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The role of future agricultural productivity assumptions in integrated assessment model projections of land use change

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Overview

- Introduction to the GCAM integrated assessment model
- Standard assumptions on agricultural productivity growth over the next century
- Sensitivity studies of agricultural productivity parameters in GCAM
- The role of agricultural productivity in climate mitigation scenarios
  - Are there climate consequences?
- Two case studies: Climate change impacts on crop yield and the implications for climate mitigation

- “Agricultural productivity” refers to the amount of harvested product per land area, and is analogous to “crop yield”

Integrated Assessment Models (IAMs)

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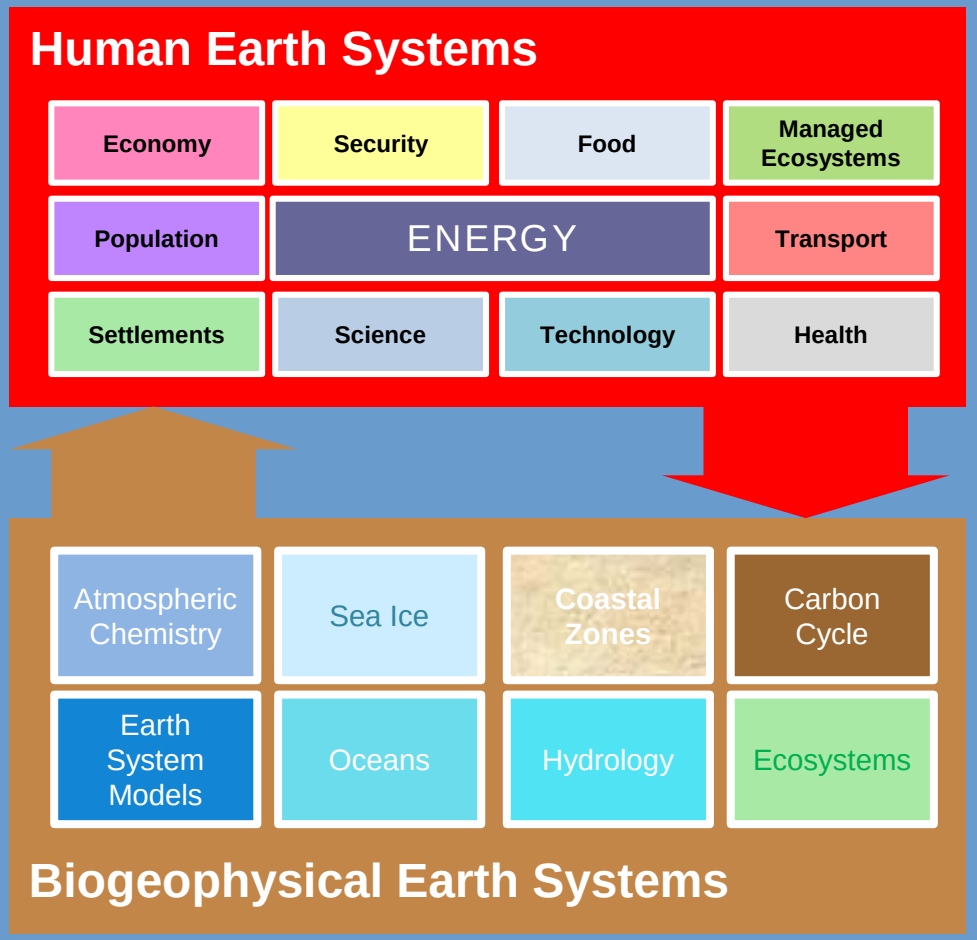
IAMs integrate human and biogeochemical Earth system climate science.

- IAMs provide insights that would be otherwise unavailable from disciplinary research.
- IAMs capture interactions between complex and highly nonlinear systems.
- IAMs provide biogeochemical science researchers with information about human systems such as GHG emissions, land use and land cover.

IAMs provide important, science-based decision support tools.

- IAMs support national, international, regional, and private-sector decisions.



Examples of IAM Questions

- What is the lowest cost pathway to a particular climate target?
- What are the effects of land decisions on the energy system?
- What are the effects of energy decisions on the terrestrial system?
- What are plausible future emissions pathways under various socioeconomic and policy conditions?
- What is the effect of technological development on the energy system and the cost of mitigation?
- How do impacts & adaptation interact with efforts to mitigate?

The Global Change Assessment Model

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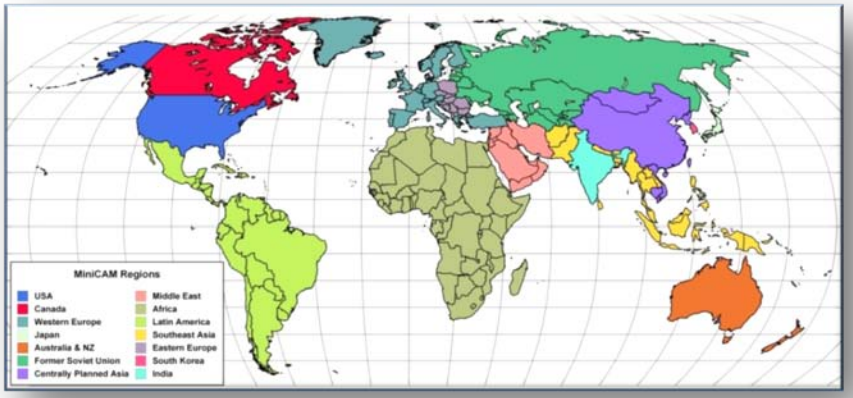
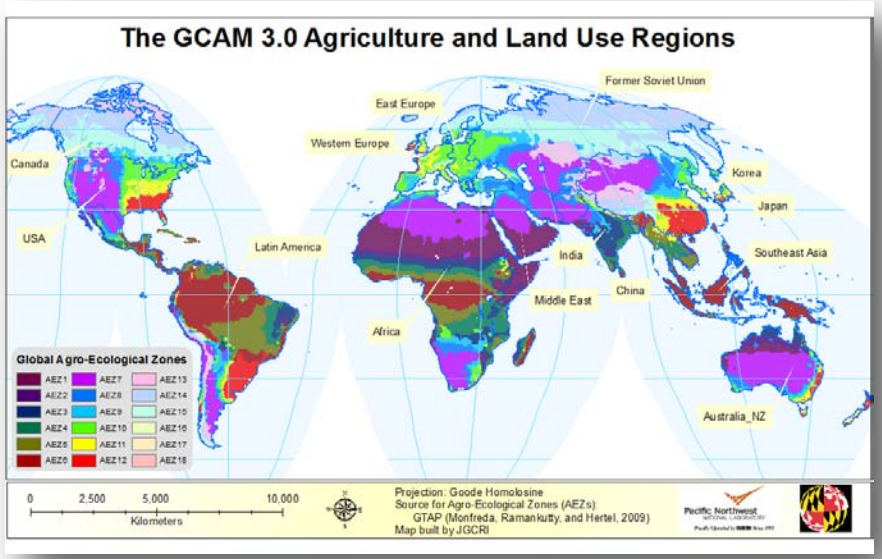
14 Region Energy/Economy Model



