Opportunities and limitations of model collaboration for the assessment of biomass supplies and impacts

CRC WORKSHOP ON LIFE CYCLE ANALYSISOF TRANSPORTATION FUELS

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Largely based on the publication by:
Birka Wicke, Floor van der Hilst, Vassilis Daioglou, Martin Banse, Tim Beringer, Sarah Gerssen-Gondelach, Sanne Heijnen, Derek Karssenberg, **David Laborde**, Melvin Lippe, Hans van Meijl, André Nassar, Jeff Powell, Anne Gerdien Prins, Steve Rose, Edward Smeets, Elke Stehfest, **Wallace E. Tyner**, Judith Verstegen, Hugo Valin, Detlef van Vuuren, Sonia Yeh*, Andre Faaij (2013). Submitted to GCB Bioenergy

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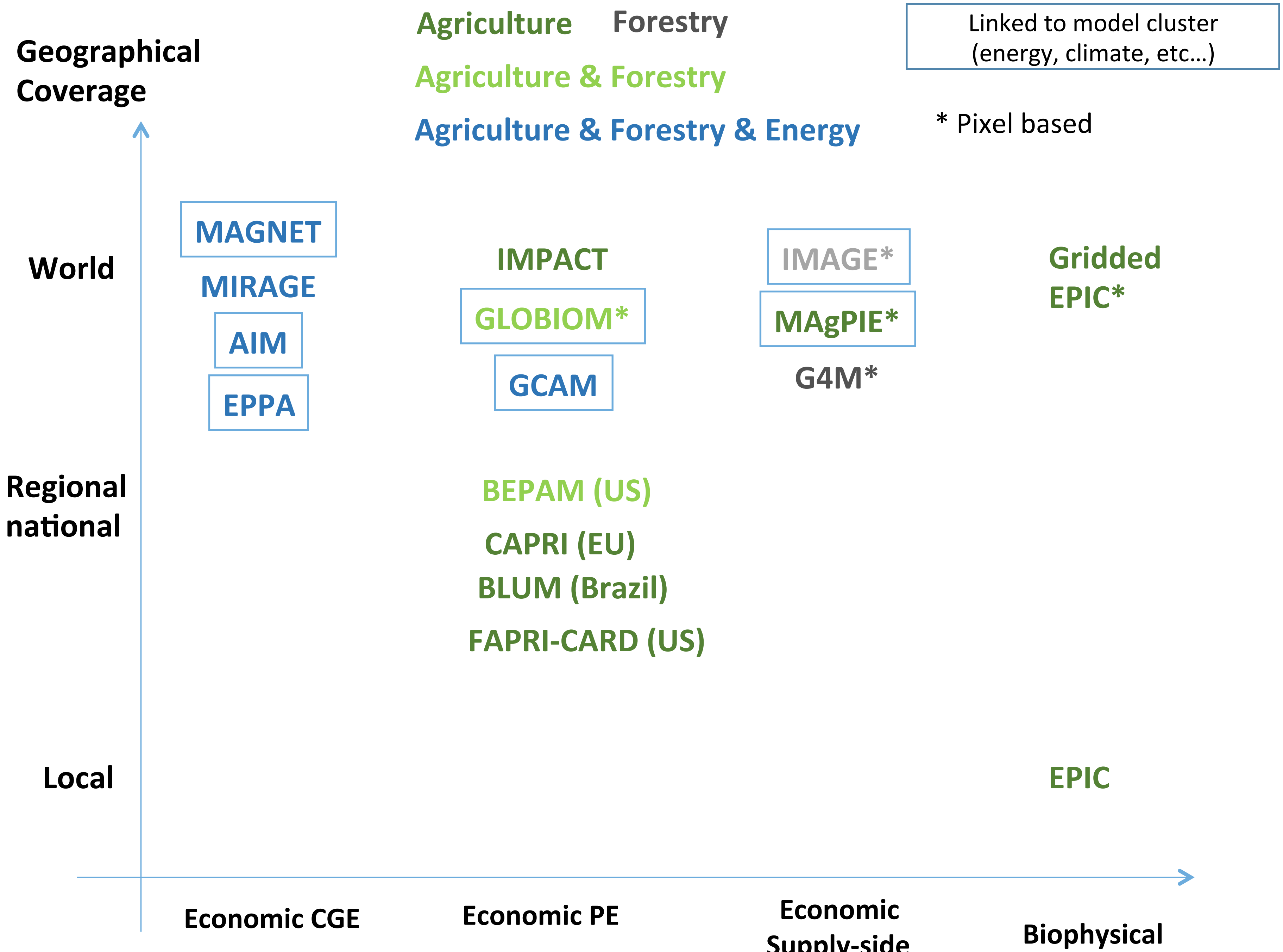
Outline

