United States Department of Agriculture

Scenarios of bioenergy and food demand: implications for land use and carbon storage

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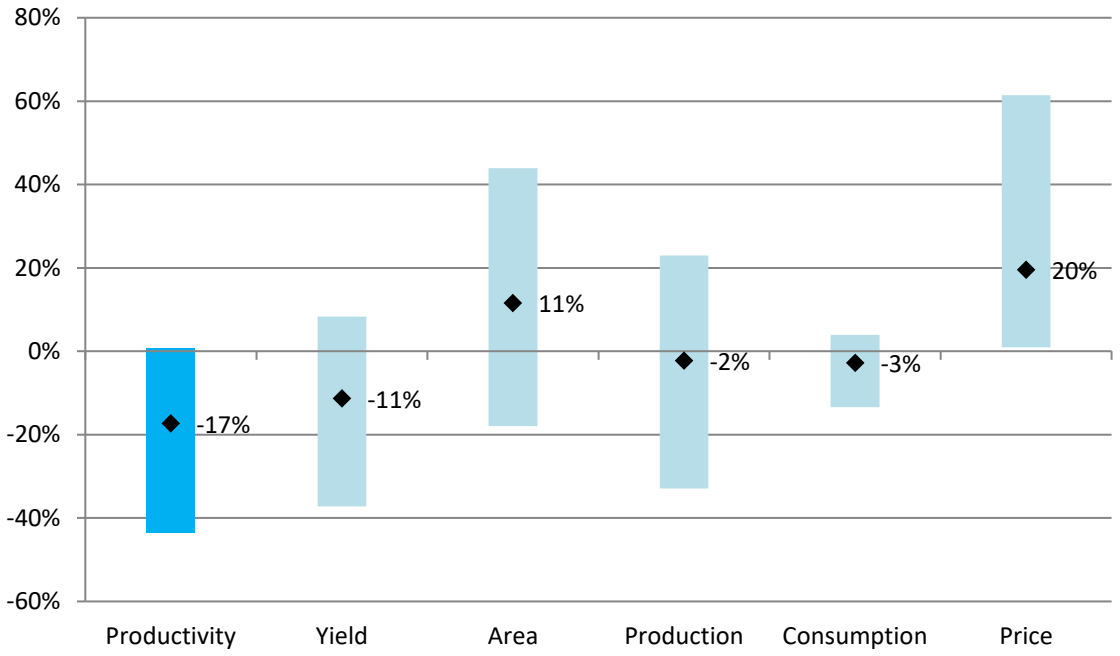
The 27th Asia-Pacific Integrated Modeling (AIM) International Workshop
National Institute for Environmental Studies, Tsukuba, Japan

September 30 and October 1, 2021
Online Workshop

Future Agricultural Resources Model (FARM)

- Structure
  - Computable general equilibrium
  - 13 world regions
  - Five-year times steps beginning in 2011 (base year for GTAP 9 social accounting matrix) through 2101
  - World agriculture and energy systems
  - Match monetary values to quantities: land (hectares), food (calories), energy (joules)
- Major drivers of global change
  - Population
  - Per capita income
  - Agricultural productivity
  - Dietary preference
  - Climate change effects on agriculture
  - Climate change mitigation
- Indicators
  - Food consumption
  - Crop production
  - Land use
  - Bioenergy production
  - Carbon dioxide emissions

