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Development and Climate Change

BACKGROUND NOTE

COMPETITION FOR LAND BETWEEN FOOD, BIOENERGY AND CONSERVATION

by

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Background note to the World Development Report 2010

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Background

Increased future demands for food, fibre and fuels from biomass can only be met if the available land and water resources on a global scale are used and managed as efficiently as possible. The main routes for making the global agricultural system more productive are through intensification and technological change on currently used agricultural land, land expansion into currently non-agricultural areas, and international trade in agricultural commodities and processed goods. In order to analyse the trade-offs and synergies between these options, we have developed the global bio-economic model MAgPIE with a special focus on spatially explicit land and water constraints as well as technological change in agricultural production (Lotze-Campen et al. 2008a, 2008b).

For different scenarios on population and income trends, climate change, bioenergy demand, and spatially explicit land and water constraints, we calculate the required rate of productivity increase on agricultural land. As additional technological change will only be provided at additional costs of production (through investment or research and development), we also translate this into increased costs of production. Our non-linear programming model enables us to translate various biophysical constraints to agricultural production into relevant production costs, and through derived shadow prices it also provides a quantitative measure of scarcity for land and water resources. For future projections the model works on a time step of 10 years in a recursive dynamic mode. The link between two consecutive periods is established through the land-use pattern. The optimized land-use pattern from one period is taken as the initial land constraint in the next. If necessary, additional land from the non-agricultural area can be converted into cropland at additional costs.

Potential crop yields for each grid cell are supplied by LPJmL (Sitch et al., 2003; Bondeau et al., 2007). In addition to major food and feed crops, also cellulose-based bioenergy crops have been implemented. LPJmL endogenously models the dynamic processes linking climate and soil conditions, water availability and plant growth, and takes the impacts of CO_2, temperature and radiation on yield directly into account.

Spatially explicit data on yield levels and freshwater availability for irrigation in MAgPIE is used on a regular geographic grid, with a resolution of three by three degrees, dividing the terrestrial land area into 2178 discrete grid cells of an approximate size of 300 km by 300 km at the equator. Each cell of the geographic grid is assigned to one of ten economic world regions. While all supply-side activities in the model are grid-cell specific, the demand side is aggregated at the regional level. Aggregate demand within each region, defined by total population, average income and net trade, is being met by the sum of production from all grid cells within the region. Trade in food products between regions is simulated endogenously, constrained by minimum self-sufficiency ratios for each region. Land conversion activities provide for potential expansion and shifts of agricultural land in specific locations. Bioenergy in MAgPIE is supplied as a mix of three different types: vegetable-oil-based from various oil crops, starch/sugar-based from cereals and sugar crops, and cellulose-based from specialized grassy and woody bioenergy crops.

Besides changes in population, economic growth and environmental production conditions, the issue of technological change in production (i.e. yield increase) is of crucial importance for the resulting spatial patterns of land and water use. This can be tackled in two directions. With most other modelling approaches, this is done by assuming a future trend in productivity growth and then deriving the economic and environmental consequences. In contrast, with our mathematical programming model the issue can be turned around, and the minimum rate of technological change required to meet certain constraints can be derived. Hence, the main question behind the scenarios described here is: "How much yield increase (or technological change) is required to fulfill future global demand for bioenergy and food under different spatial restrictions on land and water use?"

We run the MAgPIE model in six 10-year time steps from 1995 until 2055 in a recursive dynamic manner. The model is driven by external scenarios on population growth and GDP growth taken from the SRES A2 scenario (IPCC, 2000). Global population increases up to about 9 billion in the year 2055, and average world income per capita reaches about 15,000 US$ (in 1995 purchasing power parity terms). Global bioenergy demand in the ten world regions is taken from various climate stabilization scenarios generated by the macroeconomy-energy system model REMIND at PIK.

Scenarios

We have constructed a set of scenarios which demonstrate the increasing need for productivity increase in global agriculture under increasing pressure from various sources. In the scenarios, the pressures are added up to show their combined cumulative effects.