- Typology of models
- What is model collaboration?
- What can be done and how?
- Examples of model collaboration
- Recommendations

Motivation

- Sustainability of biomass production has been a subject of debate in recent years particularly the estimates of indirect land use change
- Some disagreements can be attributed to differences in:
  - System boundaries (e.g. ag system vs. ag+energy system)
  - What model captures (e.g. prices effect vs. physical processes)
  - Treatment of time (e.g. static vs. dynamic)
  - Time scale of impacts (e.g. 2020 vs. 2050)
  - Input assumptions (e.g. definition of available/accessible land)
- Model collaboration can make progress toward
  - identify key drivers for the differences in results
  - compare the robustness of the input assumptions and the results
  - Identify strength and weaknesses of different approaches, and
  - improve validation and calibration of the models



Geographical Coverage
Agriculture
Forestry
Agriculture & Forestry
Agriculture & Forestry & Energy
Linked to model cluster (energy, climate, etc...)
* Pixel based
World
Regional national
Local
MAGNET
MIRAGE
AIM
EPPA
IMPACT
GLOBIOM*
GCAM
IMAGE*
MAgPIE*
G4M*
Gridded EPIC*
BEPAM (US)
CAPRI (EU)
BLUM (Brazil)
FAPRI-CARD (US)
EPIC
Economic CGE
Economic PE
Economic Supply-side
Biophysical

Overview of Modeling Approaches for Bioenergy Studies

Category	Description	Geographic coverage	Examples
Pure Economic CGE	Everything is modeled as (relative) price. All flows are quantified in prices and that there is no direct relationship with quantities.	Global, regional. Can not be local	MIRAGE, GTAP, LEITAP/MAGNET
Partial Equilibrium (PE)	Only a selection of sectors are represented but they are still market models. Each market is represented with a supply function AND a demand function. The two function gives an equilibrium market price.	Global, regional, local	IMPACT, GLOBIOM, GCAM, BEPAM, FAPRI
Biophysical/Economic-Engineering Bottom-Up	Detailed behavioral, or process-based modeling of biophysical or socioeconomic-engineering change at technology (broadly defined) level via the modeling of absolute price (if included) and quantity. Often have well-defined system boundaries in terms of geographic or sectoral coverage but lack broad price/physical/technology response to changes outside of the system boundary.	Global, regional, local	LPJ, EPIC, IMPACT, bioenergy supply models, LCAs, econometric models, learning curves
Integrated Assessment Modeling (IAM)	Contains the characteristics of broad price-based competition with detailed technology/biophysical modeling. Or it can be a cluster of models linking price-based model(s) with biophysical/engineering model(s)	Global	IMAGE, AIM, GLOBIOM

Strengths

CGE	PE	Bottom-up	IAM
• Comprehensive coverage of economic sectors and regions to account for interlinkages • Explicit modeling of limited economic resources • Measuring the total economy wide and global effects of bioenergy policies (including indirect and rebound effects)	• Detailed coverage of sectors of interest with full market representation • Explicit representation of biophysical flows and absolute prices • Usually more regional details and environmental indicators	• Focus on specific aspects, processes, technologies or agents. • Suitable for prospective analyses of latent technologies. • Useful for policy analysis involving specific technologies and targeted impacts	• Integrating different relevant systems in one modeling framework • Possibility to analyze feedbacks between human and nature systems, and trade-offs and synergies of policy strategies • Built around long-term dynamics