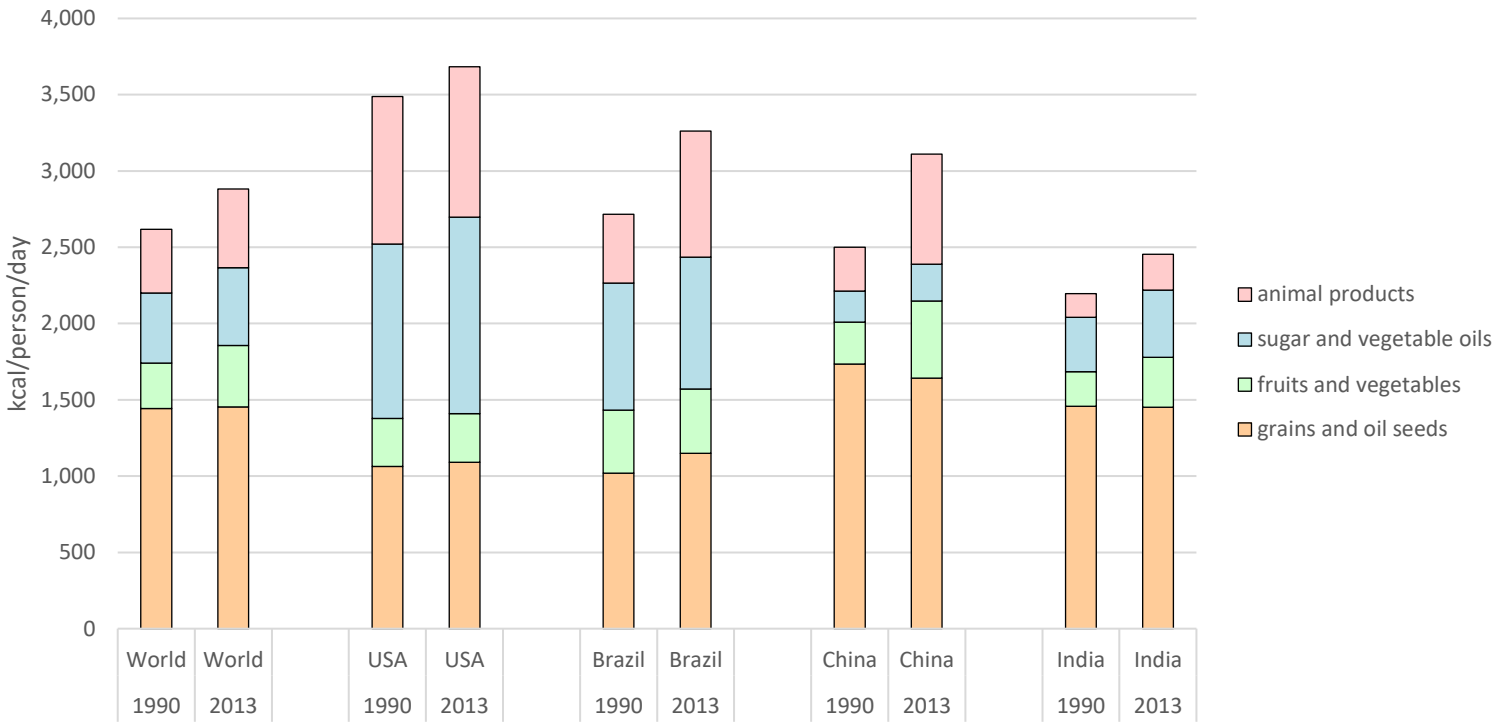
Economic responses to a decline in agricultural productivity due to climate change in 2050



Change in Productivity is the exogenous shock. All other changes are endogenous responses relative to baseline. The black diamond is the average (mean) percent change with climate change compared to no climate change in year 2050; the height of a column is the range across climate models, crop models, and economic models. Results are a world average across major field crops: wheat, rice, coarse grains, and oil seeds.

Source: Nelson et al. (2014) *Proceedings of the National Academy of Sciences*, Vol. 111(9): 3274-3279.

