Climate Slashing

Public debates on global warming focus on one main cause: CO_2 emissions from the combustion of fossil fuels. But humankind is also changing the climate by clearing forests and through farming, forestry and animal husbandry. Together with her Research Group at the **Max Planck Institute for Meteorology** in Hamburg, **Julia Pongratz** is investigating the consequences of these activities for the climate – and how these interventions could be used to counter global climate change.

TEXT **UTE KEHSE**

A large map of the world hangs on the wall in Julia Pongratz' office. The oceans on it are white, the continents multicolored. A mosaic of violet, green, brown and gray shades covers the land areas. "This map shows the world's different land use systems," explains the researcher from the Hamburg-based Max Planck Institute for Meteorology. Dark green represents virgin forest, and light green, forests in which forestry is carried out. The purple and pink shades symbolize different types of farmland, while orange shades are grasslands with different levels of livestock farming. The lighter the shade, the more heavily the land is used.

It is apparent that humans have taken over the great majority of the land on Earth. "Three-quarters of the ice-free land surface is anthropogenically influenced," says Julia Pongratz. On around a quarter of the world's continents, humans have destroyed the natural vegetation over time to create cropland, rice fields or pastures. This process has accelerated since 1950, as heavy deforestation in the tropics testifies. Around half of the land surface is still covered by the original type of vegetation, but even here, some form of management takes place. Studies show that humans thus account for almost a quarter of the global terrestrial net primary production, or more specifically, 24 percent of the annual renewable plant biomass.

Humankind has, one might say, truly subjugated the planet – and this comprehensive exploitation of nature

Photo: iStockphoto/AVTG

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Forests with different climate impacts: An unmanaged forest with trees of different ages and a lot of deadwood (this page) exchanges different quantities of greenhouse gases, water and energy with the atmosphere than a spruce monoculture (left).

isn't without consequences for the climate. A total of one-third of the carbon dioxide ever released by humans – including historic deforestation – can be attributed to the original vegetation of the land surface being altered. Currently, changes in land use cause about 10 percent of human CO_2 emissions.

GREENHOUSE GASES FROM FERTILIZERS, LIVESTOCK AND RICE

The effect is even greater when climate-changing gases such as methane and nitrous oxide from agriculture are included in the balance sheet. These greenhouse gases enter the atmosphere through fertilizers, animal husbandry and rice cultivation, for instance. "If we add methane and nitrous oxide to carbon dioxide, the share of land use in today's greenhouse gas emissions increases to about one-third," reports Julia Pongratz. On the balance sheet of individual countries such as Brazil, land use emissions play an even greater role than fossil fuels.

When humans turn forests into fields, for example, they not only intervene in biogeochemical cycles, such as the carbon and nitrogen cycles, and alter the atmospheric CO_2 balance, they also influence various biogeophysical processes, such as albedo – the propor-

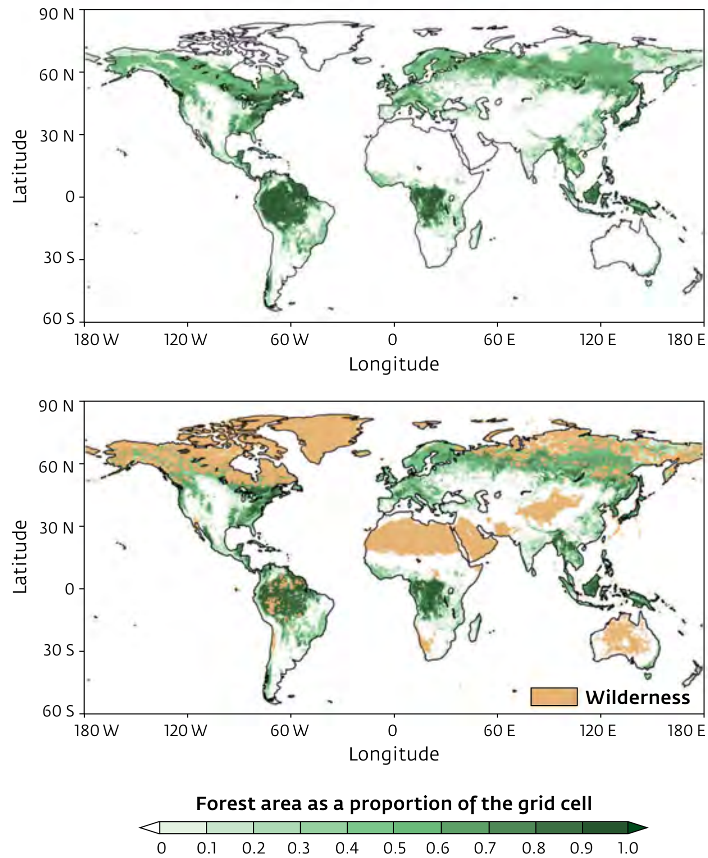
Complex climate factor: When a forest is cleared, not only does a carbon sink disappear – the albedo and other physical properties change, as well (top). However, how vegetation influences the climate also generally depends on which crops – corn or wheat, for instance – are cultivated on a field (center). These multifaceted effects should be taken into consideration, for example, when cultivating elephant grass as a substitute for fossil fuels (bottom).