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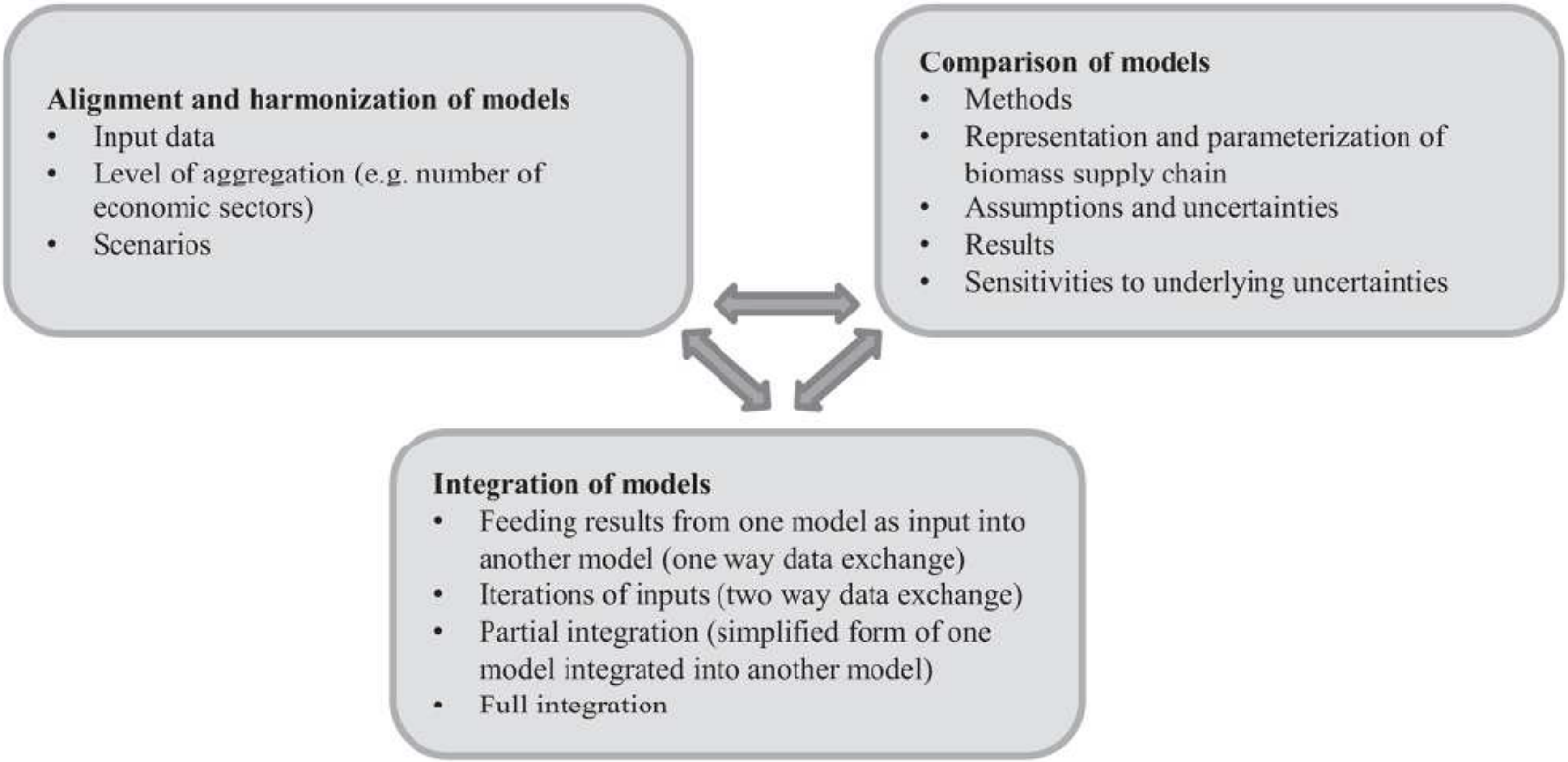
Limitations