151 Agriculture and Land Use Model



- GCAM is a **global integrated assessment model**
- GCAM links **Economic, Energy, Land-use,** and **Climate** systems
- Technology-rich model
- Emissions of 16 greenhouse gases and short-lived species: CO_2, CH_4, N_2O, halocarbons, carbonaceous aerosols, reactive gases, sulfur dioxide.
- Runs through **2095** in **5-year time-steps.**
- Dynamic Recursive
- Open Source
- Documentation available at: **wiki.umd.edu/gcam**

The Global Change Assessment Model

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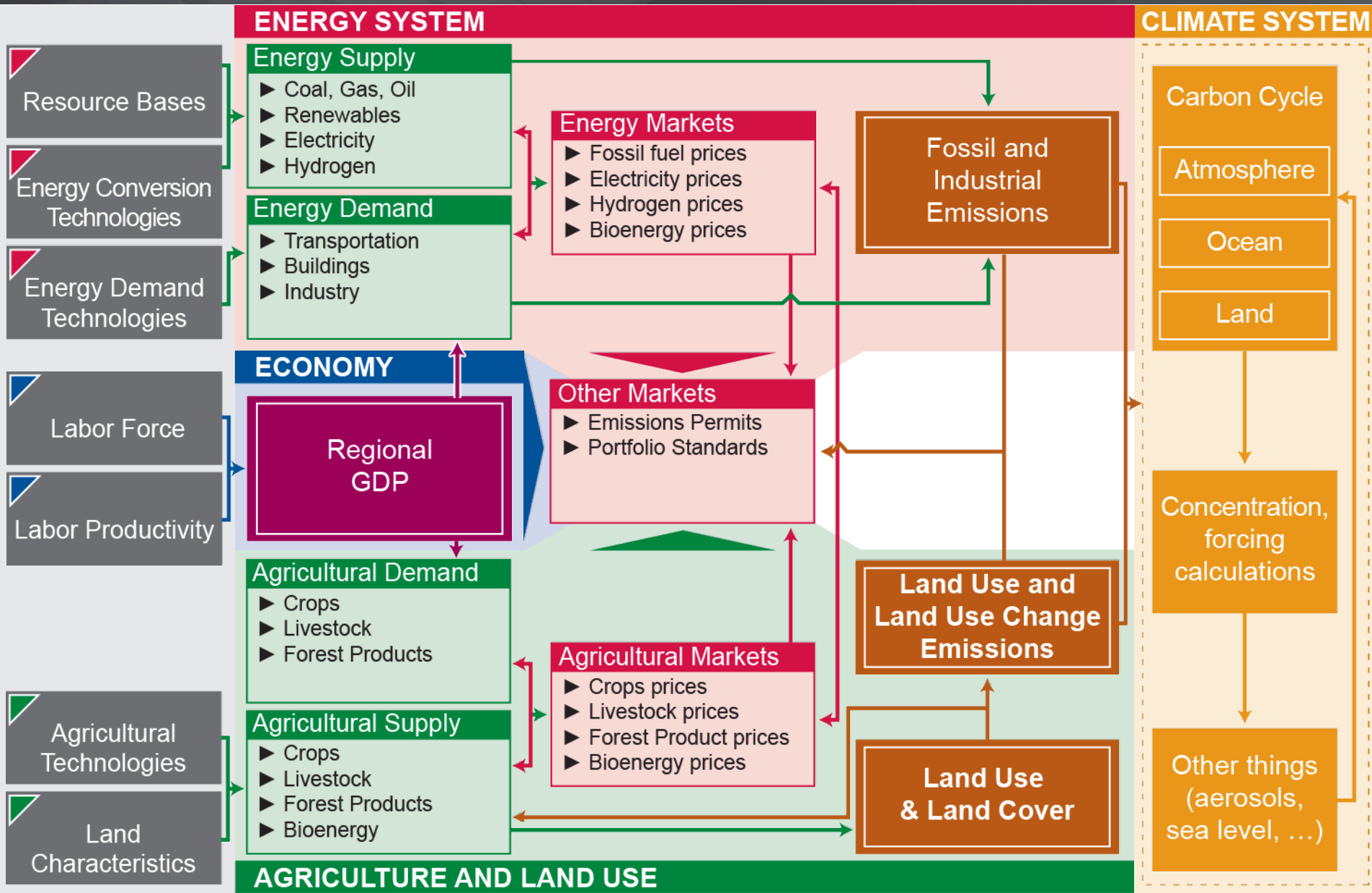
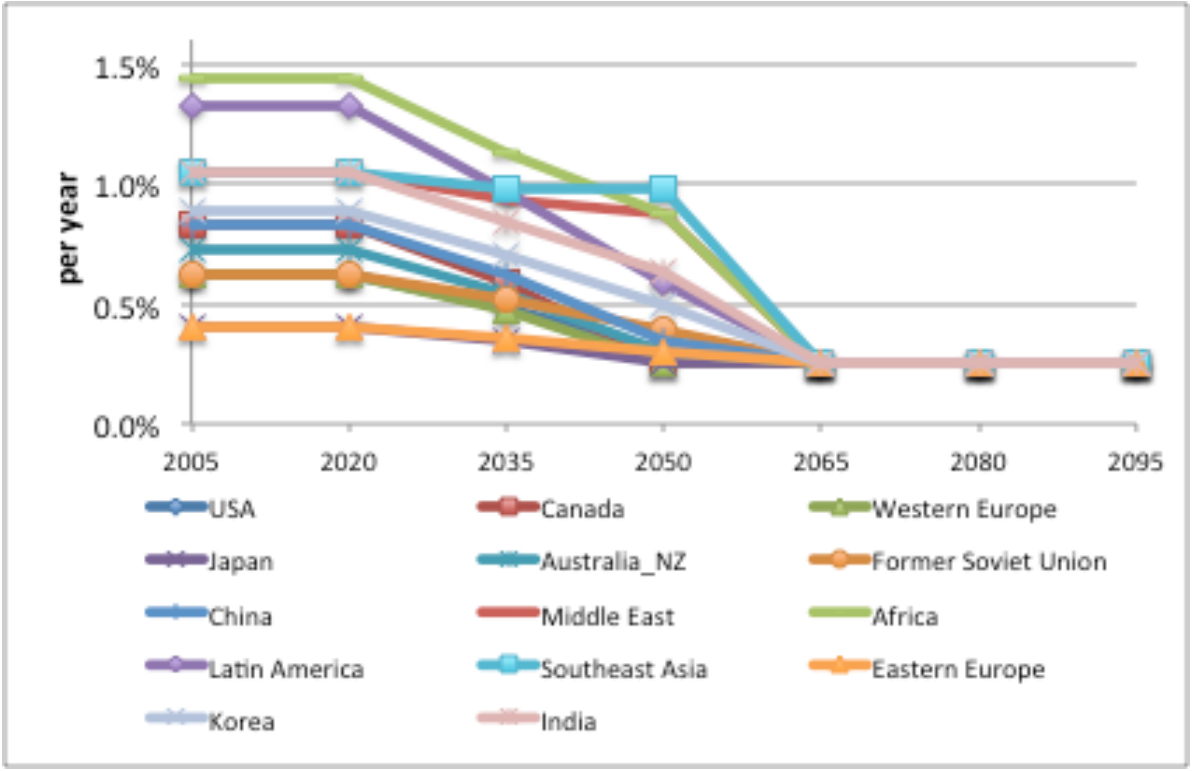


