Comparison of Regions and Modeling of Land in the GTAP-DEPS and BLUM

Gbadebo Oladosu[1]
Marcelo M. R Moreira[2]
Keith Kline[1]
Maggie Davis[1]
Willian Kmura[2]

Objective:
This report compares the AEZ-based allocation of land in the Global Trade Analysis Project (GTAP)-Dynamic Energy Policy Simulations (DEPS) model to the regional allocation in the Brazilian Land Use Model (BLUM) model. The purpose of this comparison is to evaluate the prospects for interactions among the two models, and to determine how to translate inputs/outputs from one model to the other in simulating the effects of biofuel production on land use change in Brazil.

Background:
The GTAP-DEPS model is a multi-regional, global computable general equilibrium (CGE) economic model that incorporates cellulosic biofuels, dynamics and other enhancements to enable a robust simulation of the evolution and impacts of biofuel policy. The prices of fossil fuels are determined endogenously allowing the model to capture the crucial effects of biofuel policies on energy markets, and its implications for the global economy. It includes 18 world regions and 33 economic sectors, with one of these sectors representing the production of investment goods (Oladosu, 2012). Land use within each region is based on agro-ecological zones (AEZ), which is an 18-category classification of the global land base using a combination of climate types (3) and length of growing period (6).

BLUM (Brazilian Land Use Model) is a partial equilibrium model of agricultural production for evaluating the land use change impacts of biofuels in Brazil (Nassar *et al*, 2012). BLUM includes 10 agricultural products (soybeans, corn, cotton, rice, dry beans, sugarcane, wheat, barley, dairy and livestock) but considers commercial forests to be exogenous[3].

1. Comparison of Regional Classifications for Land Allocation

The regional classification of land use in the BLUM model is shown in Figure 1 (ICONE, 2012). The six regions are based on a combination of agricultural production homogeneity and biomes of Brazil:

- South (states of Paraná, Santa Catarina, and Rio Grande do Sul);
- Southeast (states of São Paulo, Rio de Janeiro, Espírito Santo, and Minas Gerais);
- Center-West Cerrado (states of Mato Grosso do Sul, Goiás and part of the state of Mato Grosso inside the biomes Cerrado and Pantanal);

[1] Oak Ridge National Laboratory
[2] Institute for International Trade Negotiations
[3] Actually ICONE is improving the BLUM model to incorporate the energy, pulp and paper markets, so omercial forest ill soon become endogenous to the model.

- Northern Amazon (part of the state of Mato Grosso inside the Amazon biome, Amazonas, Pará, Acre, Amapá, Rondônia, and Roraima);
- Northeast Coast (Alagoas, Ceará, Paraíba, Pernambuco, Rio Grande do Norte, and Sergipe);
- Northeast Cerrado (Maranhão, Piauí, Tocantins, and Bahia).

Except for Mato Grosso, each state of Brazil is assigned to a single region. Thus the regional classification in BLUM also accounted for administrative boundaries in addition to the two factors identified above.

