Max-Planck-Institut für Meteorologie

Forest and climate – potentials and side effects of future reforestation

Summary
Reforestation is a widely discussed measure to counteract the increase of atmospheric carbon dioxide (CO_2) concentrations. Earlier studies often referred to a reversal of the effects of past deforestation. The global model simulations presented here, however, show that the potential of reforestation to sequester carbon in a warm, CO_2-rich world may be larger than anticipated. Adaptation to climate change will continue to be necessary, but climate extremes may be dampened by reforestation.

The Anthropocene
The human influence on the Earth system is so fundamental that a new geological epoch was proposed: the Anthropocene [1]. It is not yet known whether this term, as an epoch on its own, will find its way into the official geological time scale. If so, the decision would probably be made on the basis of stratigraphic criteria. The stratigraphy would essentially reveal a layer of long-lived waste such as radioactive waste, plastic and concrete. These considerations illustrate that humanity not only influences the Earth system, but also dominates it in many respects [2]. For example, the atmospheric CO_2 content has risen more rapidly in recent decades than ever before in the last hundreds of thousands of years. With the development of the Haber-Bosch process (industrial ammonia synthesis), and the introduction of artificial fertilizers, more nitrogen is bound than in all natural ecosystems. And also a simple look at the Earth's surface reveals the dominant human impact: through land use.

Three-quarters of the ice-free land surface are managed by humans (fig. 1) [3]. The land cover was partly altered by transforming forest to farmland. Essentially, the vegetation type remained unchanged in larger areas, but humans cultivate these areas by grazing or wood harvesting, for example. Even the remaining quarter of "wilderness" is indirectly affected by anthropogenic climate change.

Land use has a significant effect on many components of the Earth system, from carbon and nutrient cycles to water budget and biodiversity. About one third of the total anthropogenic CO_2 emissions throughout the last 150 years can be attributed to past deforestation [4]. The effects on the Earth system have long been largely unknown. In the light of global climate change, however, scientists now begin to understand how climate can be influenced by land use in a targeted way. A widely discussed measure is reforestation. Through photosynthesis, regrowing forests remove carbon from the atmosphere and store it in their stems and in soils in the long term.

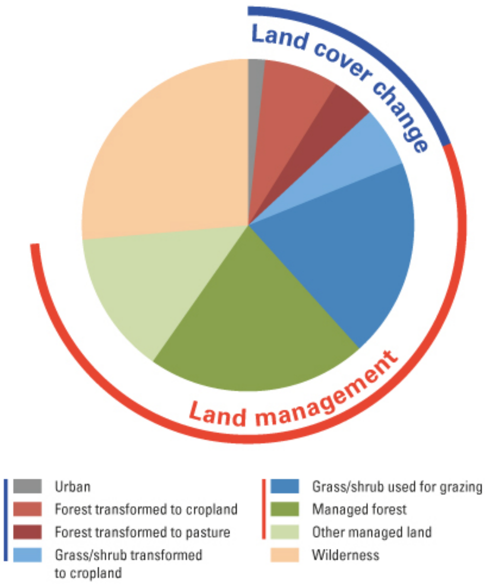

Fig. 1: About three quarters of the ice-free land surface is managed by humans.

“Geoengineering” by reforestation

Deliberately influencing the climate system through land use changes, such as reforestation, is often referred to as “geoengineering”. This term, however, also covers many widely discussed methods such as the injection of dust particles into the atmosphere, to partly reflect solar radiation away from Earth, or altering ocean chemistry in order to sequester more carbon dioxide from the atmosphere. These methods are often expensive and involve high risks regarding the climatic consequences of unforeseen side effects. The climate-relevant use of land, on the other hand, considerably distinguishes itself from these methods. Many land use activities have a long history and their climate impact can thus be observed. Effects of future land use changes are therefore easier to assess [5].

The competition with other types of land use constitutes an obstacle to large-scale reforestation: Food supply and biodiversity conservation in particular must be ensured. The estimates of how much area will be available for reforestation are therefore rather low in most previous studies. Some economic studies, however, suggest that agriculture will be intensified and higher yields can be achieved with the same or even smaller surface areas. The growing demand for food and plant-based materials of an increasing population could not only be met with the existing areas, but agricultural areas would even be abandoned. According to economic studies, the areas becoming available could be used for reforestation [6]. It is, however, unclear how large the potential of such additional forests for carbon uptake actually is. Earlier studies suggest that only about five percent of the future anthropogenic CO_2 increase expected in case of increasing fossil-fuels consumption could be compensated by reforestation [7].

These estimates, however, are based on observations of the past. According to the assumptions, the CO_2 released into the atmosphere due to deforestation is taken up again by the regrowing forests.