Standard agricultural productivity assumptions in GCAM

GCAM reference scenario agricultural productivity gain assumptions



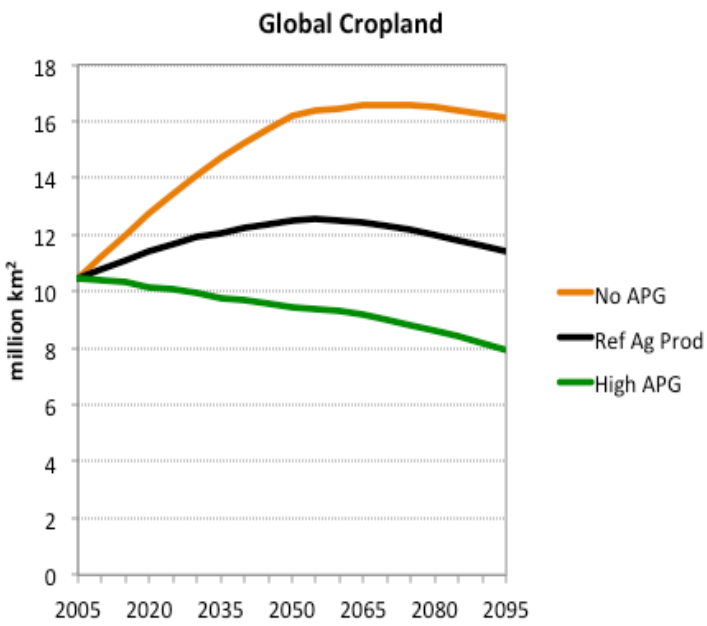
- Based on FAO projections to 2050
- Converge after 2050 to a conservative 0.25% per year

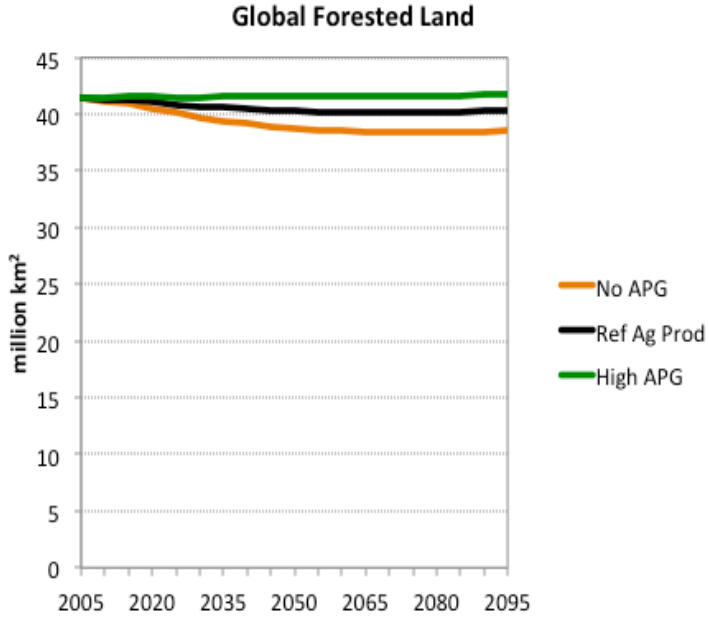
Alternate assumptions to test model sensitivity to this assumption:

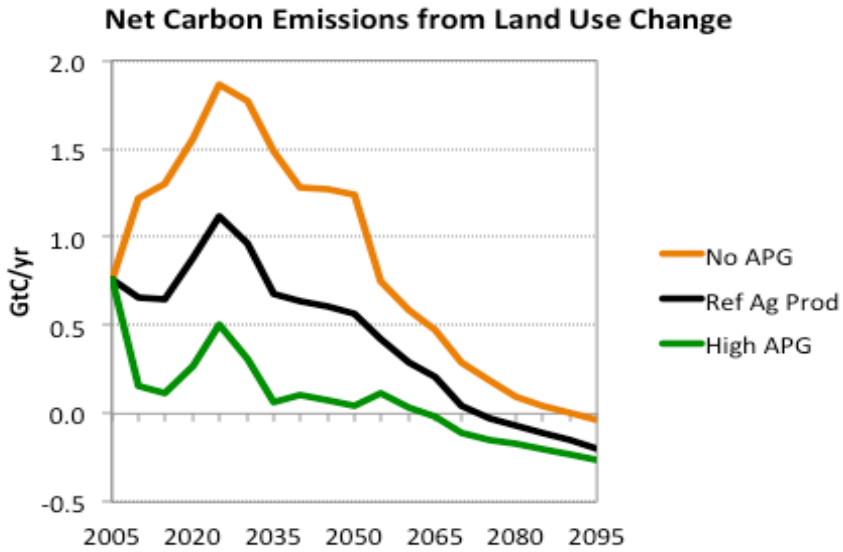
- **NoAPG** – Hold crop yields constant at 2005 levels
- **HighAPG** – Double the percentage improvement per year