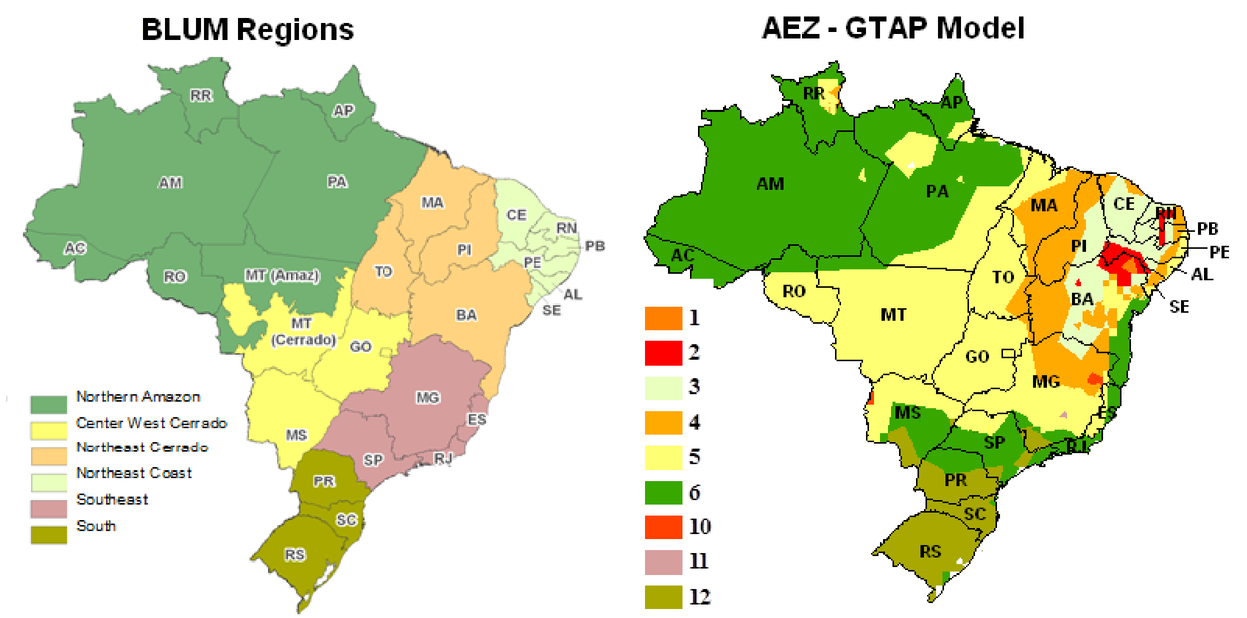
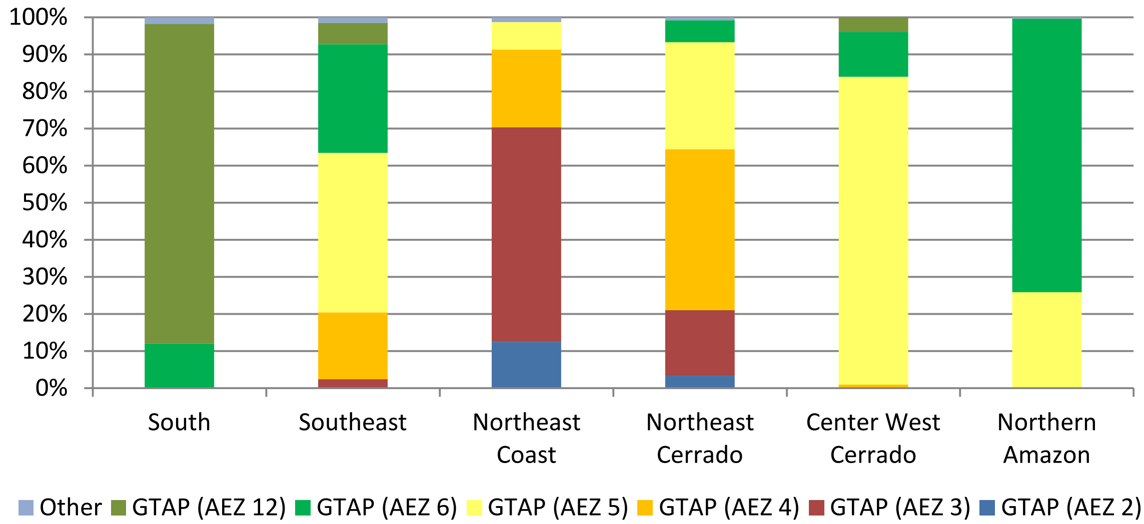


Figure 1 – Regions in the Brazilian Land Use Model (BLUM) and Agro-Ecological Zones (AEZ) used in GTAP-DEPS for Brazil (Source: From the authors)

Given that the AEZ classification is based on climate and length of growing period[4], these regions reflect the different biomes of Brazil and bear a close resemblance to those in the BLUM. For the quantification of the similarities of AEZ and BLUM regions, the two maps above were overlaid and the intersections of both maps were estimated in a GIS platform. Figure 2 shows the share of each AEZ category in the BLUM regions.

[4] The period (days) during the year when both moisture availability and temperature are conducive to crop growth.



Graph 1: The Share of GTAP-DEPS AEZ's in BLUM Regions (Source: from the authors)

Most of the six BLUM regions clearly have one or two dominant AEZ. The AEZ 12 represents almost 90% of the South region, but is not significant in any other regions. The AEZ 5 and 6 are dominant in the Southeast, Center West Cerrado and Northern Amazon regions, although having different shares in each region. The AEZ 3 is highly representative in the Northeast Coast region, but this is a region with very low suitability for agriculture (Sparovek et al 2010). The AEZ 4 is relevant only for the Northeast Cerrado and in a minor amount in Southeast and Northeast Coast.

