Land-based climate change mitigation: modeling bioenergy production, afforestation and avoidance of deforestation

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Summary

Global food demand is projected to increase in the coming decades due to a growing and more affluent world population. In addition to agriculture, ambitious climate targets could further increase anthropogenic land-use in the course of the 21st century. Currently, bioenergy use in combination with Carbon Capture and Storage (CCS), afforestation and avoidance of deforestation are the most discussed land-based mitigation options. To evaluate these land-based options, it is crucial to investigate their mitigation potential and land requirement under consideration of interactions with the traditional agricultural sector. For instance, land-based mitigation might compete for land with food crop production, which could trigger investments in agricultural R&D targeted at yield increases.

Thus, the overarching research question of this thesis is: *What is the global potential of land-based carbon mitigation in the 21st century, what are the associated land requirements and what are the implications for the agricultural sector?* The overarching research question is subdivided into five specific research questions: (1) What is the carbon mitigation potential of global forest and land-use protection schemes? (2) How much bioenergy can be supplied at what price, with and w/o GHG emissions pricing in the land system? (3) How does irrigation in bioenergy production affect land and water resources, and what are the impacts on bioenergy prices? (4) How much land do afforestation and bioenergy with CCS require for how much carbon dioxide removal (CDR) from the atmosphere? (5) What are the direct and indirect effects of moderate climate change on terrestrial carbon stocks and what are the implications for land-based carbon mitigation?

To answer these research questions, this thesis employs methods of model-based computer simulation and scenario analysis. Central to this thesis is the Model of Agricultural Production and its Impacts on the Environment (MAgPIE), a spatially explicit economic land-use model with global coverage for simulations up to the year 2100. MAgPIE optimizes land-use patterns with the objective of minimizing global agricultural production costs and calculates the associated GHG emissions. Furthermore, MAgPIE derives economic indicators, e.g. bioenergy prices. The model simulations are subject to socio-economic assumptions, such as future food demand, and climate policy assumptions, such as bioenergy demand and GHG prices. Under carbon pricing, the model features endogenous abatement of carbon dioxide (CO_2) emissions through reduced deforestation. For this thesis, the existing model has been extended by large-scale afforestation as option for CDR.

(1) The MAgPIE results indicate that a price on CO_2 emissions from deforestation substantially reduces land-use change emissions. However, due to partial displacement of agricultural expansion to non-forest land types, land-use change emissions are still considerable. More comprehensive land-use protection schemes can further reduce land-use change emissions, but require larger productivity increases in the agricultural sector. (2) Without GHG emissions pricing, supply prices for modern bioenergy increase almost linearly with bioenergy demand. This relationship becomes non-linear under GHG emissions pricing in the land system since the price on CO_2 emissions reduces the availability of forests for agricultural expansion. (3) Prohibition of irrigated bioenergy production can avoid additional pressure on global blue water resources, but considerably increases land

requirements for bioenergy production, which is reflected in higher bioenergy supply prices. (4) The cumulative CDR per unit area from bioenergy use with CCS is 4-5 times higher compared to large-scale afforestation, since one unit of land can be used several times for bioenergy production but just once for afforestation. However, bioenergy with CCS is only cost-effective at relatively high carbon prices. (5) Moderate climate change (RCP2.6) has beneficial effects on global agricultural yields, which reduces agricultural land requirements and in consequence deforestation. Thus, direct climate impacts on agricultural yields indirectly affect the terrestrial carbon balance. However, such beneficial climate impacts on terrestrial carbon stocks only marginally increase the potential of land-based carbon mitigation since the potential is already large without further climate change.