Wise and Calvin, 2011

Land cover change and resulting emissions in a No Policy GCAM scenario



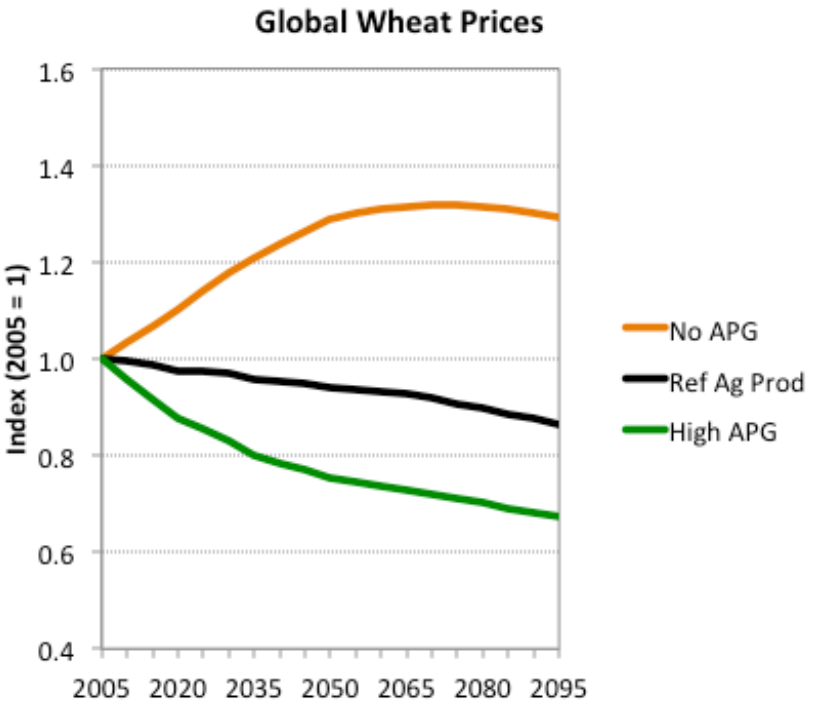


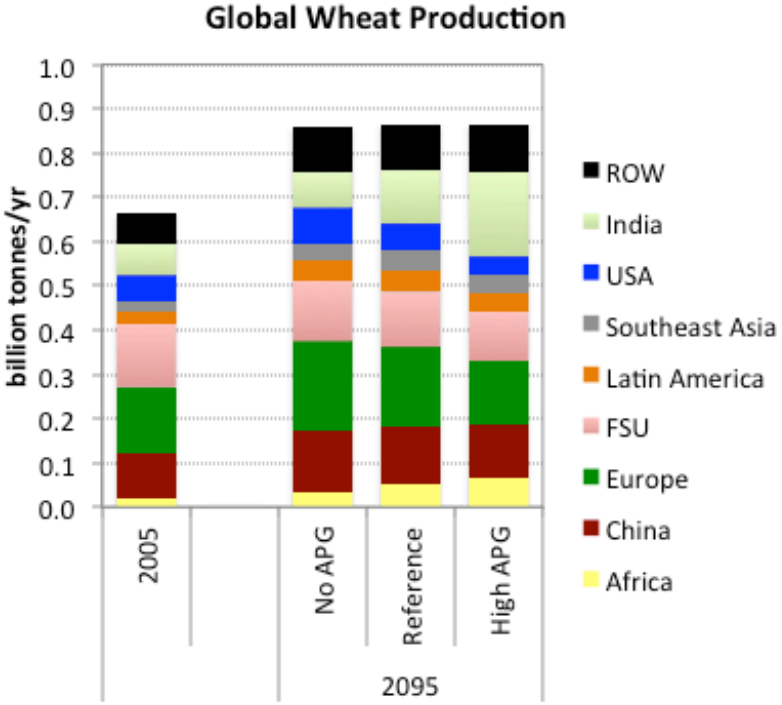


Without gains in agricultural productivity:

- More cropland is required
- More deforestation occurs
- Land use change emissions are substantially higher

