Consequences of Climate Change Impacts for Land-Use and Bioenergy

Allison Thomson, Marshall Wise, Kate Calvin, Leon Clarke, Ron Sands, Ben Bond-Lamberty, Steve Smith, Tony Janetos, Jae Edmonds

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GTSP Technical Review
Washington, DC
Review: The value of terrestrial carbon stocks is significant.

- All human activities must be limited to about 500 PgC (2005 to 2095) to limit atmospheric CO$_2$ to 450 ppm.

- When the value of terrestrial carbon is considered in Integrated Assessment modeling, it places new pressures on land-use change.
  - Indirect land-use change emissions influence the path to and cost of stabilization.

- Agricultural technologies are a major uncertainty in the fate of the 2000 PgC stored in terrestrial ecosystems.
  - Agricultural productivity (food per unit of land)
  - Livestock land efficiency
Review: Including terrestrial carbon in a climate policy results in lower CO$_2$ emissions from land-use change.

In the **FFICT** case, land use emissions are driven by an unrestricted demand for bioenergy on high yielding cropland, forcing an expansion of cropland for food production.

Under the **UCT**, LUC emissions are reduced through afforestation and avoided deforestation.
Review: Valuing terrestrial carbon in a climate policy reduces the necessary carbon tax.

When only fossil fuel and industrial carbon is included in a climate policy

When terrestrial carbon is also included at an equivalent value
Conclusion: Agricultural crop productivity is an important emissions mitigation option.

- Improving agricultural crop productivity reduces deforestation pressure.
- Cumulative land-use change emissions 2005 to 2095:
  - Difference between a zero rate of crop productivity growth and assumed reference scenario productivity growth is 72 PgC.

Agricultural productivity is likely to change as the climate changes.
The missing link in integrated assessment is dynamic feedbacks to climate change.
Will the impacts of climate change on agricultural productivity alter the pressure on land-use change in MiniCAM?

- Link results from ecosystem models (EPIC/BIOME/CENTURY) and ESMs to MiniCAM.
- Use sensitivity studies to begin to develop a concept of the scale of impacts in the context of integrated assessment.
- Develop a reduced-form representation of ecosystem processes and response to climate change in MiniCAM.
Methods for Understanding Climate Change Impacts on Agricultural Productivity
Climate Impacts in Process-level Agricultural Modeling

<table>
<thead>
<tr>
<th>GMT</th>
<th>GMT (°C)</th>
<th>US ΔT (°C)</th>
<th>US ΔP (mm)</th>
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<tbody>
<tr>
<td>BMRC</td>
<td>1.0</td>
<td>1.5</td>
<td>-39</td>
</tr>
<tr>
<td></td>
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<td>UIUC+Sulf.</td>
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<td></td>
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<td>1.6</td>
<td>287</td>
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</tbody>
</table>

**ΔTemp.**

**ΔPrec.**
Changes in Dryland Winter Wheat Yield (Mg ha$^{-1}$)

**BMRC**
- GMT = 1
- CO2 = 365

**UIUC**
- GMT = 2.5
- CO2 = 560

The diagrams show the changes in dryland winter wheat yield across the United States for different GMT and CO2 values. The color scale indicates the magnitude of the changes, with darker colors representing larger changes in yield.
Synthesis of process-level impact studies

(a) Maize, mid- to high-latitude

(b) Maize, low latitude

(c) Wheat, mid- to high-latitude

(d) Wheat, low latitude
Crop yield response to MiniCAM CO₂ pathways

Wheat Productivity in Low Latitude Regions

-1.0 -0.5 0.0 0.5 1.0 1.5 2.0 2.5
Annual percentage change in crop yield
2020 2040 2060 2080 2100
No Policy 450 Stabilization 500 Stabilization 550 Stabilization

Wheat Productivity in High Latitude Regions

-1.0 -0.5 0.0 0.5 1.0 1.5 2.0 2.5
Annual percentage change in crop yield
2020 2040 2060 2080 2100
No Policy 450 Stabilization 500 Stabilization 550 Stabilization

Corn Productivity in Low Latitude Regions

-1.0 -0.5 0.0 0.5 1.0 1.5 2.0 2.5
Annual percentage change in crop yield
2020 2040 2060 2080 2100
No Policy 450 Stabilization 500 Stabilization 550 Stabilization

Corn Productivity in High Latitude Regions

-1.0 -0.5 0.0 0.5 1.0 1.5 2.0 2.5
Annual percentage change in crop yield
2020 2040 2060 2080 2100
No Policy 450 Stabilization 500 Stabilization 550 Stabilization
The model recognizes food as essential, therefore demand for food is inelastic.

Land use change is driven by land profitability and future productivity.
Climate Change Impacts and Land Use Change
Global land area with a policy target of 450 ppm and no technological productivity improvement

Valuing carbon in land provides incentives for increasing forest land and bioenergy production...

...but that is only possible if the land is not needed for agriculture.
Difference in Land-Use Change from the scenarios without impacts

![Graph showing land-use change](image)

No Policy Case

- Shrubland
- Grassland
- Pasture
- Forest
- Bioenergy
- Cropland

500 ppm Stabilization

- Shrubland
- Grassland
- Pasture
- Forest
- Bioenergy
- Cropland
Climate change impacts on cropland area

- Cropland necessary to produce food increases when changes in temperature and precipitation reduce crop yields.

Mitigation scenarios moderate the land use consequences of climate change.
Climate Change Impacts and Indirect Land Use Change Emissions (ILUC)
400 years of land-use change emissions

2005 fossil fuel and industrial emissions: ~8 PgC per year
Climate mitigation policies can reduce future land-use change emissions

By 2095, ILUC emissions go below 0 with climate policy cases
Economic Consequences of Climate Change Impacts
Global cost of food production

Climate impacts exert some upward pressure on crop price

That upward pressure is magnified if technology or carbon pricing achievements are not realized.
The total cost of land-use change emissions over the century
Summary

- Mitigation of greenhouse gas emissions results in avoidance of some climate change impacts on agricultural productivity.

- The cost of production of agricultural crops is increased when:
  - Climate impacts on crop productivity are negative impacts.
  - Terrestrial carbon is not valued in a climate policy.

- By not including climate change impacts we may be underestimating the total cost of mitigation.
  - Full integration of feedbacks and terrestrial processes could provide new cross-disciplinary insights.
Full integration of climate change impacts is underway

- Dynamic feedbacks of CO$_2$, temperature and precipitation are being developed
- New development of Agriculture-Land Use module is underway that will:
  - Make more dynamic use of physical data and process-based models on land-cover and land-use, including potential vegetation, soil types and climate regime
  - Allow for endogenous representation of the impacts of changes in CO$_2$, temperature and precipitation
Questions?