Determining a correspondence between the AEZ regions and the BLUM regions is an important first step for comparison of land use dynamics of both models. By inspection, the following correlation can be established:

- South: AEZ-12/AEZ-6
- Southeast: AEZ-5/AEZ-6/AEZ-4
- Center-West Cerrado: AEZ-5/AEZ-6
- Northeast Coast: AEZ3/AEZ-4/AEZ-2
- Northern Amazon: AEZ6/AEZ-5
- Northeast Cerrado: AEZ-4/AEZ-5

2. Comparison of Land Use/Allocation Modeling

Specifications for land allocation to crops and livestock vary greatly among models. However, the general approach involves the following steps:

1. Calculation of agricultural land demand by crops and livestock.
2. Allocation of total land base among different land cover types.
3. Allocation of total agricultural land among crops and livestock.

In the GTAP-DEPS model, agricultural land demand for crop and livestock production are based on cost minimization by producers using nested constant elasticity of substitution functions. Agricultural land supply in each AEZ sub-region of the model is based on a three-stage allocation process as follows:

1. In the first and second stages, total land in each AEZ is endogenously allocated among four land cover categories: forest, shrub/grass land, other land and agriculture (crops and pasture).
2. In the third stage, agricultural land is allocated among crops (coarse grains, oilseeds, sugarcane, other grains, other agriculture), livestock (dairy, non-ruminants, cattle & ruminants), and forestry[5].

Agricultural land demand in BLUM is calculated based on reduced-form demand functions for crop and livestock products at the national level. Land supply in the model is performed in each of its six regions as follows:

1. BLUM does not model the distribution of total land among land cover categories. Instead, an estimate of the potential land available for agriculture in each region is estimated and provided as an exogenous input to the model. A supply function is used to determine the share of available land used for agriculture based on average returns to agricultural production.
2. Pasture land is modeled as the residual of the total agricultural land and cropland. The allocation of cropland among different crops is based on a competition elasticity matrix.

3. Options for GTAP-DEPS/BLUM Interaction

The above comparisons of the regional classification and land modeling in the GTAP-DEPS and BLUM models show that these are based on the same economic principles. The two models also incorporate similar details in their regional classification and crop/livestock categories. The main difference in modeling agricultural production is that GTAP-DEPS is a general equilibrium model, while BLUM is a partial equilibrium model. Thus, the GTAP-DEPS model uses a structural specification for agricultural product demand, whereas the BLUM uses reduced form equations. Apart from this, other differences are due to specification choices during the modeling process and the availability of data. In particular, BLUM includes a bit more detail in modeling the demand for agricultural products than GTAP-DEPS, but all the processes are present in the latter model. Similarly, the GTAP-DEPS model includes the allocation of total land to land cover categories, whereas this is exogenous to BLUM. Still, land use change is driven mainly by agricultural prices in both models.

Given the overall similarity in the modeling of Brazilian agricultural production and land use in the two models, the most productive interaction would be:

[5] Note that these crop/livestock categories can be mapped to those in the BLUM model as follows (GTAP-DEPS (BLUM): coarse grains (corn, barley); other grains (wheat, rice); oilseeds (soybeans, dry beans); other agric (cotton); sugarcane (sugarcane); dairy (dairy); cattle & ruminants, non-ruminants (livestock). The forestry sector will be improved in BLUM and might be an interesting collaboration between ICONE and ORNL

1. Comparison of agricultural land supply/allocation parameters for Brazil in the two models, and potential adjustments based on empirical evidence from the literature.
2. Comparison of results for similar simulations from the two models, focused mainly on highlighting the implications of partial vs. general equilibrium models[6].

4. Comparison of land supply parameters for Brazil

4.1. Elasticity comparison

The parameters of the nested constant elasticity of transformation functions used in GTAP-DEPS model can be converted into agricultural land expansion elasticities (Ahmed et al, 2008) similar to the ones used in BLUM. In the land supply of GTAP-DEPS, cross elasticity ($\varepsilon_{i,j}$) of land use i relative to price of land use j can be defined as the multiplication of the share of area of land use j times the CET of the correspondent nest (σ), as follows

$$\varepsilon_{i,j} = \theta_j \sigma.$$

Once total available land is allocated among the j land uses, we infer that

$$\varepsilon_{i,i} = -\sum_1^j \varepsilon_{i,j},$$

which is comparable to the agricultural expansion elasticities used in BLUM.