Crop productivity influences the economy



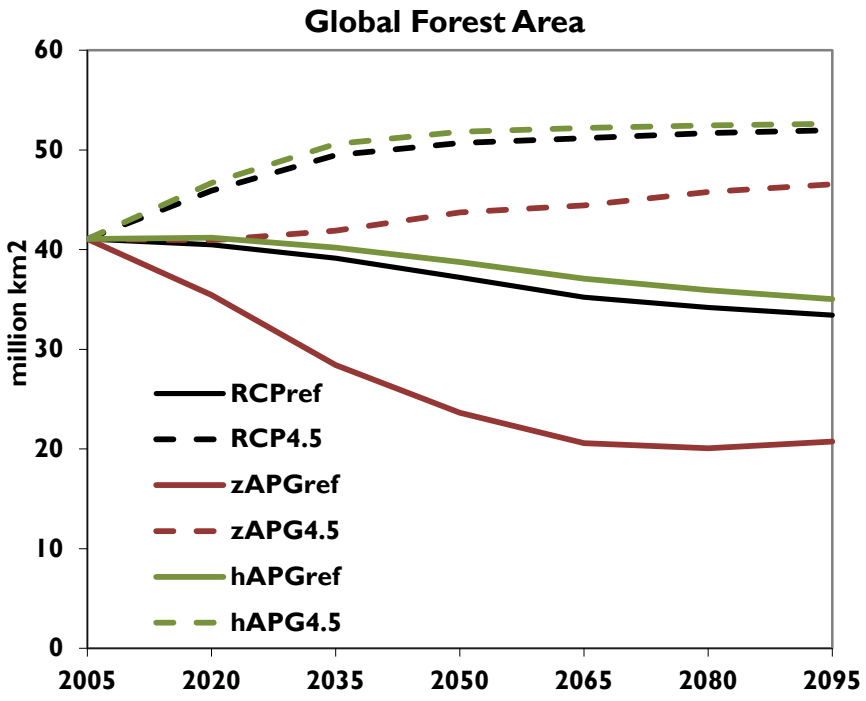


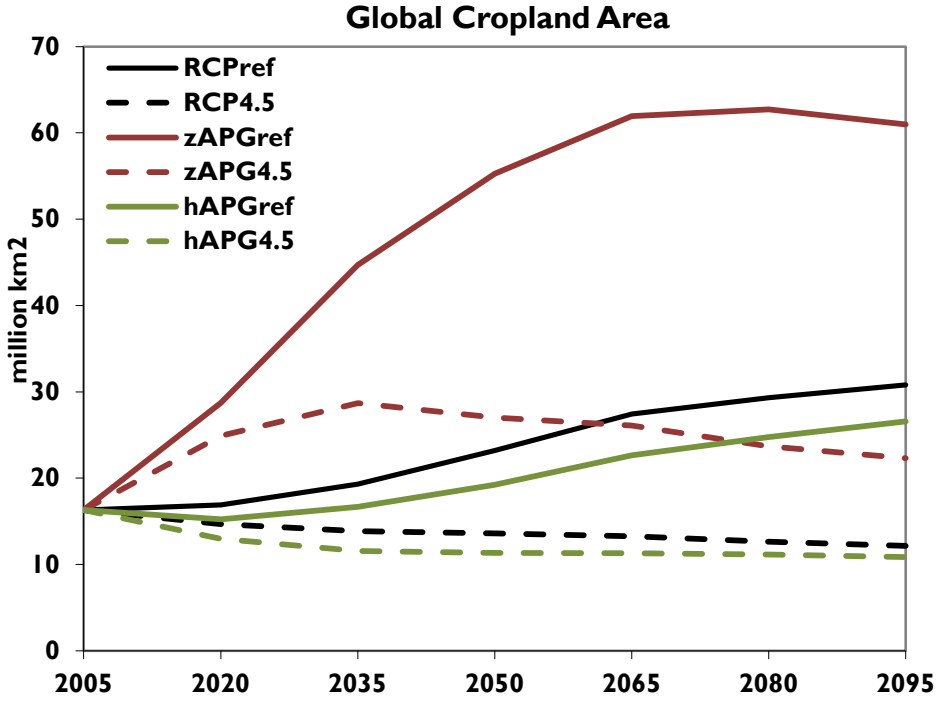
Without gains in agricultural productivity

- Crop prices are higher
- The location of production shifts globally due to changes in the productivity assumptions

Sensitivity of climate mitigation (RCP4.5) to crop yield

- The RCP4.5 is replicated with different productivity assumptions
- Mitigation policy includes a carbon tax on all terrestrial carbon, resulting in afforestation
- Competing economic pressure for afforestation interacts with the agricultural productivity assumptions

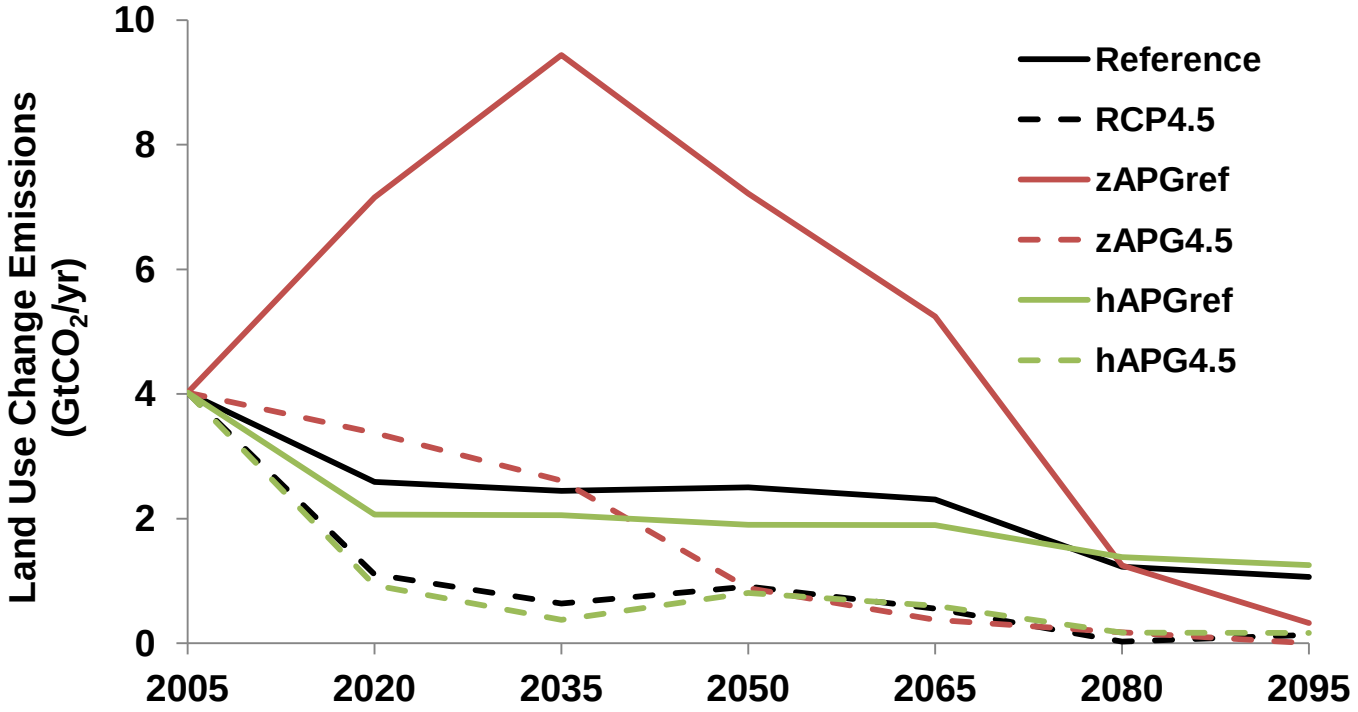




Thomson et al., 2010, PNAS

*Note: These simulations are conducted with an earlier version of GCAM than the previous slides

