International Max Planck Research School on
EARTH SYSTEM MODELLING

Climate Change and Global Land-Use Patterns — Quantifying the Human Impact on the Terrestrial Biosphere

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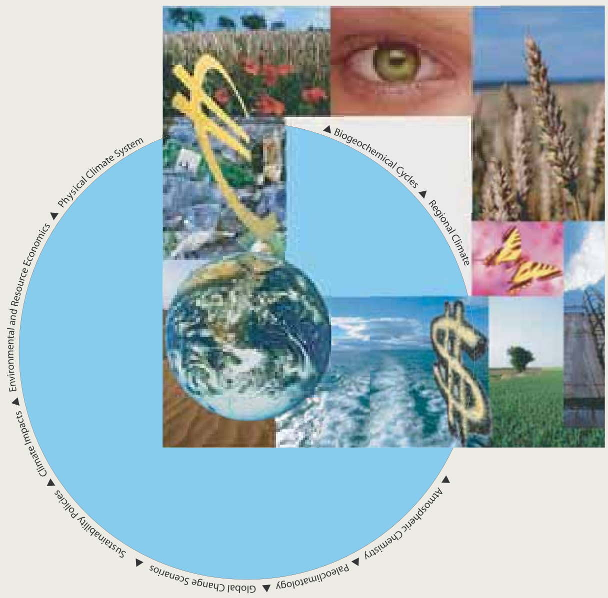

Abstract

Humans actively shape the terrestrial biosphere in order to produce essential resources such as food, fiber, and wood as well as for settlements, industries, and infrastructure. Their activities also affect climate, oceans, and the functioning of the Earth System and, thus, change the terrestrial biosphere also indirectly. It is important to understand the processes, dynamics, and interactions of the Earth System in order to assess the consequences of human activity, such as large-scale fossil fuel combustion or tropical deforestation. With the help of computer models, the future development of the Earth System can be projected into the future under different scenarios of societal development.

This study focuses on the effects of human land use and climate change on the global terrestrial biosphere. I demonstrate the importance of land use and land-use change for the global terrestrial carbon and water cycles in two different analyses: In a static-comparative setting, investigating the effects of three different socio-economic drivers of land-use change (demography, diet, market structure) and in consistent future projections of the 21^{st} century, analyzing the effects of land-use change and climate change. For the first study, I generated stylized spatially explicit land-use data. In the second, I used the consistent land-use and climate data sets generated by the Integrated Model to Assess the Global Environment (IMAGE 2.2) for the Special Report on Emission Scenarios (SRES) A2, B1, and B2. Both analyses show that the effects of land use and land-use change on the global terrestrial carbon cycle are equally important to the effects of CO_2 fertilization and climate change, causing terrestrial carbon losses of up to 450 PgC under the A2 scenario. For the terrestrial water cycle, land use and land-use change mainly result in reduced transpiration and increased evaporation fluxes, with little effects on runoff at the global scale.

The rate of land-use change and the spatial localization of agricultural production are of major importance for the effects of land use and land-use change on the terrestrial biosphere. However, reliable, spatially explicit data on global land-use change for future projections are hardly available. To overcome this imbalance between importance and availability of land-use data, a globally applicable, spatially explicit land-use model is needed. In a review of the state-of-the-art of large-scale land-use modeling, I provide an overview of existing models and approaches. Geographic approaches focus on land suitability, spatial interaction and constraints on the supply side, while economic approaches focus on the demand side, employing preferences, motivations, as well as market and population structures to explain changes in the production of land-intensive goods. Integrated approaches exist that combine economic and geographic methodologies. However, they do not exploit the entire potential of this integration yet. A major obstacle in integrating economic and geographic approaches is the difference in spatial scales. Economic models typically operate at regional or national scales, while geographic models mainly operate on spatially explicit grids. To bridge the gap between these spatial scales, I explore the robustness of Dynamic Global Vegetation Model (DGVM) simulations against reductions in spatial resolution. Coarser spatial resolutions do not differ qualitatively from finer spatial grids, as the deviation from the typically used 0.5° grid increases linearly with grid coarseness with a small slope (less than 1.5 percent deviation per degree).

As an outlook, I introduce a newly developed globally applicable land-use model, MAgPIE (Model of Agricultural Production and its Impact on the Environment), an economic optimization model, which generates spatially explicit land-use patterns at a spatial resolution of 3.0° x 3.0°. Essential inputs are spatially explicit data on yield levels and freshwater availability, which are provided by the Lund-Potsdam-Jena DGVM for managed Lands (LPJ/mL), and regional data on population, production costs, and Gross Domestic Product (GDP) only. MAgPIE internally computes changes in diets, and thus demand, based on empirical relations to GDP if no suitable input data are available. Besides generating spatially explicit land-use patterns, MAgPIE allows for exploring the effects of technology change and trade liberalization, and for valuating the competition for land and water.