Applying the procedure above on the relevant AEZs in Brazil, we obtain the following expansion elasticities.

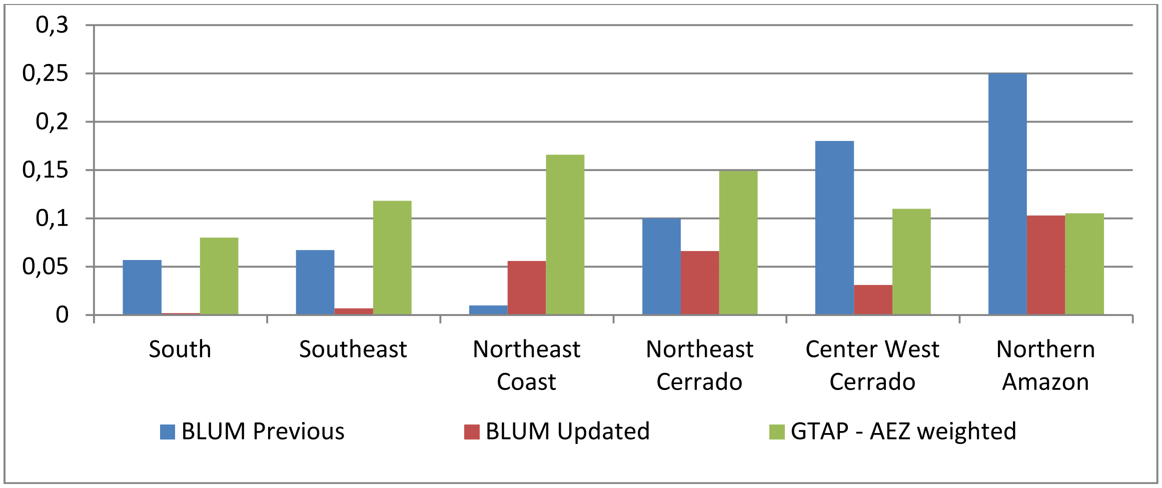
The table below lists the elasticity values for the most relevant AEZ in Brazil.

GTAP AEZ	AEZ 2	AEZ 3	AEZ 4	AEZ 5	AEZ 6	AEZ 12
Elasticity	0.189259	0.17094	0.167344	0.111744	0.103257	0.078302

Source: from the authors

As noted in section 2, the BLUM and AEZ regions have no direct relationship. To allow for direct elasticity comparison, we weighted the AEZs for each BLUM region according to its share of area, as presented in graph 1. For illustration proposes, we presented the previous elasticities of the BLUM model, before GIS data was considered for elasticity calculation.

[6] A comparison of simulation results between the two models must proceed cautiously, since the global general equilibrium model, GTAP-DEPS, contains a wider set of adjustment processes that are absent or exogenous to BLUM, such as feedbacks from world market and from other industrial sectors.



Graph 2: Comparison of BLUM and GTAP-DEPS land supply elasticities
Source: from the authors

The first insight is that the elasticity sizes are quite different between GTAP-DEPS and BLUM. All GTAP-DEPS elasticities are higher than the ones actually used in BLUM, and so it is important to verify that the same happens between previous and updated BLUM elasticities. One of the major findings of Nassar *et al* (2012) is that land supply elasticities tend to be lower when observed deforestation data is considered for elasticity estimates.

On the other hand, the cross-regional correlation between GTAP-DEPS is better when we consider updated BLUM elasticities than with previous BLUM elasticities. The correlation between the GTAP-DEPS and previous BLUM elasticities is negative (-0.39), whereas the correlation between BLUM updated version and GTAP model is 0.36.

To further investigate the elasticities relationship, it would be interesting to benchmark those elasticities with observed data. The work being done at ICONE is valuable for this potential next step and the empirical data collected thus far suggests that elasticity values in the two models are significantly different.

4.2. Pattern of agricultural expansion

Once we have looked at the parameters that determine the amount of agricultural expansion, it is also important to examine the pattern of conversion of natural vegetation, by land cover types.

GTAP-DEPS models the pattern of natural vegetation conversion explicitly. Agricultural expansion in GTAP-DEPS is endogenously allocated into three types of natural land cover: other land, forest land and shrubland/grassland. Other GTAP versions, such as the one used by CARB for the Low Carbon Fuel Standard regulation, only calculate agricultural expansion and relies on external models such as Plevin *et al* (2011) to translate total agricultural expansion into deforestation by land cover type.