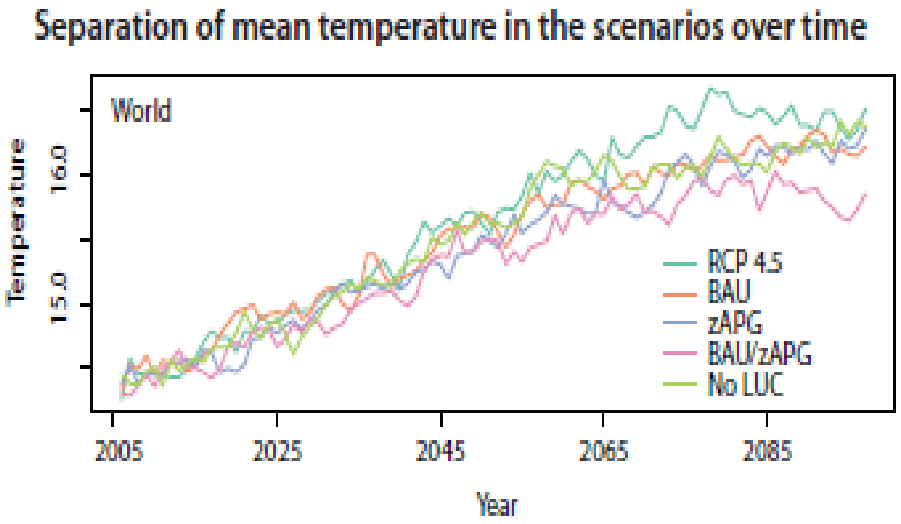
Mitigation of LUC emissions



- Mitigation policy encourages afforestation, which limits LUC emissions
- This is more difficult to achieve without agricultural productivity growth
- With no agricultural productivity growth and no mitigation policy, greater cropland expansion leads to high emissions

Implementing agricultural productivity scenarios in HadGEM2

The Reference and RCP4.5 cases with standard and zero agricultural productivity growth were run in the HadGEM2 model.



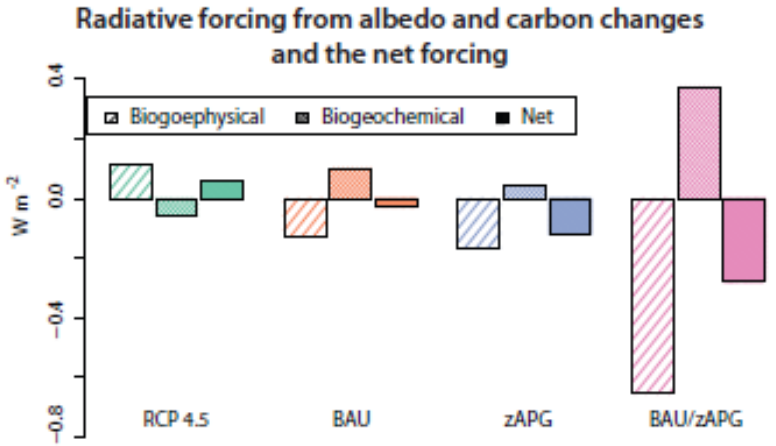


Fig. 7. Radiative forcing at the troposphere in the runs (biogeophysical), the equivalent radiative forcing from land carbon fluxes (biogeochemical) and the net biogeochemical and biogeophysical effects. Calculated for the last 10 years of the simulations, relative to the no land use change control.

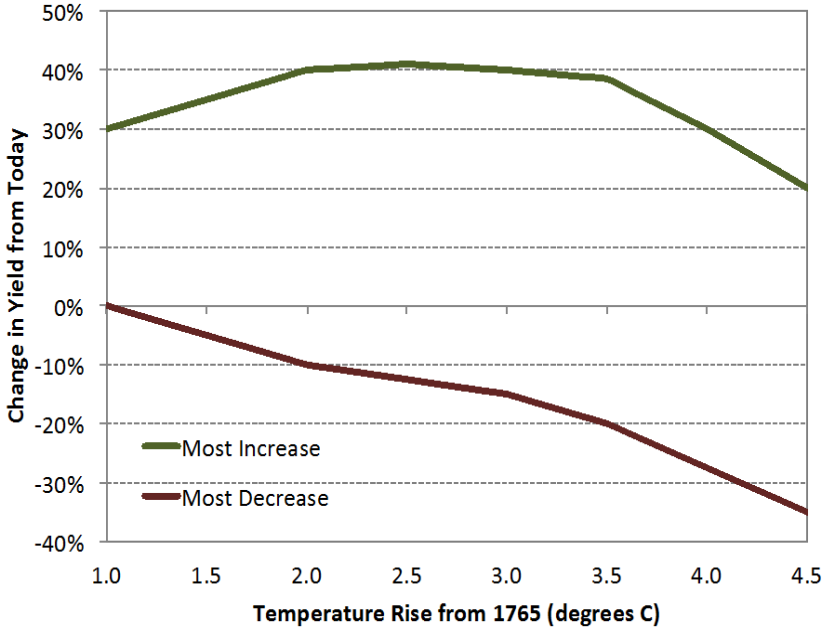
- For the RCP4.5, changing agricultural productivity assumptions to zero shifts the net terrestrial carbon flux from a sink to a source.
- The scale of LUC results in very different biogeophysical forcing from albedo.
- Net effect of cropland expansion is a global cooling

Source: T Davies –Bernard et al., Climatic impacts of land carbon pricing and agricultural productivity growth. AGU Fall Meeting 2012.

Case Study #1: Climate change impacts on future agricultural productivity

- How important are the anticipated impacts on crop yield from a changing climate?
- Does incorporating those impacts significantly influence the path to a mitigation target?