Photos: shutterstock, Julia Pongratz, shutterstock (from top to bottom) tion of reflected sunlight – or the exchange of heat and moisture between land and atmosphere. These biogeophysical contributions can lead to atmospheric warming or cooling and thus enhance or counteract the climatic effect of an increase in the CO_2 concentration.

Because biochemical and physical factors interact in complex ways when land use is altered through agriculture and forestry, researchers currently understand the climate impacts of such interventions far less well than they do the effects of burning fossil fuels. The climate balance of the various factors can vary depending on the latitude or the assemblage of vegetation species – and as if that weren't enough, sometimes it can also take a different direction locally than it does globally.

Just how complicated the connections are is demonstrated by a relatively simple example: the transformation of a forest into cropland. The first effect is that there are now fewer forests available to absorb CO_2 and store it over the long term, fostering global warming. But there are also biogeophysical effects: at the site of the deforestation on the one hand, but also in more remote regions, on the other hand, because air currents carry the changes in the heat and hydrologic balances of the atmosphere further downwind.

Johannes Winckler, a mathematician in Julia Pongratz's group, was the first to make a clear distinction between the remote effects of these biogeophysical changes and the local effects. "The non-local effects were previously ignored because they weren't captured by observational data," says Winckler. However, he succeeded in unraveling the effects of massive deforestation worldwide and locally, and found that



Ample forestry: Forest covers large sections of the tropics and the high northern latitudes (top). However, only around 40 percent of this area is wilderness, as the orange regions in the bottom map show.

deforestation carried out to date has cooled more-distant regions. The non-local biogeophysical effects thus compensate for some of the global warming caused by the CO_2 emissions produced by clear-cutting.

For actual living conditions, though, the global mean temperature is far less relevant than the local climate. And even locally, the climate consequences of deforestation aren't easy to assess, because the change in vegetation typically makes the surface brighter – in other words, its albedo increases. Clear-cutting thus has a cooling effect, as more sunlight is reflected back into space. But deforestation can also induce a warming effect, since it reduces transpiration, or evaporation from the leaf surface. A field of grain often gives off less moisture than a forest, which normally has a larger leaf surface and deeper roots.

Which impact has the greater influence depends mainly on the latitude. At high latitudes, such as in northern Europe, the albedo effect is usually stronger, so deforestation tends to lead to local cooling. In the humid tropics, in contrast, the transpiration effect dominates, and deforestation here thus leads to warming. >

Graphic: Julia Pongratz/MPI for Meteorology

"One thing that is special about our group is that we consider both the biogeochemical and the biogeophysical aspects of land use," says Julia Pongratz. "This is important, because the climate sees both factors, and both are politically relevant." A geographer by degree, she finds the political significance of her research topic, which is essentially oriented toward basic research, particularly attractive.