The GTAP-DEPS approach seems to be theoretically more advanced than the approach actually used for LCFS regulation (Tyner, 2011). The following example helps to explain this statement. It is well known that sugarcane production is virtually non-existent and formally restricted in the Amazon region, whereas São Paulo state is the traditional region for sugarcane. Since forest carbon stocks vary significantly between regions it is imperative to guarantee that any sugarcane expansion will occur outside the Amazon region. However, as we can verify in figure 1, the AEZ 6 is relevant both in the Amazon, São Paulo state, as well as in Mato Grosso do Sul. The AEZ based models tend therefore not to distinguish adequately the regions of sugarcane expansion and the ones over which it cannot expand. The GTAP-DEPS capability to inform the type of vegetation that will be converted is particularly interesting in this case. The GTAP-DEPS is able to inform that agricultural expansion will occur much more over shrubland/grassland and not over forests, whereas the GTAP version used for CARB regulation only informs agricultural expansion.

The BLUM regions are set in a way that avoids the possible mistake exemplified above, but it does not calculate pattern of land conversion endogenously. As in the LCFS, the BLUM model adopts an allocation methodology to translate agricultural expansion into fixed shares of deforestation in each BLUM region, by vegetation type. This methodology was mainly based on Winrock/ICF satellite data developed for the RFS2 regulation (USEPA, 2010). ICONE researchers are currently developing an endogenous economic based model to downscale the BLUM results (in six macro-regions) into 560 micro-regions. It will still need an external model to state which kind of vegetation will be converted in each one of those 560 micro-regions, but the non-economic interference in the final results will be significantly lower.

Although it is the current standard approach, all efforts to allocate historic deforestation among economic activities based on observed land use *after* clearing takes place run a high risk of causation error. The implicit assumption is that land is cleared because of the demand for the use observed after clearing. Field research and observation show that this is not the case; there are multiple drivers of deforestation (extractive activities, government policies, incremental high-grading of timber, land speculation, poverty, clearing to establish and maintain land claims, and other social, political and cultural factors) which are likely to be predominant causal factors for initial deforestation (Kline and Dale 2008; Kline et al. 2009). Economic models that incorporate market factors and relative prices help explain changes in land use on privately managed lands after initial deforestation takes place. But these models might omit most predominant drivers of initial conversion in the world, in part because the majority of recent and current deforestation occurs on public lands.

The description above is enriched by the comparison of results in the next section.

5. Comparison of results for similar simulations

For the comparison between GTAP-DEPS and BLUM, and being especially focused on the iLUC calculations for sugarcane ethanol, we implemented a similar shock in Brazilian ethanol exports in 2022 in both models. More specifically, we exogenously forced the BLUM model to generate the same ethanol exports that GTAP-DEPS generated endogenously in simulating the

United States RFS2 mandates (Oladosu and Kline, 2012). As a global model GTAP-DEPS has a better capability to simulate international trade, since it will consider all the international feed-backs from changes on Brazilian agricultural exports. Ethanol exports are set exogenously in BLUM from 2012 to 2022[7] in the simulations.

5.1. Comparison of supply and demand variables of the sugarcane sector

BLUM explicitly models physical production and prices whereas GTAP-DEPS generates results in annual growth rates of (monetary) value of production of broader sectors. However, it is possible to compare physical results adding up annual growth rates to initial production, or dividing projected total production (in monetary value) by its initial price. This is particularly true for the ethanol and sugarcane sectors that are well disaggregated. This is less evident for the sugar market, which aggregates sugar and beverage. One additional difficulty is related to the base year of each model. GTAP-DEPS departs from 2001 and BLUM model has been updated with observed data until 2011.

As we can see in the table below, after converting GTAP-DEPS results into physical units, the difference in ethanol net exports between baseline and alternative scenario is equivalent to 9.268 billion liters in 2022. The same expansion in net exports led to an increase in production of 7.2 billion liters in BLUM, and slightly less than 6 billion liters in GTAP-DEPS.