CGE	PE	Bottom-up	IAM
• Level of aggregation that may mask the variation in the underlying constituent elements • Scope of CGE models necessitates simplified representation of agent choices, in particular favoring smooth mathematical forms and reduced number of parameters required to calibrate the models • Often no or little explicit representation of quantities for biophysical flows	• Optimization of agent welfare, but only the sectors represented in the model · No consideration of macroeconomic balances and impacts on not-represented sectors · Need large number of assumptions for long-term projections	• No inclusion of indirect and induced effects outside the boundaries of the study, i.e. often deliberately ignore interactions with other sectors	• High level of aggregation or too complex systems • Unsuitable for short-term assessments • Large number of assumptions (and the communication of these to the public)

Typology of model collaboration



Example 1: Livestock production and impacts on land availability

Problems

- Livestock productivity developments could potentially spare large areas of land, yet drivers are poorly understood
- CGE models typically model the following two drivers:

(1) substitution between grass and animal feed

- 2 or 3 level nesting structure with exogenously defined substitution elasticities.
- does not guarantee that the energy and protein balances in animal feeding are satisfied

(2) ex-/intensification of grassland use

- Lack of basic understanding of grassland productivity, the intensification potential and impacts of intensification

What do we needed to know

- Specific assessment of where and to what degree pasture productivity and/or livestock density can be increased, what the drivers are and what the environmental and socio-economic impacts
- How to incorporate insights into CGEs?

Example 1: Livestock production and impacts on land availability

- Data exchange:
  - Technical model (TM) and biophysical assessment (BA)➔land use allocation (LUA): Pasture occupations and management, intensification potential (spatially disaggregated information), impacts of changes in management
  - TM➔CGE and PE: feed requirements, composition and substitution possibilities
  - PE or CGE➔BA: level of livestock intensification (pastures and feeding system)
- Model integration (partial or full):
  - PE with detailed description of livestock sector and its land use, and CGE
- Analysis of cross-cutting issues:
  - Economy-wide impacts of bioenergy mandates (e.g. crop prices, LUC-induced GHG emissions) under different scenarios of livestock sector developments (incl. pasture intensification, substitution between pasture- and crop-based animal feed)

Example 2: Availability, use and impacts of agricultural residues for energetic purposes

Problems

- Ag and forest residues have the potentials to form a significant part of the total primary biomass availability and may play a crucial role in bioenergy supply
- Huge uncertainties in the underlying data, assumptions, and estimates of potentials
- Little understanding of the technical and economic aspects of residue supply, competition with other uses or services, and environmental impacts of residue removal

Example 2: Availability, use and impacts of agricultural residues for energetic purposes

- Model comparison:
  - Results and methods applied in PE, CGE and IAM models to determine projected supply, use and impacts of residue use and the driving forces behind results.
- Data exchange or iteration:
  - TM ➔ BA and CGE: factors determining residue availability; collection costs
  - LUA➔ CGE: biophysical suitability
  - CGE➔ LUA and IAM: potential direct and indirect effects in ag and energy sectors and LUC
- Analysis of cross-cutting issues:
  - Environmental, economic and GHG impacts of residues used as feedstocks for bioenergy under scenarios with different levels of restrictions for residue removal or sustainability criteria

Example 3: Magnitude, location and impacts of land use change induced by bioenergy

Problems

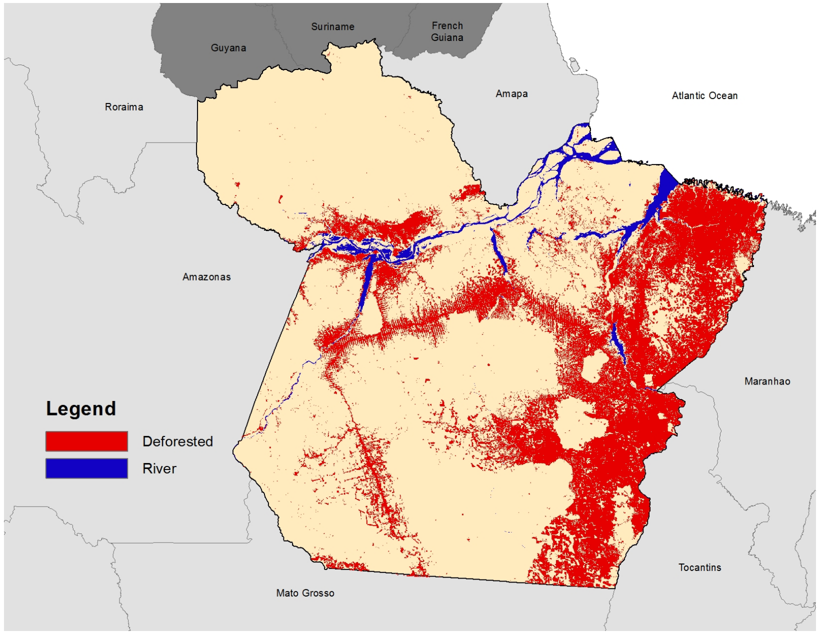
- CGE models estimate LUC based on economic factors governed by the land transformation elasticity
  - Recent refinements to differentiate elasticities for different regions and types of LUC
- Cannot account for the complex interactions driving LUC between social, economic and biophysical drivers
  - e.g., neighboring land use, conversion elasticity, access to infrastructure, distance to markets, and land suitability) operating at multiple temporal and spatial scales and varying for different crops
- Double cropping or the integration of livestock and bioenergy production are not generally accounted for in CGE models