<u>(1) Business as usual</u> (baseline): Global population increases to 9 billion people in 2055. Total calorie consumption per capita and the dietary share of animal calories increase in relation to rising per-capita income from progressing economic growth. The process of globalization and further trade liberalization is expected to continue. We model this by doubling the share of agricultural trade in total production over the next 50 years. Expansion of cropland is expected to continue at historical rates of about 0.8% per year. There are no climate impacts on yields in the baseline scenario. Note that all of these conditions are implemented specifically for each of the ten regions.

Increasing cumulative pressures are added in the following scenarios:

<u>(2) + Reduced trade</u>: The share of agricultural trade in total production is kept constant at 1995 levels of about 7%.

(3) + Bioenergy 100 EJ: Demand for bioenergy is continuously rising until it reaches 100 EJ globally in 2055. Bioenergy is region-specific and assumed to be fulfilled within each region.

(4) + Avoided deforestation: Cropland expansion is reduced by excluding intact and frontier forests from conversion, i.e. some effective measures for avoiding deforestation are expected to be implemented.

(5) + Climate change impacts on yields (CC with full CO_2 effect; CC with constant CO_2 effect): Climate impact results from LPJmL are fed into the MAgPIE model, and the average effects on the need for additional technological change are simulated with and without CO_2 fertilization.

Results on required future technological change rates

The resulting rates of technological change (TC) for business as usual and various scenarios are provided in Figure 2.6.1. The model results are compared with past observations on yield increase from FAO statistics between 1961 and 2005. The numbers describe average regional yield increases per year for all crops over a given period (2005-2055 for the future scenarios). Note that the model searches for a cost-minimal spatial cropping pattern within and across regions. If given demand cannot be fulfilled by optimizing the land use pattern, the model can "purchase" additional technological change to solve the problem.

The average required productivity increase in agriculture for the world as a whole in the business-as-usual scenario is about 1% p.a., compared to about 1.4% p.a. over the period 1961-2005. Even with reduced trade the average rate is still below past observations. With increased bioenergy demand up to 100 EJ in 2055, the required TC rate rises to about 1.5% p.a. which already exceeds past trends. If, in addition, further deforestation of intact and frontier forests is avoided, the average global rate is pushed up to about 1.6% p.a.. As expected from section 2.2, the climate change impacts are ambiguous. We show the mean results for GCM scenarios with and without CO_2 fertilization, i.e. full CO_2 effect and constant CO_2 effect, respectively. With constant CO_2 , global required TC rates on average are increased to 1.8% p.a.. With full CO_2 effects, the cumulative pressure from our scenarios is reduced, and an average TC rate of about 1.4% p.a. would be sufficient to fulfil global demand for food and bioenergy, while avoiding deforestation.

The regions most heavily affected in the business-as-usual scenario are AFR and MEA. They would require very strong TC increases compared to the past. FSU will be most strongly affected by increased bioenergy demand. The regions most heavily affected by avoided deforestation are AFR and LAM, where required TC rates increase by about 0.3 percentage points p.a. specifically in this scenario. Climate change impacts without CO_2 fertilization are expected to be strongest in PAS and SAS. Regions with relatively slow population growth, like CPA, EUR, NAM and PAO, face comparatively low additional pressure on their land resources. However, it must be taken into account, that current productivity levels are already relatively high in these regions, leaving potentially less room for further improvements in the future.

In Figure 2.6.2, we have converted the global average TC rates p.a. into a productivity index (2005=100), in order to show the effect of different annual rates over time. With bioenergy and avoided deforestation, average productivity on the available cropland would have to more than double by 2055. The green wedge indicates the range of climate impacts. At constant CO_2 levels, the required productivity level would rise to about 250% of current levels, in order to fulfil all food and energy demands.