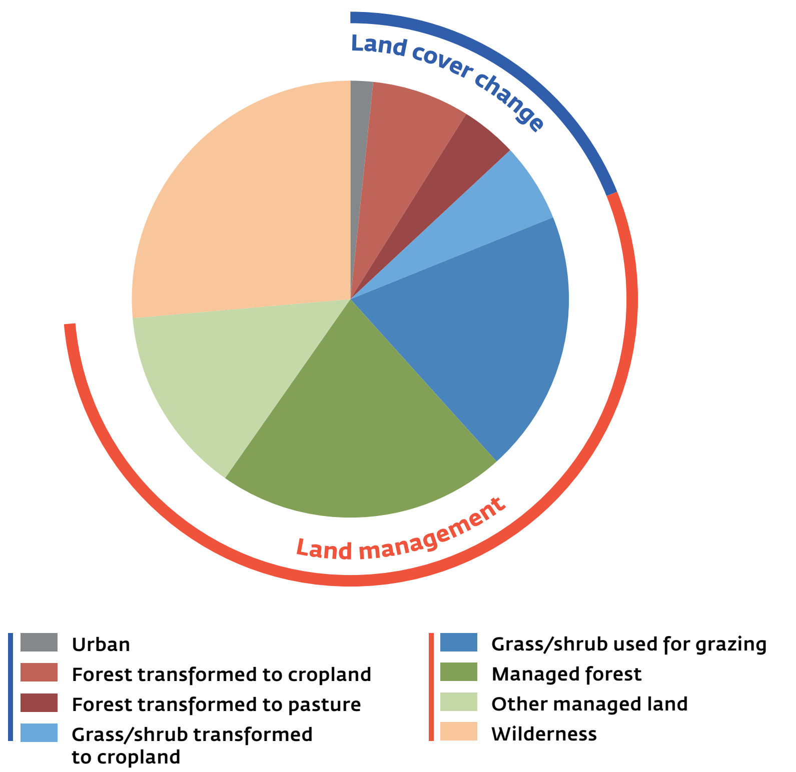
CLIMATE-RELEVANT PROCESSES IN FORESTRY

Since the establishment of her Emmy Noether Group in July 2013, she and her interdisciplinary team have been working to investigate climate-relevant biogeophysical and biogeochemical processes that play a role in land use, and especially in forestry. In addition, the group aims to discover to what extent land management can be used in climate change mitigation. To this end, the ten researchers are working to incorporate some previously neglected processes into the MPI-ESM Earth System Model of the Max Planck Institute in Hamburg.

Such Earth system models are among the climate researchers' most important tools. They have long been capable of modeling what happens when forests, for example, must give way to grazing land or fields – that is, when the land cover changes. The more

The climate researchers and their tools: Julia Pongratz, Sebastian Sonntag and Julia Nabel (from left) between a few of the towers of the Mistral supercomputer at the German Climate Computing Center in Hamburg.

Photo: Tom Pingel



Diverse land-use changes: Wilderness is found on only around a quarter of the ice-free land surface. Often, regions are altered in a way that also changes land cover, for example from forest to cropland. More common, however, is a different type of management, such as when people start to use grasslands as pastures. Both types of change influence the climate to a similar degree.

common case, however, when only the form of management in an area changes, hasn't yet been covered by the models. There are numerous variables in agriculture and forestry, such as fertilization, irrigation, harvesting cycles and grazing. They influence biogeophysical and biogeochemical variables, such as albedo, surface roughness, carbon uptake and other climatic factors. This is why Julia Pongratz' team takes both into consideration: changes in land use that alter the land cover and those that concern only land management.

The importance of considering changes in land management in climate models was demonstrated in a 2014 study by a team of researchers headed by Sebastiaan Luyssaert from the French Laboratory for Climate and Environmental Sciences in Gif-sur-Yvette. In the journal Nature Climate Change, the team – of which Julia Pongratz was also a member – reported that a change in land management, such as the transition from a virgin forest to a managed one, or the cultivation of different crop species – can affect temperatures just as strongly as changes in land cover.

At the locations that the researchers compared, both activities produced an average warming of two degrees Celsius. The team thus concluded that climate mitigation strategies shouldn't address merely fossil fuel emissions and deforestation, but also take into account the consequences of agriculture and forestry, which will likely become more intensive in the future.