- Crop yield change is indexed to global mean temperature rise and connected to CO_2 concentration in GCAM scenario



Calvin et al., 2012 Climatic Change

Range of climate impacts on crop yield from IPCC 4th Assessment Report

GCAM scenarios considered

Case	Without Climate Impacts	With Climate Impacts
Reference	Reference, w/o Impacts	Reference, w Impacts
550 ppm CO2	550 ppm, w/o Impacts	550 ppm, w Impacts

Impacts influence LUC and emissions

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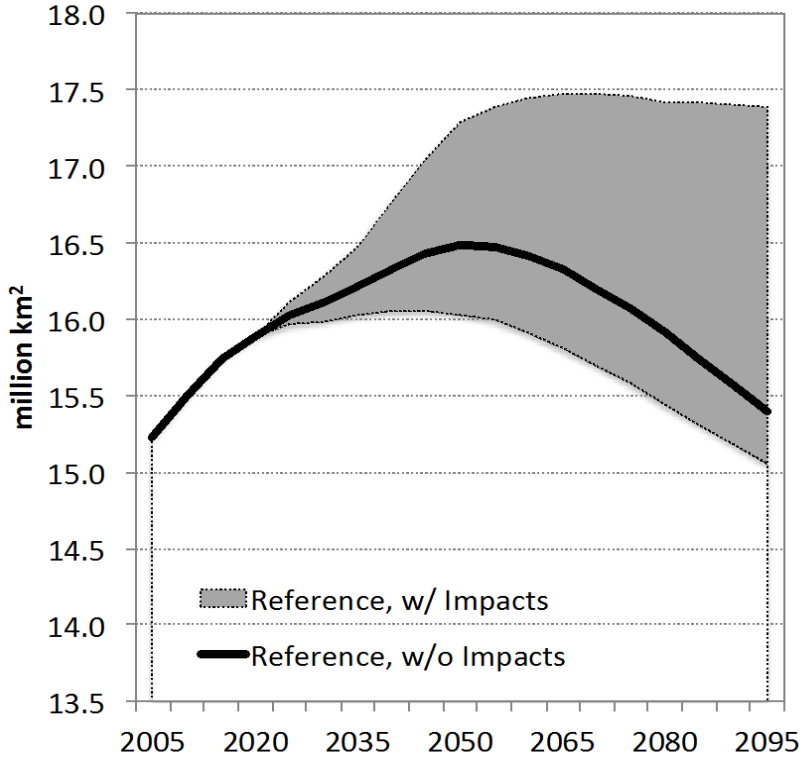
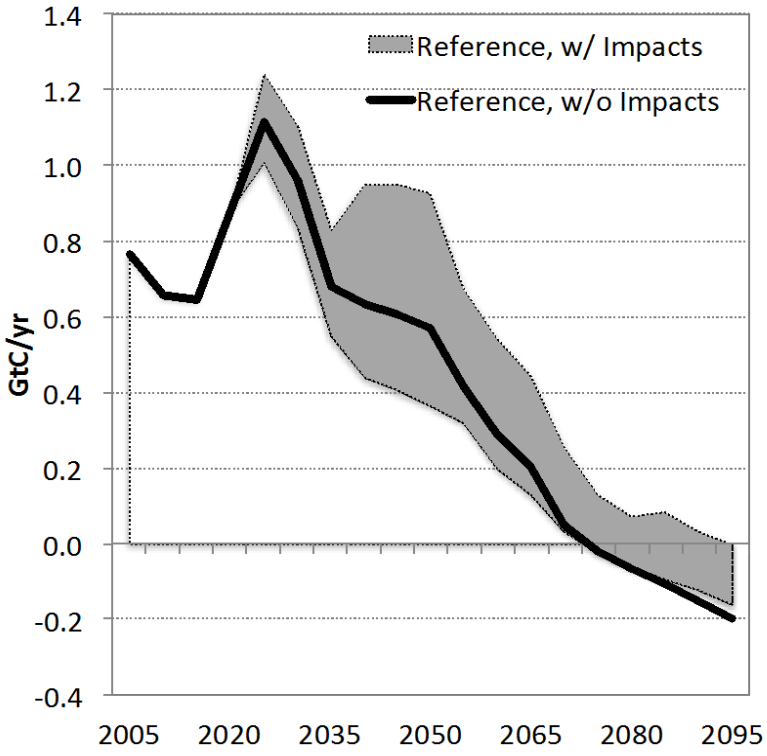
Global Cropland



LUC Emissions



- Under no climate policy, the impacts lead to a wide uncertainty in future cropland
- In turn, a range of future LUC emissions levels results from these scenarios

Changing LUC emissions in turn affects global carbon price

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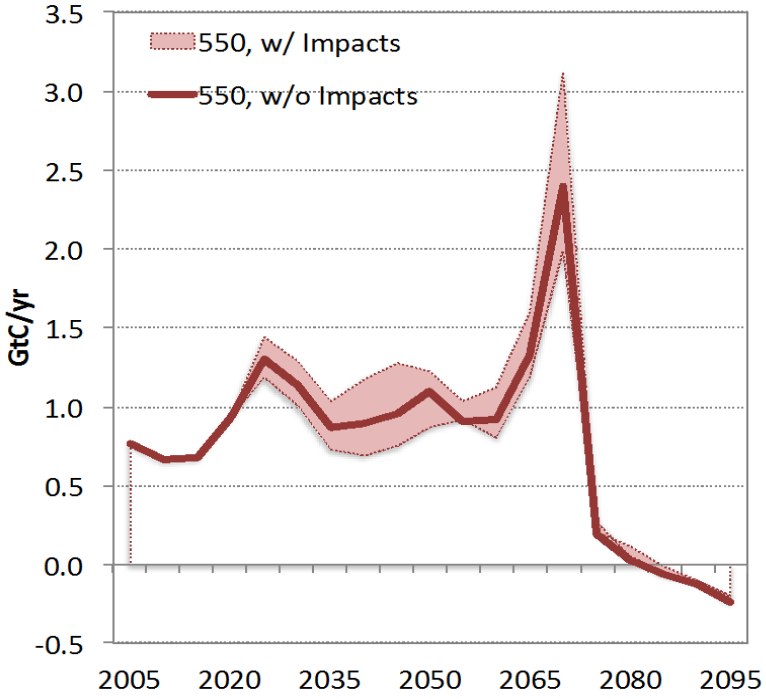
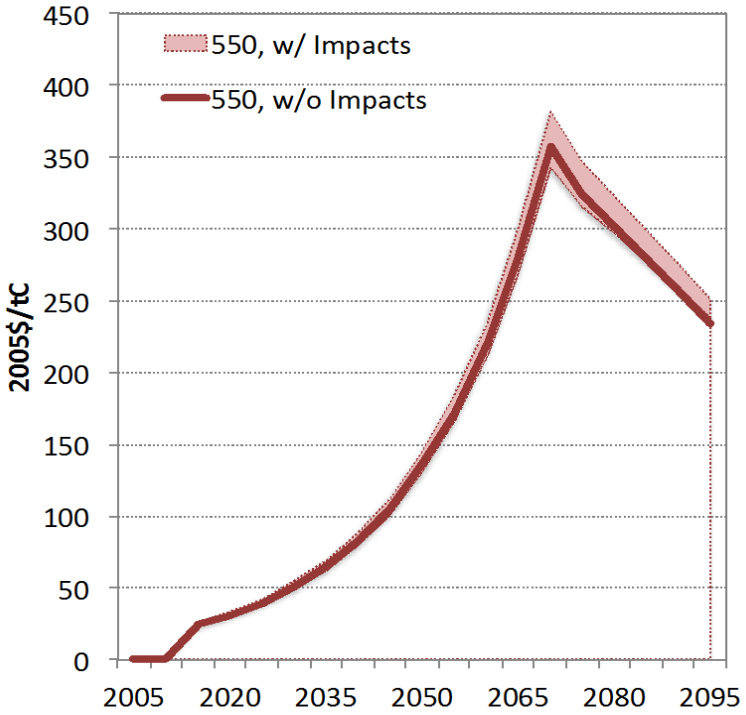
LUC Emissions



