The role of bioenergy production in the terrestrial carbon cycle and energy balance

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Land Use and Land Cover Change (LULCC) affects the climate not only by changing the carbon stock of different terrestrial carbon pools and thereby changing the atmospheric CO_2 concentration, but also through changes in biogeophysical parameters like albedo and evapotranspiration. While LULCC has been one of the major sources of anthropogenic carbon emissions, it also has the potential to reduce the atmospheric CO_2 concentration by increasing the terrestrial carbon pools or by de-carbonization of the energy system through utilizing energy from biomass plantations. This thesis focuses thus on the role of bioenergy production is the terrestrial carbon cycle and energy balance which is investigated using global vegetation and climate models.

Previous modeling studies have shown that the net effect of deforestation of the high latitudes is a cooling. However, a mismatch with a few observational studies indicates an underestimation of emissions estimated by these studies. I performed a purely hypothetical experiment of high latitude deforestation using terrestrial biosphere model, LPJmL and found the emissions due to deforestation accumulated over the 21st century to be higher than in previous modeling studies. This reflects the difference in how ‘deforestation’ is implemented and how the carbon cycle is represented in the different models. Moreover, it was found that even when bioenergy plantations were carried out only on suitable parts of the deforested areas, the emissions saved by the end of the 21st century, by avoided usage of fossil fuels, could not compensate for the total carbon emitted by deforestation. Therefore, considering only biogeochemical effects, even if extensive deforestation is followed by bioenergy cropping, it leads to an anthropogenic warming.

Some fraction of former agricultural land in the temperate and boreal region was abandoned in the near past due to different reasons. If such abandoned areas were to be managed by allowing natural reforestation or by bioenergy plantations, there would have been a sequestration of carbon or saving of carbon emissions by avoided usage of fossil fuels. In addition, there would have been no negative side effects like emissions from LULCC or competition for land with food crops. Using LPJmL to determine which of these two management methods are more effective, I found that the bioenergy plantations are more effective as the total carbon potentially saved by fossil fuel substitution is more than an order of magnitude higher than the total carbon sequestered by natural vegetation by the end of the 21^{st} century.

Tropical forests are highly productive and some fraction of agricultural land has been abandoned in the near past mainly due to damage and degradation. Thus I used LPJmL to determine whether allowing tropical abandoned croplands to revert naturally to forests and increase the carbon storage, is a more effective mitigation measure than carrying out bioenergy plantations. As for the temperate and boreal regions, I found bioenergy plantations to be more effective.

I conclude that, (i) extensive deforestation even if followed by bioenergy cropping causes more climate change than it reduces, (ii) bioenergy plantations on abandoned croplands is a more effective mitigation measure compared to natural re-growth of forests, (iii) lignocellulosic bioenergy grass species, having the ability to grow on nutrient poor soils, can be considered to be the most effective, and (iv) the tropical region has the highest mitigation potential compared to the temperate region, mainly because of the higher terrestrial net primary productivity.