Example 3: Magnitude, location and impacts of land use change induced by bioenergy

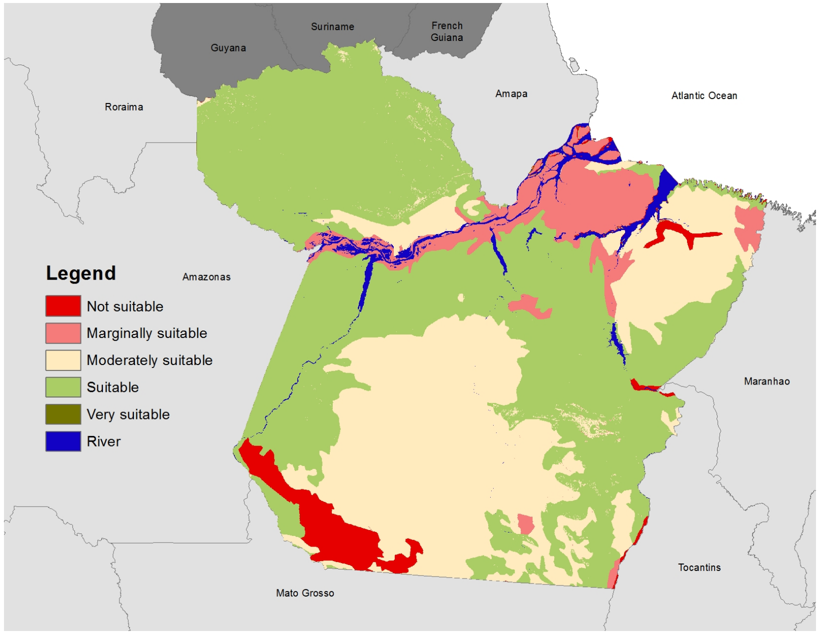
- Model comparison:
  - Results on magnitude, location and type of LUC from CGE and LUA models (where results from LUA model are aggregated to spatial scale of CGE model)
  - Mechanisms defining LUC in models
- Data exchange:
  - TM and BA➔LUA: Biophysical and socioeconomic suitability factors
  - LUA➔BA: Spatiotemporal representation of LUC dynamics
- Iteration of inputs:
  - CGE➔LUA: Production demand and prices of agricultural commodities
  - LUA➔CGE: Calibration of results
- Analysis of cross-cutting issues:
  - Effect of bioenergy mandates on magnitude, location and type of LUC with different allowable carbon stock changes and/or sustainability