Global Carbon Price



- Under a mitigation scenario, the LUC emissions are constrained in a narrower range
- The global carbon price is also sensitive to the climate impacts

Case Study #2: Applying climate impacts results from a crop model in GCAM RCP replications

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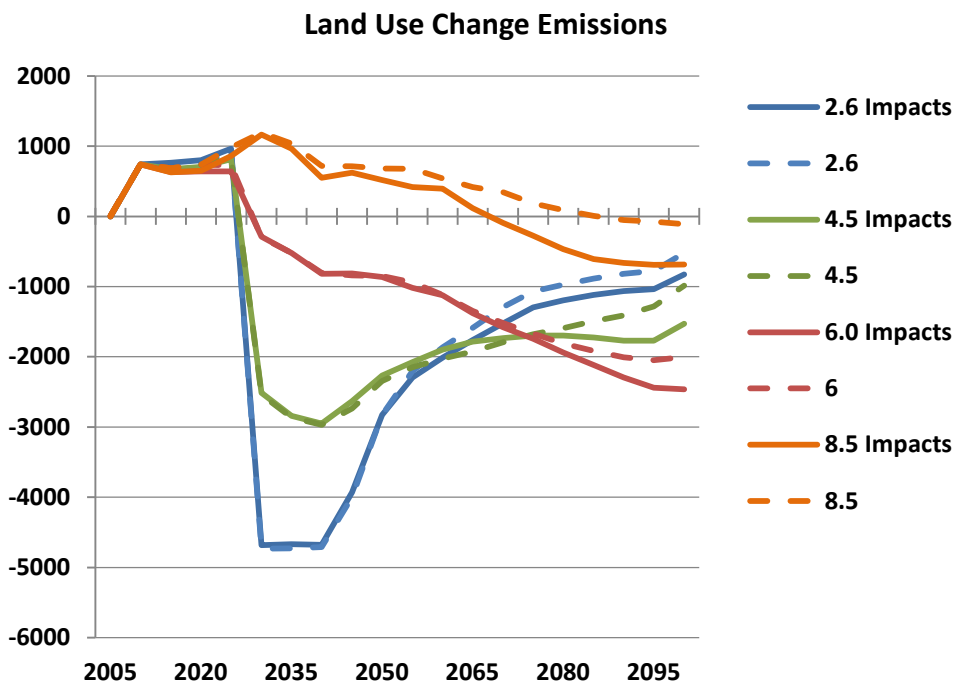
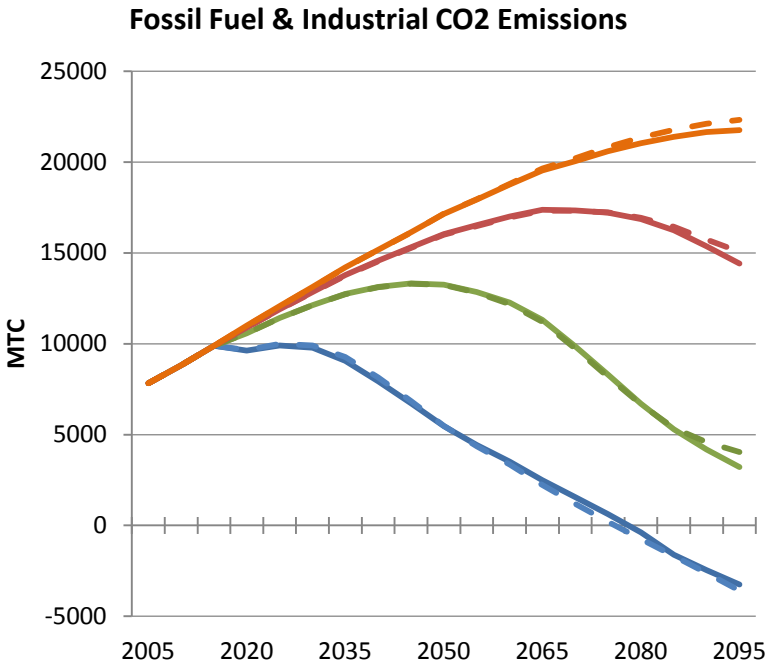
- Replications of the RCP pathways in GCAM 3.0 with and without climate impacts on crop yields
- Climate impacts simulated in the LPJmL model using HadGEM2-ES results from CMIP5
- LPJmL run on 0.5 degree grid for 1980-2100 for 11 crops (ISI-MIP project)
  - Assumes no CO2 fertilization effect
  - Assumes crop technology improvement only in the economic model
- Climate impacts are consistent with the mitigation scenario





Kyle et al., in prep

Conclusions and Next Steps

- Sensitivity studies of agricultural productivity growth provide the range of possible GCAM responses
- Given uncertainty in future crop yield change, this is a valuable range to consider when bounding land use change scenarios
- Two climate impacts studies provide further insights
- Case Study #1 provides a range based on very aggregated data from a range of sources
- Case Study #2 illustrates the capability to use individual crop model projections
  - Fully diagnosing these impacts will require detailed look at spatial patterns of change in climate and crop yields

- Caveats: AgMIP results indicate that the different crop models are even more variable in their projected impacts than climate models