Uncertainty in land resource projection associated with static geographic land units in GCAM

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Global distributions of Paddy Rice Production
Boundaries affect biomass energy production

Global (new minus original boundaries)

- FSU +31%
- Middle East +14%
- Global -11%
- India -41%
- Eastern Europe -71%

Region:
- Latin America
- Africa
- Australia_NZ
- Canada
- China
- Eastern Europe
- Former Soviet Union
- Global
- India
- Japan
- Korea
- Middle East
- Southeast Asia
- USA
- Western Europe
IAMs have different regions/land units

- Unquantified spatial uncertainty confounds inter-model comparison and ensemble analysis

<table>
<thead>
<tr>
<th>Model</th>
<th>Regions</th>
<th>Land units for projection</th>
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<tbody>
<tr>
<td>IMAGE (RCP 2.6)</td>
<td>26</td>
<td>half-degree grid</td>
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<tr>
<td>MiniCAM (RCP 4.5)</td>
<td>14</td>
<td>GCAM: 151 land units</td>
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<tr>
<td>AIM (RCP 6.0)</td>
<td>24</td>
<td>half-degree grid</td>
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<td>MESSAGE (RCP 8.5)</td>
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<td>half-degree grid</td>
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</tbody>
</table>
Land use/cover inconsistencies across IAMs and ESMs can alter the global carbon cycle.

**Change in global area (from 2015)**

- **Forest**
  - $7.7 \text{ M km}^2$
  - $5.1 \text{ M km}^2$
- **Pasture**
  - $4.4 \text{ M km}^2$
  - $4.1 \text{ M km}^2$

Di Vittorio et al., 2014
Different land use/cover representations in ESMs obscure land use/cover change effects on regional climate

- Uncertainty chain:
  - IAM land use/cover spatial uncertainty
  - Land use/cover translation
  - ESM land use/cover

Temperature effect of RCP 8.5 land use change for 2071-2100 (Brovkin et al. 2013)
In the context of coupled whole earth system modeling

• How do we make robust projections of land resources in the context of projected climate change?

• How do spatial boundaries influence land resource projections?
Agro-Ecological Zones (AEZs) are bio-climatically defined.
Current land units become heterogeneous.
Workflow to create new AgLU crop and land rent inputs

Data

Identify land cells

Optional: recalibrate to different FAO data year

Calculate crop production and harvested area per 18 AEZs X 226 GTAP countries

Aggregate original land rents by use sector to 87 GTAP countries

Disaggregate crop land rents to 18 AEZs based on production and price

Disaggregate forest land rents to 18 AEZs based on original land rents and forest area
Data required to create new AgLU crop and land rent inputs

Spatially explicit data
- VMAP0 countries (246)
- AEZ countries (160)
- SAGE data:
  - crop yield, area
  - cropland
  - pasture
  - land area
  - potential vegetation
- HYDE3.1 data:
  - urban
  - land area
- AEZ boundaries

Tabular data
- GTAP countries (226, 87)
- FAO countries (241)
- GTAP (SAGE) crops
- GTAP use sector
- GTAP land rent
- FAO crops
- FAO crop production
- FAO producer prices
- FAO crop yield, area
  - for recalibration
Validation: Mean of crop regressions against GTAP data

Country level comparison

FAO $r^2 = 0.90$

Orig $r^2 = 0.95$

FAO $r^2 = 0.90$

Orig $r^2 = 0.95$

86 crops with $n \geq 20$ countries
Geographic shift of initial conditions: Mean of crop regressions against Original AEZs

GCAM land unit comparison

GTAP $r^2 = 0.94$

New $r^2 = 0.73$

117 crops with $n \geq 20$ land units
Each crop is uniquely affected by new land units.
Global distributions of forest land rent, by GTAP land unit

Forestry land rent cumulative distribution comparison

Cumulative probability

New AEZs
Original AEZs
GTAP

Land Rent (US$)

GTAP
Original AEZs
New AEZs
Boundaries affect projected land use/cover

Global (new minus original boundaries)

- fodder crops +13%
- biomass +8.3%
- harvested forest -3.4%
- intensive pasture -9.3%
- other crops +1.8%
- grain crops -2.4%
- forest (harvested)
- forest
- non-arable
- other crops
- pasture (intensive)
- grassland
- grain crops
- biomass
- fodder crops
Boundaries affect projected land use/cover

Southeast Asia (new minus original boundaries)

fodder crops +40%
biomass +12%
harvested forest -15%
intensive pasture -13%
grain crops -5.7%
other crops +6.8%

Percent difference in area

Year

2010 2040 2070 2100
Boundaries affect crop price

Global (new minus original boundaries)

Percent difference in crop price

- FodderGrass -19%
- FodderHerb -13%
- Pasture -9.1%
- PalmFruit -5.9%
- MiscCrop +2.7%
- biomass +2.1%

Year

2010 2040 2070 2100
Boundaries affect projected crop production

Global (new minus original boundaries)

Percent difference in crop production

Year

PalmFruit +22%
FodderGrass +14%
FodderHerb +6.0%
pasture -3.3%
biomass -11%
Boundaries affect biomass energy production

Global (new minus original boundaries)

- FSU +31%
- Middle East +14%
- Global -11%
- India -41%
- Eastern Europe -71%

Percent difference in biomass energy production

Year:
- 2020
- 2040
- 2060
- 2080
- 2100

Region:
- Latin America
- Africa
- Australia_NZ
- Canada
- China
- Eastern Europe
- Former Soviet Union
- Global
- India
- Japan
- Korea
- Middle East
- Southeast Asia
- USA
- Western Europe
Validation (water basins): global distributions of Paddy Rice, by country

PaddyRice production cumulative distribution comparison

PaddyRice harvested area cumulative distribution comparison

Production (t)

Harvested area (ha)

Cumulative probability

Original AEZs
LDS AEZs
FAO
Summary

• AEZ-based land units do not consistently meet homogeneity assumption for land use projection
  • Negative implications for averaging climate impacts for feedback studies

• Boundary and initial conditions are different between the original and new land units

• Substantial regional and global differences in projected land use/cover, crop production/prices, bioenergy production/use

• Spatial uncertainty and feedbacks: climate, impact, and land resources
  • Geography matters!
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Opportunities

- Spatially align GCAM water and land modules
- Energy-Water-Land Nexus questions

- Integrated land use and land cover data analysis and projection

- Facilitate spatial data consistency across global models
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Different boundaries give different “local” estimates.

Temperature maximum, Jan. 1, 2003

Cell size is 2.5 minutes (~5 km)

1 degree (~100 km) per side

0.5 degree (~50 km) per side

0.25 degree (~25 km) per side

10.66 °C

12.00 °C

12.24 °C

12.66 °C

1 degree (~100 km) per side

Temperature maximum, Jan. 1, 2003
Cell size is 2.5 minutes (~5 km)
Current land units become heterogeneous.
Current AEZs become heterogeneous
Current AEZs become heterogeneous

Length of growing period (for no TZ change): ECHAM 2100 – original
Current AEZs become heterogeneous

Length of growing period (for +1 TZ change): ECHAM 2100 – original
Validation: global distributions of Paddy Rice, by country

- PaddyRice production cumulative distribution comparison
- PaddyRice harvested area cumulative distribution comparison

Graphs showing the cumulative distribution of paddy rice production and harvested area, comparing GTAP, Original AEZs, and FAO data.
Distribution differences for Paddy Rice, by country

PaddyRice % production difference histogram comparison

- GTAP – FAO
- Original AEZs – FAO

Production difference (%)