Assessment of Oil Palm Potentials in Brazil

Available land by type



Suitability



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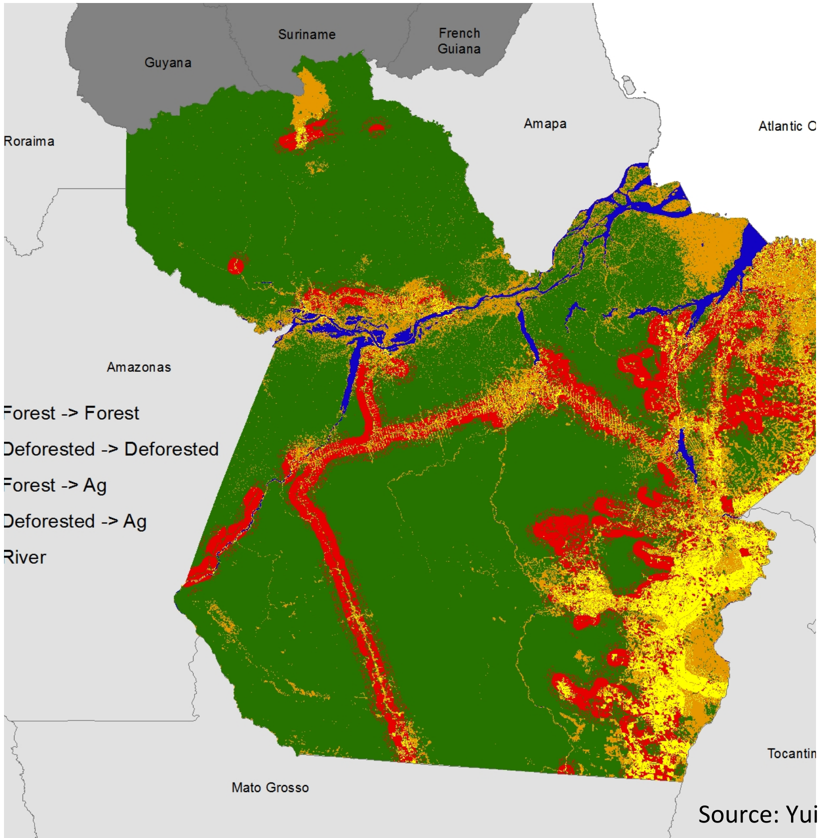
Source: Yui and Yeh (2013) ERL

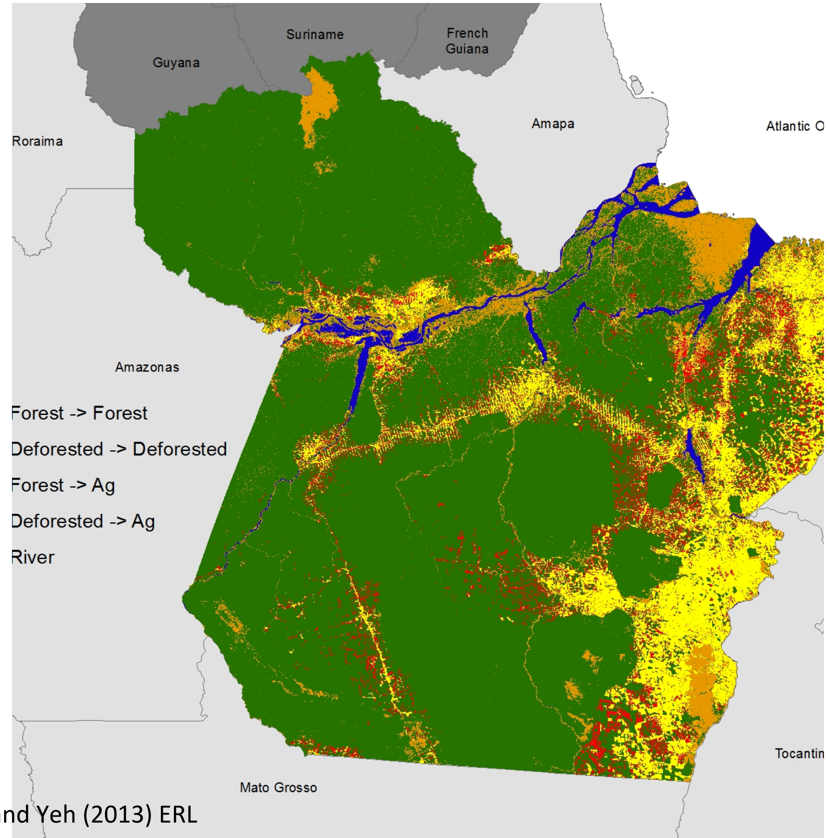
Simulation of Non-Economic Drivers of LUC

Simulate socioeconomic and biophysical drivers so that the *type and location* of LUC depend on drivers such as neighboring land use, conversion probability (access to infrastructure, distance to markets, and land suitability) and other "discouragers" or "no-go areas".