It is not taken into account that the future climate can differ drastically from the one in the past. Despite political efforts, humanity emits 10 billion tons of carbon every year. The increase in atmospheric CO_2 and the resulting environmental conditions influence forest growth. Therefore, scientists in the department "The Land in the Earth System" at the Max Planck Institute for Meteorology (MPI-M) investigate the feedback of vegetation and climate also in scenarios of massive climate change.

Assessing the carbon sink potential of reforestation

Simulating future climates and the productivity of vegetation on a global scale is a prime application of Earth system models. They describe the interplay of processes in the atmosphere, the ocean and on the land surface on the basis of laws of nature, which were translated into corresponding mathematical equations and ultimately turned into a computer simulation.

The above-described reforestation scenario was calculated with an Earth system model. The fossil-fuel emissions, which predominantly determine climate, were taken from a scenario that assumes a strong increase in greenhouse gas emissions from fossil fuels. If this scenario had been adopted as a whole - including not only the greenhouse gas emissions from fossil fuels, but also the land use scenario - a strong expansion of agricultural land would have been assumed. In contrast to the reforestation scenario, an intensification would not take place. This scenario as a whole serves the researchers as a reference, an otherwise similar world, but not permitting reforestation. As shown in fig. 2, the agricultural land decreases substantially, and the forested areas strongly increase in the reforestation scenario over the course of the century. In the reference scenario, on the other hand, agricultural land increases and forested areas slightly decrease.

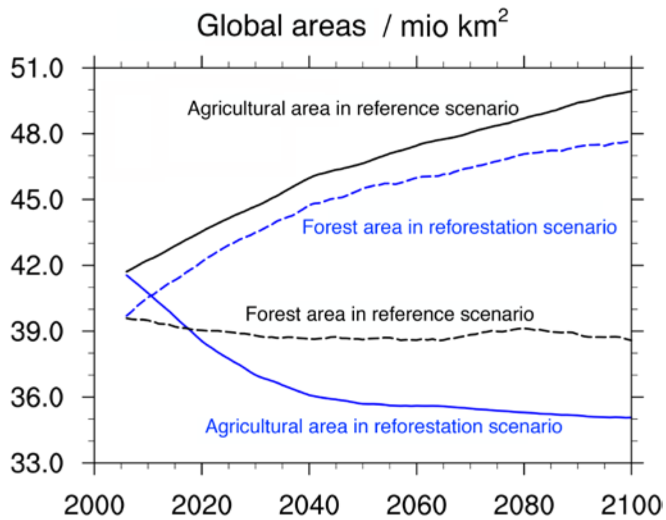

Fig. 2: In the reference scenario, the global agricultural areas increase strongly over the course of the century, while the forest areas slightly decline. Due to the agricultural areas set up in the reforestation scenario, large areas are reforested, leading to a strong increase in global forest areas.

The results of the Earth System model simulations at MPI-M suggest a higher carbon sink potential than previously assumed [8]. The reason is the combined effect of an extension of forest areas and an increased carbon uptake of the terrestrial biosphere in a warm and CO_2-rich climate. As a result, the simulated CO_2 concentration is reduced by 85 ppm ("parts per million", about 10 percent of the projected increase, see fig. 3), compared to the reference scenario at the end of the 21st century, and reforestation leads to a slight decrease in global warming by the end of the century (fig. 3).

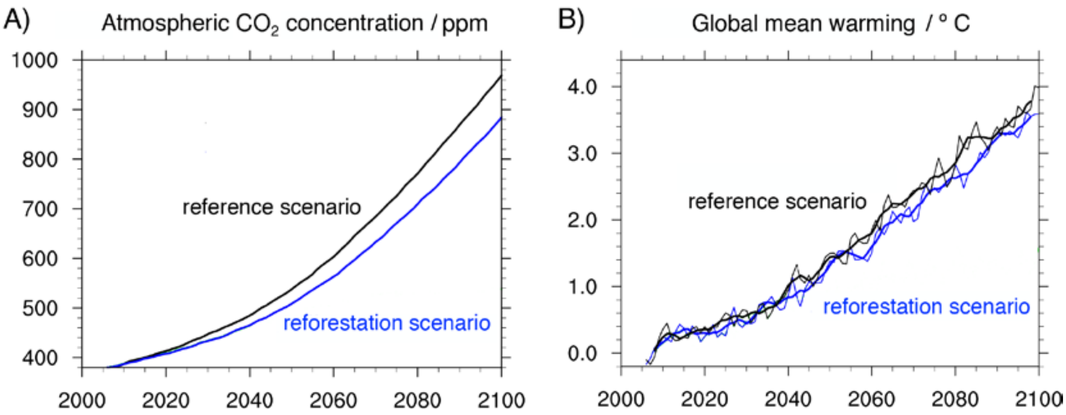

Fig. 3: Both the atmospheric CO_2 concentration compared to the simulated value for 2005 (A) and the average global surface temperature (B) are clearly increasing in both scenarios over the course of the century. In the reforestation scenario, however, this increase is weaker than in the reference scenario.

