decade or so should guide climate policy in the future on where to plant new trees. The perspective discussed here is focused only on the climate benefits of forests. We should not lose sight of the numerous other benefits and services provided by forests: they provide livelihood for several communities around the world, timber and other forest products for the global economy, habitat for wild animals, support biodiversity, prevent soil erosion and floods, etc.

How can the carbon sequestration benefit of tree planting be enhanced for effective climate change mitigation? The discussion above shows that the biophysical effect can enhance the climate benefits if trees are planted in tropical regions. The other attractive option is to employ bioenergy with carbon capture and storage (BECCS), wherein plants capture CO_2 from the atmosphere, and we use the biomass for energy production in power plants, capture the CO_2 before it is released to the atmosphere and sequester it in geological reservoirs permanently. The latest IPCC report on the mitigation of climate change, released on 13 April 2014, finds that these land-based carbon removal methods such as afforestation and BECCS are absolutely essential for mitigation – it projects that scenarios which reach 450 ppm of CO_2-equivalent by 2100 and keep temperature change below the 'dangerous threshold' of 2°C will rely on the availability and widespread deployment of BECCS and afforestation in the second half of the century.

Since CO_2-equivalent is already 430 ppm and the current growth rate of atmospheric CO_2 is more than 2 ppm, CO_2-equivalent may reach 450 ppm within 10 years if emission reductions do not happen immediately – the window for action on climate change is rapidly closing. According to IPCC, overshoot scenarios where CO_2-equivalent exceeds 500–550 ppm before 2100, but stabilizes to 450 ppm by 2100 are about as likely as not to limit warming to 2°C. It is these overshoot scenarios that absolutely need afforestation and BECCS. Given the demand for land for agricultural and other developmental activities and the uncertainties in costs and effectiveness, the prospects of afforestation and BECCS as mitigation tools appear bleak. Conservation, rapid improvement in energy efficiency and increase in the share of zero- and low-carbon energy supply from renewables such as solar and wind may be the only options left to avoid dangerous climate change.

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