Non-enforcement



Limits LUC to deforested land



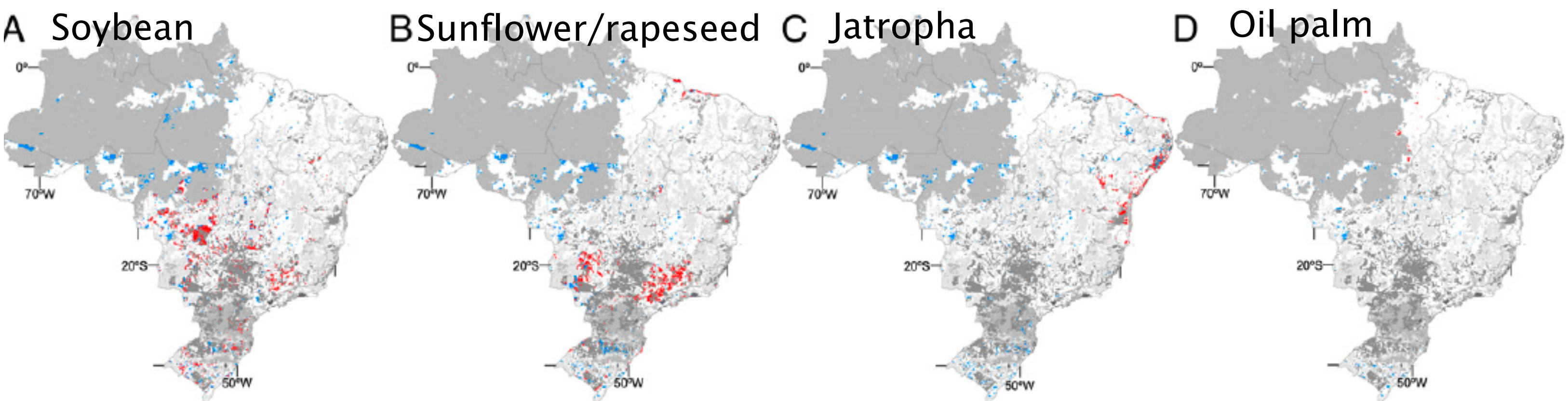
Source: Yui and Yeh (2013) ERL

Projections of Direct Land use Change and C Emissions/Intensity Given Scenarios of Policy Enforcement

	Scenarios					
	1: No enforcement		2: Some enforcement		3: Strict enforcement	
	Percent	Land Area (sq mi)	Percent	Land Area (sq mi)	Percent	Land Area (sq mi)
Land converted	18%	86,700	18%	86,700	18%	86,700
Of the land converted						
Previously deforested land	29%	25,000	46%	40,000	78%	68,000
Forest	62%	54,000	48%	42,000	22%	19,000
Conservation units[a]	0.5%	400	0.3%	300	0%	0
Wetlands	2.1%	1,800	1.7%	1,400	0.4%	400
Indigenous lands[a]	1%	900	0.9%	800	0%	0
Carbon emissions						
Average loss of carbon (t C/ha)	**77**		**55**		**13**	
Average carbon intensity from direct LUC (g CO2/MJ)	**84**		**60**		**14**	

Source: Yui and Yeh (2013) ERL

Estimation of DLUC (red) and ILUC (blue) in Brazil Given Biofuel Targets



- LandSHIFT: LUA model that spatially describes settlement, crop, and grazing LU activities (5 arc minutes resolution)
- Data input:
  - International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT): future country-level food demands, yields
  - LPJ for managed Lands (LPJmL) dynamic global vegetation model: crop and grassland potential productivity on a 0.5° resolution grid.

Source: Lapola et al. (2010) PNAS

Recommendations for Improved Assessment of Biomass Supply and Impacts

I. A better understanding of underlying processes in order to ensure proper representation of these processes in the models,

II. Increased calibration and validation of models in order to increase accuracy and reliability, and

III. Extended uncertainty analysis (including uncertainty propagation throughout the whole modeling chain) in order to identify and quantify the key input uncertainties, interpret the model results and prioritize future research activities.