Regional climate effects of reforestation

Politics focus on reforestation because of its carbon storage capacity. It is, however, also climate-relevant in other respects. The greenhouse gas effects need to be contrasted to the biogeophysical effects, which affect local and regional climate. Viewed from above, a field often is much brighter than a forest, reflecting more solar radiation back to space and thus warming the surface less. However, a dense forest often transpires more water than a shallow rooted field. This self-cooling by transpiration counteracts the warming effect of a dark forest.

While the emissions mix rapidly in the atmosphere, and thus always have a global effect, biogeophysical effects are primarily limited to the local and regional climate. On this scale, for example in North America and Europe, historical land use has to a large extent reduced the rise in global temperatures caused by emissions from both deforestation and fossil-fuel combustion [9].

The average warming in densely populated areas is only slightly reduced in the reforestation scenario (fig. 4). Therefore, reforestation has hardly any consequences for the need to adapt to climate change in these areas. However, the results also suggest that the reduction of temperature extremes reduces the need for adaptation in some regions. In the simulations, for example, the warmest days of a year in parts of Europe, compared to the reference scenario, are less warm in the reforestation scenario.

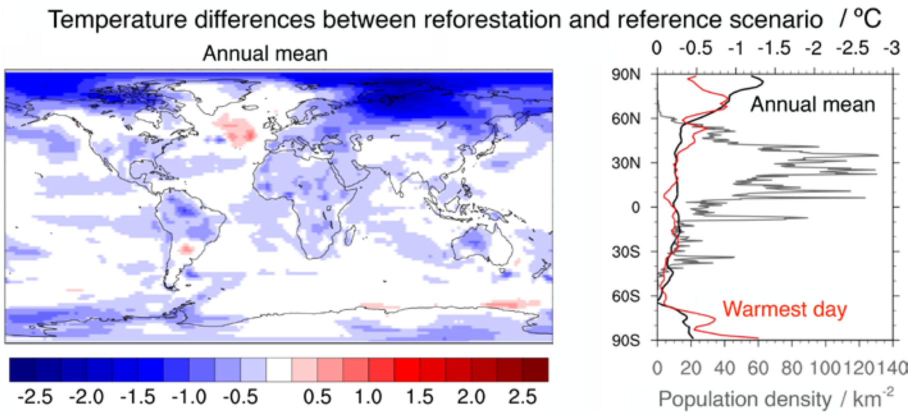

Fig. 4: The temperature differences between the reforestation and reference scenario, averaged over the years 2081 to 2100, are highest on average in areas with very low population densities. In some less sparsely populated areas, however, the temperature differences are larger for the warmest day of a year than for the annual mean. (The right figure shows zonally averaged values.)

5. Outlook

Although the carbon sink potential of reforestation may have been underestimated previously and although reforestation could be used for climate change adaptation in order to mitigate climate extremes: When it comes to "business as usual", the global development of climate remains dominated by industrial activities. However, other types of land use change could help reduce fossil energy consumption. Biomass plantations such as highly productive grasses or short-rotation coppices, where fast-growing tree species are harvested at short intervals, could partially replace fossil fuels. Plantations store much less carbon in their biomass than a forest, but they contribute to the reduction of fossil-fuel emissions through their harvest and use as bioenergy.

To compare these effects on climate with those of reforestation - via the carbon cycle as well as via the energy and water budget - is therefore an ongoing project at the Max Planck Institute for Meteorology. However, follow-up work is needed to better understand the limitations of the methods. The choice of a particular model entails uncertainties because each model is ultimately only a simplified image of reality. A favored approach is therefore to use many different models. The spectrum of their results is a more reliable framework for the actual development than could be derived from individual models. Model comparison studies are also the basis for the assessment reports of the Intergovernmental Panel on Climate Change (IPCC). Preparations for the next assessment report of the IPCC are underway. It will provide an analysis of a future reforestation scenario and will paint a more comprehensive picture of the potentials and side effects of this kind of interference with the climate system.

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Publication

Sonntag, S., J. Pongratz, C.H. Reick, and H. Schmidt (2016). Reforestation in a high-CO_2 world - Higher mitigation potential than expected, lower adaptation potential than hoped for. Geophysical Research Letters, 43, 1-8, doi: 10.1002/2016GL068824

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