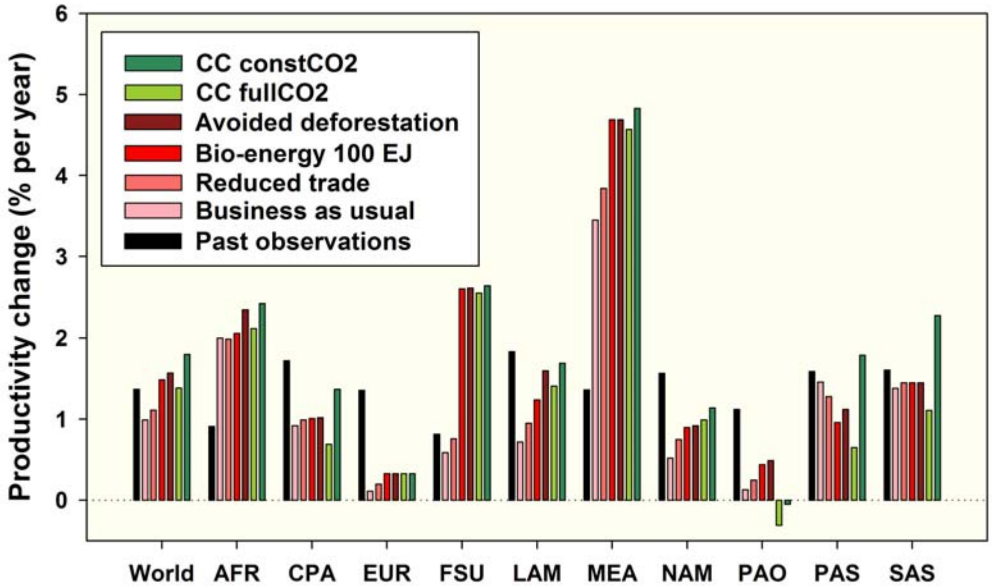

Figure 2.6.1: Region-specific required future productivity increase under increasing pressures on land and water use (<u>cumulative effects</u> of reduced trade, 100 EJ bioenergy demand in 2055, avoided deforestation, and climate change)

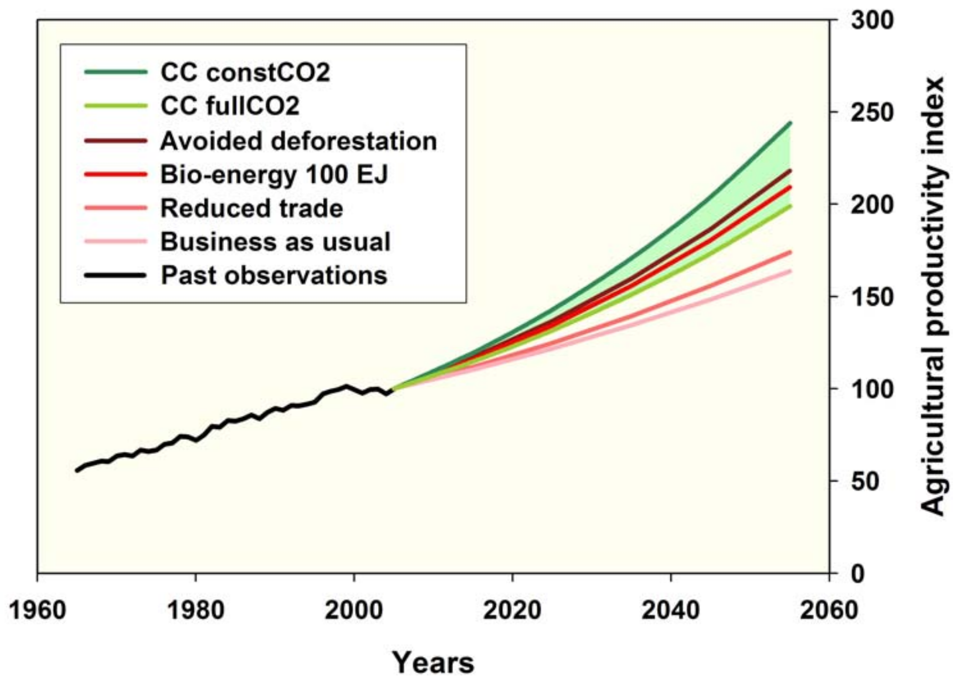

Fig. 2.6.2: Past observed trends in agricultural productivity (global average across all crops) and required future trends in productivity increase under increasing pressures on land and water use (<u>cumulative effects</u> of reduced trade, 100 EJ bioenergy demand in 2050, avoided deforestation, climate change)