Historical diet patterns

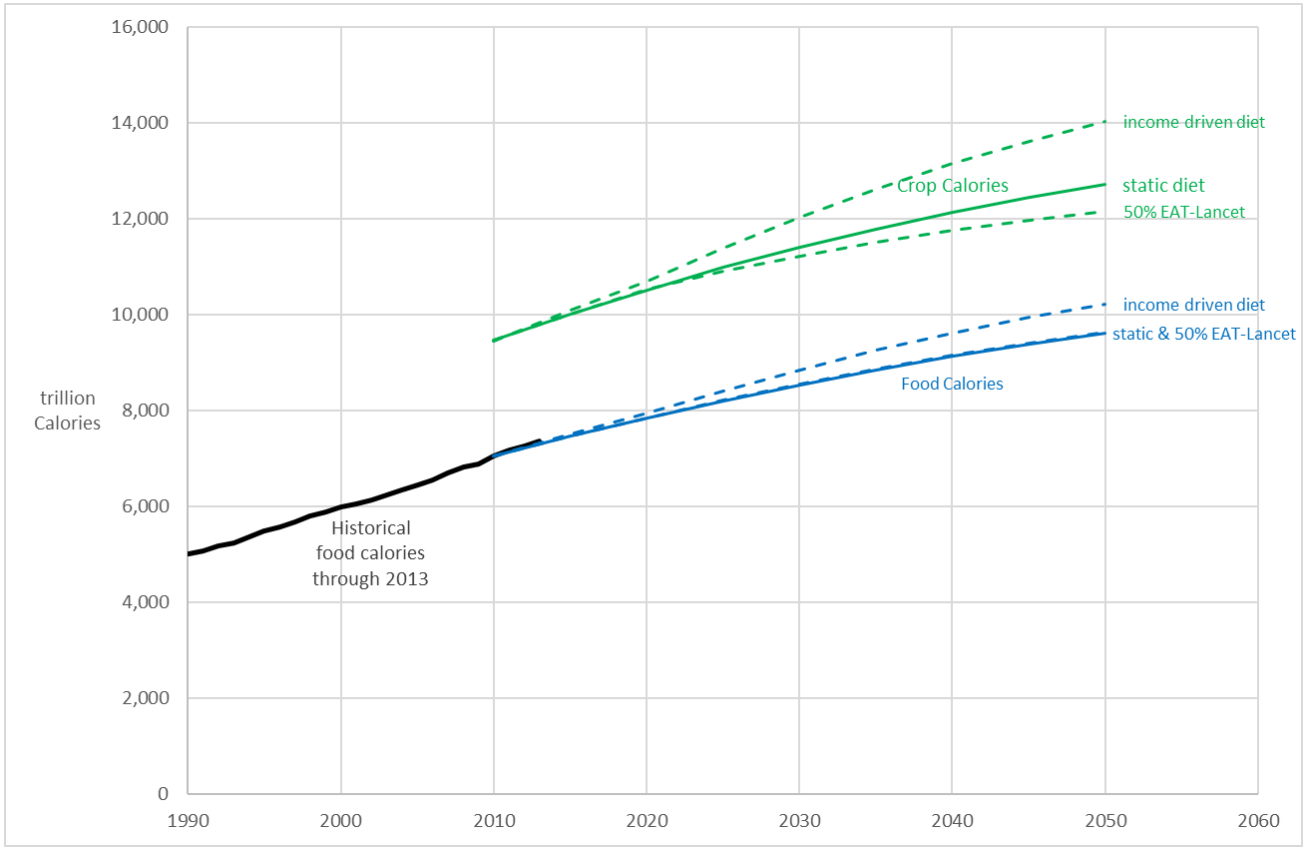


Diet scenarios

- Static diet (reference scenario): All world regions maintain their 2011 historical diet. There is no income or price response in this scenario.
- Income-driven diet: based on historical food consumption patterns in response to increasing per capita income. The general pattern is for total per capita calories to increase, along with a greater share of animal products in the diet.
- 50 percent EAT-Lancet healthy diet: 50 percent convergence from 2011 historical diet toward the Healthy Reference Diet in Willet et al. (2019). With full convergence, average consumption of food calories becomes 2500 kcal/person/day within each world region, which is an increase for developing countries and a decrease for wealthy countries. Consumption of animal products increases in developing countries but declines in wealthy countries.

W. Willett et al. (2019) Food in the Anthropocene: the EAT–Lancet Commission on healthy diets from sustainable food systems, The Lancet 393: 447-492.