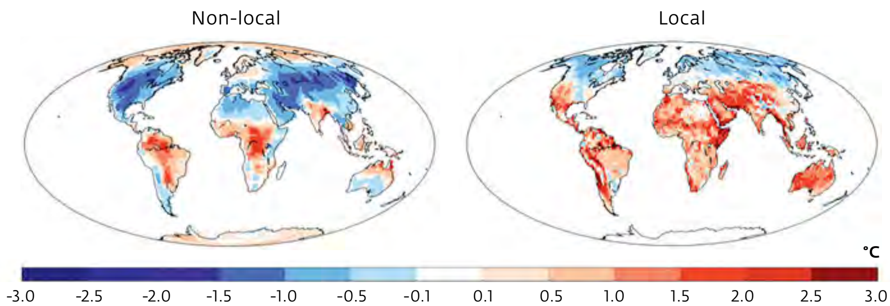
Julia Pongratz' group is therefore dedicated to the task of integrating various aspects of land management into climate models. A recently published study, in which Julia Pongratz played a key role, shows that the models didn't realistically simulate the effects of different types of land management.

In January 2017, a team of researchers led by Almut Arneth at the Karlsruhe Institute of Technology reported in the journal Nature Geoscience that land use and land management likely released more carbon dioxide in the past than was previously thought. This factor in the climate system would therefore have contributed more than a third to the increase in atmospheric carbon dioxide since humans took control of the Earth. Vegetation models have apparently underestimated these emissions to date because they didn't model land management realistically. "For example, the models don't currently address whether timber is harvested in a forest, and if so, how," says Julia Pongratz.

Post-doctoral student Kim Naudts is working on integrating the effects of land management into the climate models, assisted by Julia Nabel. As the group's scientific programmer, Nabel, a computer scientist, incorporates the processes being studied into the Max Planck Institute for Meteorology's complex Earth system model. She also ensures that the models run on the large supercomputer at the German Climate Computing Center. Efficient computing on the supercomputer is essential for modeling the diverse interactions between vegetation and atmosphere, as well as regional variations.

"We study primarily the effects of forestry," Naudts says. In an earlier study, the researcher, together with a

Graphic: MPI for Meteorology



Globally, deforestation leads to warming due to the loss of a carbon dioxide (CO_2) sink. However, global deforestation has a cooling effect (blue) across large areas due to non-local biogeophysical effects. Locally, the biogeophysical factors can increase temperatures (red) or decrease them (blue). (Scale in degrees Celsius)

Extreme differences in albedo occur when – as here in Zillertal – snowy, well-reflecting surfaces meet dark coniferous forest, which absorbs most of the light.

team from the French Laboratory for Sciences of Climate and Environment (LSCE), investigated how species selection by humans affects a forest's climate impact. For example, as coniferous trees have been cultivated in Europe in recent centuries for economic reasons, the vegetation has absorbed more heat. Although the conifers stored more carbon than the deciduous trees grown previously, the albedo effect had a greater impact. "Coniferous trees are probably not the best species for mitigating climate change in Europe," says Kim Naudts.

Now she is looking at what influence a forest's age has on the exchange of carbon, water and energy with the atmosphere. In most climate models to date, the age structure of the forests has not played a role. The Belgian-born researcher therefore investigated different harvesting methods – and showed that there are significant differences in the amount of stored carbon or in albedo when forest age is taken into account in their management. "To properly assess how much forestry can contribute to mitigating global warming, climate models must also incorporate the age of the forests," says Kim Naudts.

HOW WELL CAN REFORESTATION MITIGATE CLIMATE CHANGE?

In addition to investigating the consequences of land use changes, Julia Pongratz and her team are also investigating climate mitigation strategies. Sebastian Sonntag, for example, is researching how well reforestation could mitigate climate change. Together with Pongratz and other colleagues, he found that reforestation reduces the CO_2 level in the atmosphere more than was previously thought: in some scenarios, the growth of forests on land no longer needed for farming could lower the CO_2 increase by 85 ppm by the year 2100 – current calculations show an increase from today's 400 ppm to around 700 ppm. Consequently, the average global temperature would increase, not by 3.7 degrees Celsius by 2100, but by just 3.4 degrees.