This difference is partially explained by the greater decrease in national ethanol consumption in GTAP-DEPS (-3.294 billion liters) compared to BLUM (-2.059 billion liters). Once differences in initial values in year 2011 are taken into account, the decrease in consumption predicted by BLUM and GTAP-DEPS are still different at about 632 million liters. One possible explanation is that the BLUM model explicitly considers the differences between hydrous ethanol (E100 consumed in FFV vehicles) and anhydrous ethanol (E20 or E25 that is blended into regular gasoline), whereas the GTAP-DEPS consider ethanol only as a substitute for gasoline. In addition, because the GTAP-DEPS model captures the effect of biofuel policy in reducing the price of crude oil it is likely to allow a greater share of gasoline, and therefore a lower share of ethanol, to meet transport fuel needs than in BLUM. Further evaluation of the results, elasticities, and ethanol market structure could help to better quantify these differences.

[7] The year of 2022 was chosen as reference because of the RFS2 mandate.

Differences between base and shock scenarios ethanol sector in GTAP-DEPS and BLUM model

Year	Model	Ethanol Prod (10^6 l)	Ethanol Consump (10^6 l)	Ethanol Exports (10^6 l)	Sugarcane crush (10^6 t)	Sugar production (1000 t)
2011	GTAP-DEPS	969	-603	1,572	6	27
2011	BLUM	0	0	0	0	0
2022	GTAP-DEPS	5,974	-3,294	9,268	41.5	-5,733
2022	BLUM	7,211	-2,059	9,268	81	-486

Source: from the authors

The BLUM model projects that the additional suppression of the sugarcane sector will be due to expansion of exports of approximately 81 million tons in 2022. This already considers a reduction of 486 thousand tons of sugar production. The increase of sugarcane production is limited to 41.5 tons in GTAP-DEPS (approximately half of the expansion observed in BLUM). A major part of this difference comes from a decrease of sugar production in GTAP-DEPS (approximately -5.7 million tons)[8].

The probable reason for the differences between models in the sugar market is that the BLUM model considers sugar and ethanol as a single, integrated sector, whereas the GTAP-DEPS model treats sugar and ethanol as separate competing sectors for a single input (sugarcane). The physical structure of modern sugarcane mills in Brazil, most of which can produce both sugar and ethanol, is the reason for the BLUM model to consider the two products as outputs from one sector. This is in contrast to the GTAP-DEPS model, which follows the national accounts methodology that is based on input-output tables.

5.2. Comparison of the land use results

Given the differences listed above, we must find a common indicator to compare land use structure of GTAP-DEPS and BLUM. One possibility is to evaluate the amount and type of land converted to produce on ton of sugarcane. The GTAP-DEPS result estimated a production expansion of 41.5 million tons of sugarcane and total agricultural land expansion of 48.95 thousand hectares. Assuming an average yield of 80 t/ha, we calculate that 1 ha of sugarcane expansion will reflect in 0.09 ha of total agricultural expansion. In the BLUM model, the additional 81 million tons of sugarcane led to an increase in sugarcane area of 992 thousand hectares, which implies about 169 thousand hectares of total area expansion. In BLUM, we found 0.17 ha of agricultural expansion for each additional ha of sugarcane[9]. This result is

[8] As described in 5.1, it is not possible to directly calculate the sugar production, since sugar is part of the “sugar and beverage” sector. This estimate is based on the changes of ethanol and sugarcane production.

[9] This result is consistent with previous simulation of the BLUM model (Nassar *et al*., 2012), where the indirect effect is equivalent to 19% of the area of the sugarcane increase.

particularly interesting, since, as shown in section 4.1, agricultural expansion elasticities from GTAP-DEPS are higher than the ones used in BLUM.

Although the indirect effect (size of the total expansion compared to initial expansion of the biofuel crop) found by BLUM is actually higher than the one found in GTAP-DEPS, it is important to verify if some of the indirect land use change (ILUC) effects were transferred to other parts of the world. This is particularly unlikely to happen in BLUM, since no change in total production higher than 0.5% was found for all other agricultural commodities. In any case, the general message in both models is that the indirect effect is only a small part of the initial expansion of the biofuel crop.

Finally, we look at the type of land cover converted to agricultural and pasture production in both models. Following the same approach used by the US EPA for the RFS2, BLUM projects 37% expansion over savannas, 19% over grassland, 18% over forest and 17% over mixed vegetation. GTAP-DEPS results indicate a much higher share of forest conversion in overall agricultural expansion (65% of total expansion), and almost all the additional expansion over shrubland and grassland (35% of total expansion). However, the change in land cover estimated from GTAP-DEPS model represents the effect of the entire RFS2 on agricultural land use in Brazil, and not just from the export of sugarcane ethanol to the USA. In addition, distribution of the land cover change varied considerably between 2001 and 2022.