World food calories and crop calories in three diet scenarios



Food calories to crop calories

- There is no unique measure of agricultural production – it could be metric tons, calories, or an economic quantity index with prices as weights
  - Tons are useful for aggregation for a limited number of similar goods, such as grains
  - We use calories to aggregate or compare all agricultural products
- Crop calories are always greater than food calories because calories of animal feed are greater than calories of animal products
- Food calories
  - Final calories are those that can be consumed as food, covering all food products
  - Calibrated to FAO food balance sheets
  - FAO calories available for consumption include post-retail food loss
    - Food loss is a small fraction of calories consumed in developing countries
    - Food loss is a large fraction of calories consumed in wealthy countries
- Crop calories
  - Primary (crop) calories are produced from the land, before processing into animal or food products
  - At the country level, crop calories produced may be different than crop calories utilized, due to international trade
  - At the world level, international trade nets to zero, and production of crop calories equals utilization of crop calories

Mitigation scenarios using bioenergy with CO_2 capture and storage (BECCS)

This section provides simulation results on land use change and CO_2 sequestered for a reference scenario and two BECCS mitigation scenarios:

- Reference scenario: no greenhouse gas mitigation policy; U.N. medium population projections; income grows according to Shared Socio-economic Pathway 2
- Low BECCS mitigation: response to a CO_2 price path that reaches $30 per tCO_2 in 2040, and increases 5 percent per year thereafter
- High BECCS mitigation: response to a CO_2 price path that reaches $80 per tCO_2 in 2040, and increases 5 percent per year thereafter

Energy crops are used to generate electricity; CO_2 emissions from combustion are captured and stored underground. Cropland area declines as land is allocated to energy crops. Net global CO_2 emissions decline to zero by 2100 in the High BECCS scenario.

Scenario year	mitigation	Crop area (Mha)	Pasture area (Mha)	Energy crop area (Mha)	Bioenergy production (EJ)	CCS biomass (Mt CO_2)	CCS fossil (Mt CO_2)
2011 base year	None	1,466	2,704	7	6	0	0
2101 reference	None	1,406	2,694	32	17	0	0
2101	Low BECCS	1,289	2,600	246	111	8,500	8,900
2101	High BECCS	1,240	2,558	343	163	**13,300**	7,100

Expanded set of scenarios

Our indicator of agricultural intensity is the quantity of crop calories produced per hectare of cropland per year. This indicator captures the effect of changes in drivers of food demand such as population and dietary preference, as well as potential future demand for energy crops to mitigate climate change.

- 50 percent EAT-Lancet healthy diet: 50 percent convergence from 2011 historical diet toward a Healthy Reference Diet
- Static diet: All world regions maintain the 2011 historical diet.
- Income-driven diet: based on historical food consumption patterns in response to increasing per capita income

Agriculture intensity (yield) is calculated as crop calories divided by crop area.

Scenario year	mitigation	population	diet	Food calories (Pcal)	Crop calories (Pcal)	Crop area (Mha)	Yield (M kcal per ha)
2011 base year	None	Historical	Historical	7,140	9,570	1,466	**6.5**
2101	None	UN low	Static	6,980	8,910	1,187	7.5
2101	None	UN med	50 percent EAT-Lancet healthy diet	10,782	13,612	1,412	9.6
2101 reference	None	UN med	Static	10,710	14,050	1,406	**10.0**
2101	None	UN med	Income-driven	11,650	15,820	1,468	10.8
2101	Low BECCS	UN med	Static	10,700	14,000	1,289	10.9
2101	High BECCS	UN med	Static	10,700	13,940	1,240	11.2
2101	High BECCS	UN med	Income-driven	11,050	14,780	1,273	11.6
2101	None	UN high	Static	17,210	22,150	1,597	13.9

Final Thoughts

- All major drivers of global change affect land use
  - It matters whether drivers are considered alone or in combination
  - We considered dietary preference and mitigation separately and combined
- Agricultural productivity may be the least understood of land use drivers
- Crop yield is endogenous in a general equilibrium economic framework with land competition
- Economic adjustment occurs across several dimensions
  - Cropland area
  - Crop yield
  - Crop and food prices
  - International trade
- EMF-37: Deep decarbonization in North America
  - Economy-wide models
  - Sector models: buildings, transportation, industry
  - Pathways to net-zero CO_2 emissions
  - Can net-zero CO_2 emissions be achieved without carbon dioxide capture and storage (CCS)?