"The novelty of our study was that we incorporated feedback loops with the carbon cycle into the model – for example, that increasing carbon dioxide levels in the atmosphere stimulate plant growth," explains Sonntag. However, even the new model doesn't include all conceivable factors. In the future, for example, droughts or a shortage of nutrients could affect tree growth. "It's fairly unlikely that we underestimated forest growth, but it could also be less than in our model," says the physicist. The reason is that many models don't sufficiently account for the reaction of the forest to climate extremes. Droughts, for example, can cause forests to die, and their impact continues for decades: they reduce carbon storage in vegetation until young forest has been reestablished. "In the model, this legacy doesn't exist yet as such," reports postdoc Lena Boysen, whose work closes this gap.

In another paper, Sebastian Sonntag compared the reforestation scenario with another geoengineering method: ocean alkalization. "The idea is based on the fact that the oceans can

Graphic: MPI for Meteorology; photo: Julia Pongratz bind more carbon dioxide if we increase the amount of acid-binding substances," says Sonntag. In practice, ocean alkalinity could be increased by enormous amounts of ground limestone. The results of his investigation reveal that this method may be more efficient than reforesting: because forests also have a warming effect, especially at high latitudes, it would be necessary to remove more CO_2 from the atmosphere with reforestation in order to achieve the same cooling effect as alkalization.

BIOMASS PLANTATIONS CAN HELP REDUCE EMISSIONS

In addition to reforestation, bioenergy plantations have also recently been discussed as a measure to combat global warming. "In some socioeconomic models, it is assumed that, in the future, large areas can be used for cultivating energy crops," says biologist Dorothea Mayer. "The harvested biomass would be converted into fuels or heating energy and thus reduce the consumption of fossil fuels." However, this kind of land use presents its own problems because energy crops can easily compete with food production or displace natural ecosystems, as Lena Boysen impressively demonstrated in previous studies with colleagues from the Potsdam Institute for Climate Impact Research. Therefore, in her scenarios, Mayer uses only arable land vacated as a result of intensified farming on other plots.

If biomass crops, such as elephant grass, were cultivated on such land in order to replace fossil fuels, this would mitigate the increase in CO_2 projected under unchecked emissions by a maximum of one-third – if all the material harvested were able to replace fossil fuels. "However, current techniques are not that good yet," Mayer points out. So according to her studies, biomass plantations can play a certain role in slowing down the increase in CO_2, but as before, the only way to stop it completely is to forego fossil fuels.

A final verdict on which forms of agriculture and forestry can contribute to mitigating climate change isn't easy to arrive at. As Julia Pongratz concludes, by constantly improving Earth system models, integrating key types of land management, and considering both local and global effects, climatologists can better understand the impact of changes in land use. At present, however, recommendations for policy makers remain difficult. "One can certainly argue whether land use should be exploited to mitigate climate change at all, as many processes are extremely complex and often not well understood," says the Research Group Leader. In her opinion, however, these considerations are useful. "We use the land anyway, there's no reason we shouldn't do it wisely." ◂

TO THE POINT

- **At least one-third of the CO_2 emissions caused by humans to date originate from land-use changes, such as deforestation.**
- **The effects of changes in land use are often difficult to assess. For example, to date, the conversion of forests into agricultural land has led to additional global warming owing to the release of CO_2, which, however, has been mitigated by changes in heat and water fluxes. At the site of deforestation, though, it may cause cooling at high latitudes due to increased albedo, while warming usually occurs in the tropics due to reduced transpiration.**
- **Different types of agriculture and forestry prevail on about half of the ice-free land surface and can affect the climate and atmospheric CO_2 levels as much as changes in land cover. This is why Julia Pongratz' team is also working on representing the effects of land management in Earth system models.**
- **Replacing fossil fuels with biomass energy sources would reduce the predicted increase in the CO_2 concentration by a maximum of one-third.**

GLOSSARY

Albedo is a measure of the amount of sunlight that is reflected into space without warming the atmosphere.

Alkalinity is the capacity to buffer acids, or in other words, to resist changes in pH that would make the water more acidic.

Land use encompasses all the ways in which humans intervene in an area's vegetation and soil. Changes in land use can lead to changes in land cover, for example from forest to cropland. However, an area – a forest, for example – can also simply be managed differently than previously.