Bioenergy and Land Use Change Emissions: GCAM Approach and a Comparison to the Literature

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GCAM has always included terrestrial carbon emissions from land use change for biomass energy, as well as from all land use activities.

Terrestrial carbon is tracked for each use of land in each of the model’s regions (currently 151), and changes to those uses result in land use change emissions or uptake.

In all scenarios, net terrestrial carbon emissions or uptake is part of the computation of atmospheric CO$_2$ concentrations.

In scenarios where we value terrestrial carbon (e.g., our UCT as in Wise et al 2009 in Science), terrestrial carbon impacts are factored into the economic land use decisions.
Computing LUC Carbon Emissions Factors
Bioenergy: Objectives

- To isolate and quantify the land use carbon emissions impact from specific biomass sources/crops, using GCAM.

- Provide better understanding, diagnostics, and explanation for GCAM’s land use change and emissions.

- Compare our results with the literature.

- Contribute to a better understanding of the numbers, drivers, and factors related to biomass energy and land use emissions.
Model global land use emissions impact from incremental switchgrass production in different US regions.

- Here we show results for AEZ 7 and AEZ 10

Simple numerical derivative approach is applied to GCAM to measure impact from a marginal additional quantity of bioenergy.

- Isolates impact of a specific amount of bioenergy grown in specific region
- Avoids confounding emissions with bioenergy expansion in following years and their corresponding emissions pulses.
- Avoids averaging of emissions impacts over different types of resources, where resources with zero emissions like residues would be penalized.

As we will see – specific numerical results are scenario dependent.
The GCAM 3.0 Agriculture and Land Use Regions

AEZ 10

AEZ 7

Global Agro-Ecological Zones
- AEZ1
- AEZ2
- AEZ3
- AEZ4
- AEZ5
- AEZ6
- AEZ7
- AEZ8
- AEZ9
- AEZ10
- AEZ11
- AEZ12
- AEZ13
- AEZ14
- AEZ15
- AEZ16
- AEZ17
- AEZ18

Projection: Contiguous_Albers_Equal_Area_Conic
Source for Agro-Ecological Zones (AEZs):
GTAP (Monfreda, Ramankutty, and Hertel, 2009)
Map built by JGCRI
Regions show differences in extent of cropland, and amounts of land in forests, shrubland, and pasture in non-commercial uses.

- **AEZ 7** – less cropland, less forest, more pasture and shrubland.
- **AEZ 10** – lots of cropland and forest.
Carbon emissions from land use change per unit of bioenergy - from any changes in land use across the globe that result from the bioenergy production.

These are total emissions and include direct and indirect emissions.

- **Direct emissions**: net land use change (LUC) emissions in the place where the bioenergy is grown.

- **Indirect emissions**: LUC emissions that induced elsewhere by expansion of land to replace food crops or other production that was supplanted by the bioenergy crop

Within the region of biomass growth, the distinction between direct and indirect emissions may be ambiguous, and the distinction is not as important as the total (also expressed by Wang et al 2011).

  - What is important is to get the total right, not the categorization.
GCAM Results: LUC from an Incremental amount of Switchgrass in AEZ 7 and 10

- Land use change by category for a 0.1 ExaJoule marginal increase in switchgrass produced in region (with no land policy)
AEZ 7 and 10: Net Cumulative Emissions inside and Outside of the Region

Although higher yield assumed for AEZ 10, AEZ 10 emissions higher than AEZ 7 both within and outside the region due to

- Higher mix of forest displaced within region.
- More indirect emissions from cropland displaced.
Typical Pattern of Carbon Emissions from Land Use Change due to Biomass Expansion

- Initial pulse from net change in vegetative carbon followed by long tail of lagged changes in soil carbon.
LUC Carbon Emissions Intensity Factors (CIs): Considering time profile of LUC emissions

Higher discount rates increase bioenergy CIs as near-term emissions count more.

Conversely, higher rate of carbon price increase decrease bioenergy CIs.

When r-v = 0, time horizon of 30 is the same as the “standard” divide by 30 rule that has been used by EPA, CARB, and in several GTAP studies for biofuels.
GCAM LUC Carbon emissions in context to literature (though most studies are for biofuels)

- How do we interpret the range of results? (though some comparisons are to corn)
- And how do GCAM results under sensitivity assumptions compare?

For GCAM - Assuming 50% conversion efficiency to fuels and 30 year averaging rule for comparison

- Searchinger et al 2008 FAPRI US Corn Ethanol
- Wang et al 2011 GTAP US Corn Ethanol
- Hertel et al 2010 GTAP US Corn ethanol
- CARB 2009 Cellulosic on Grasslands
- EPA 2010 Switchgrass international 2022
- Mellilo et al 2009 (Case 1, 2000-2030)
- Mellilo et al 2009 (Case 1, 2000-2050)
- Mellilo et al 2009 (Case 2, 2000-2050)
- GCAM Switchgrass AEZ 10
- GCAM Switchgrass AEZ 10 Protect Forests
- GCAM Switchgrass AEZ 7
- GCAM Switchgrass AEZ 7 Protect Forests
- GCAM US demand generic cellulosic
Major Sources of Differences in LUC Emissions Results from Different Studies

- Bioenergy Feedstock Crop Yield Assumptions (e.g., how much land?)
- Mix of Types/Uses of land supplanted by Bioenergy
  - Differences in economic modeling approaches can be subtle, complex
  - International trade (e.g., global net trade, Armington, optimization)
  - Extent of noncommercial land available land for expansion into
  - Modeled preferences for land categories for bioenergy vs food crops
  - Sometimes choice of land type is done by assumption (e.g., marginal lands only or native grasslands to avoid indirect emissions)
- Terrestrial carbon contents of bioenergy cropland relative to other commercial and natural uses.
  - Direct emissions may be negative if bioenergy crop carbon higher
- Other dynamic market effects such as co-products like animal feed, yield intensification, and food demand response (Hertel et al 2010)
- Method for annualizing the time profile of land use change emissions.
Note on International Trade Approaches

- Models with Armington approach (like GTAP) have stickier trade patterns with modeled preferences for products from regions maintained.
  - Very useful approach for modeling nearer-term trade effects.

- GCAM instead uses a global integrated market for products like corn, regional production is not linked to regional demand but to global demand.
  - Production among regions is based on comparative advantage relationships.

- As a general rule, an Armington-trade approach to LUC emissions from biomass in the US will be lower as more crops will continue to be grown in the US, where the yields are higher than the rest of the world.
  - Higher prices from increased US production also drive yield intensification and other market responses.
GCAM LUC Carbon emissions factors compared to literature

- GCAM AEZ 7 and 10 results generally higher than GTAP studies.
- But when we remove non-commercial forests from the economic land allocation ("Protect Forests"), GCAM results are closer to the GTAP, CARB, and EPA studies.
  - but still higher than very-recently published GTAP study of switchgrass.

GTAP-based studies – Armington, co-products, yield intensification, market responses, commercial lands

MIT study (Melillo) – global bioenergy production, average emissions over time (i.e., total cumulative LUC emissions over total cumulative Bioenergy).
Case 2 protects non-commercial lands
Concluding Remarks

- We have a paper submitted written jointly with Bryan Mignone and Elke Hodson from DOE-PI showing explaining GCAM results LUC carbon from switchgrass and other crops in US regions.

- We are exploring LUC impacts of biofuels with EPA OTAQ.

- We are participating in the study of these issues in the upcoming EMF-30.

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