The required future TC rates from our model calculations become more challenging, if compared to the past trend over time. As can be seen in Figure 2.6.2, the trend of average productivity increase across all crops and regions was significantly slower in the period 1990-2005 than in the three decades between 1960 and 1990. According to our data, this is actually true also for all single regions. As shown by our scenarios, this trend of declining TC rates in the past not only has to be reversed, but has to be strongly accelerated due to increasing cumulative pressures on the land from various sources. This is particularly urgent for AFR and MEA.

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Appendix

Country-to-region mapping for regional aggregation of results

AFR	CPA	EUR	FSU	LAM
Sub-Saharan Africa	**Centrally-Planned Asia**	**Europe**	**Former Soviet Union**	**Latin America**
Angola	Cambodia	Albania	Azerbaijan, Republic of	Argentina
Benin	China	Austria	Belarus	Belize
Botswana	Laos	Belgium-Luxembourg	Georgia	Bolivia
Burkina Faso	Mongolia	Bosnia and Herzegovina	Kazakhstan	Brazil
Burundi	Viet Nam	Bulgaria	Kyrgyzstan	Chile
Cameroon		Croatia	Moldova, Republic of	Colombia
Central African Republic		Czech Republic	Russian Federation	Costa Rica
Chad		Denmark	Tajikistan	Cuba
Congo, Dem Republic of		Estonia	Turkmenistan	Dominican Republic
Congo, Republic of		Finland	Ukraine	Ecuador
Côte d'Ivoire		France	Uzbekistan	El Salvador
Djibouti		Germany		French Guiana
Equatorial Guinea		Greece		Guatemala
Eritrea		Hungary		Guyana
Ethiopia		Iceland		Haiti
Gabon		Ireland		Honduras
Ghana		Italy		Mexico
Guinea		Latvia		Nicaragua
Guinea-Bissau		Lithuania		Panama
Kenya		Macedonia,The Fmr Yug Rp		Paraguay
Lesotho		Netherlands		Peru
Liberia		Norway		Suriname
Madagascar		Poland		Uruguay
Malawi		Portugal		Venezuela
Mali		Romania		
Mauritania		Slovakia		
Mozambique		Slovenia		
Namibia		Spain		
Niger		Sweden		
Nigeria		Switzerland		
Rwanda		Turkey		
Senegal		United Kingdom		
Sierra Leone		Yugoslavia, Fed Rep of		
Somalia				
South Africa				
Sudan				
Swaziland				
Tanzania, United Rep of				
Togo				
Uganda				
Western Sahara				
Zambia				
Zimbabwe				

MEA	NAM	PAO	PAS	SAS
Middle East/North Africa	**North America**	**Pacific OECD**	**Pacific Asia**	**South Asia**
Algeria	Canada	Australia	Indonesia	Afghanistan
Egypt	United States of America	Japan	Korea, Dem People's Rep	Bangladesh
Iran, Islamic Rep of		New Zealand	Korea, Republic of	Bhutan
Iraq			Malaysia	India
Israel			Papua New Guinea	Myanmar
Jordan			Philippines	Nepal
Kuwait			Solomon Islands	Pakistan
Libyan Arab Jamahiriya			Thailand	Sri Lanka
Morocco				
Oman				
Saudi Arabia				
Syrian Arab Republic				
Tunisia				
United Arab Emirates				
Yemen				