Therefore, the way that the model results are translated into natural land cover conversion is one other area for future collaboration. A first step, should be to determine the compatibility of land cover classes. Endogeneity of models and compliance with observed GIS data should be considered as strengths.

6. Major findings and road map for future collaboration

The report above described a first effort of comparison and collaboration between partial and general equilibrium economic based land use models. We verified that some parts of the model can be directly compared whereas significant structural differences remain in some areas of them. These different areas might be compared through results of similar simulations.

For instance, land supply elasticities of BLUM and GTAP-DEPS were directly compared. We also identified (and quantified) the similarities of BLUM regions and the AEZs of GTAP-DEPS. On the other hand, the sugarcane and the ethanol demand structures are still quite different between the two models. It was also not possible to compare the land competition effect of the BLUM model with the land demand section of GTAP-DEPS for this report.

We can infer from the comparison of results from the two models that the specification of different sectors has more effect on final results than one single (although central) part of the model. This is the particularly the case when we compare results of section 5.2 with land supply elasticities as in section 4.1. We could expect that higher land supply elasticities would result in higher land expansion, but the simulations indicated a higher agricultural expansion in the BLUM model inside Brazil.

Several actions can generate methodological improvements:

- GTAP-DEPS land supply elasticities might be revised using the same GIS database used for the BLUM model, as described in Nassar *et al* (2012).
- It would also be interesting to review the definition of AEZ boundaries, or propose endogenous ways to avoid mixing the land use dynamics of the Amazon, Southeast and Center-West regions. We must stress that even without changing AEZ boundaries GTAP-DEPS seems to present a more robust structure than other general equilibrium models.
- The development of the forestry sector in BLUM allows gains of scope to ICONE and ORNL. The findings and database developed to can be shared between institutions.
- Although integration of models might be seen as an ultimate goal, there are still several impediments on this route. Different from partial equilibrium models, it is unlikely that we will find ways to apply structural changes in one single region in global CGE models like GTAP-DEPS.
- Further comparisons of results between models can be performed. The BLUM model seems to be more flexible to transform endogenous variables into exogenous variables. Similarly to the one presented in this report, shocks can be implemented in particular sections of the BLUM model, taking the GTAP-DEPS results as exogenous.
- Some aspects not covered in this report should also be noted. Please refer to Annex I for additional actions that are of common interest for ICONE and ORNL.

References

1. Oladosu G. Estimates of the global indirect energy-use emission impacts of USA biofuel policy, *Applied Energy*, In Press, DOI 10.1016/j.bbr.2011.03.031 (2012)
2. Oladosu G, Kline K. A Dynamic Evaluation of the Indirect Land Use Change Implications of Advanced Biofuel Policy in the USA. Report to the Office of Biomass Programs, US DOE (2012)
3. Nassar *et al*. Agricultural Expansion and Land Use Changes in Brazil: Does Empirical Evidence Matter? (2012)
4. Sparovek, G.; Berndes, G.; Klug, I. F. L.; Barretto, A. G. O. P. 2010a. Brazilian agriculture and environmental legislation: status and future challenges. Environmental Science & Technology, vol. 44, pp. 6046‑53. DOI: 10.1021/es1007824 (2010)
5. Plevin, RJ.; Gibbs, Holly K.; Duffy, J; Yeh, S. Agro-ecological zone emission factor model. California Air Resources Board (2011).
6. USEPA, Regulatory Impact Analysis for the Renewable Fuel Standard (2010)
7. Tyner WE.; Golub A; Taheripour F. Calculation of indirect land use change (iLUC) values for low carbon fuel standard (LCFS) fuel pathways. Interim Report. Draft. September (2011)
8. Ahmed SA, Hertel TW, Lubowski R Calibration of a land cover supply function using transition probabilities (2008)

ANNEX I: Land-Use Change: Current Research, Practices, and Processes for Sustainable Bioenergy Production
OBP Webinar on May 25, 2012

Featured Presenters:
Marcelo M. R Moreira, ICONE
Gbadebo Oladosu, Oak Ridge National Laboratory

Abstract:
The webinar featured presentations by Marcelo Moreira of the Institute for International Trade Negotiations (ICONE) on the Brazilian Land Use Model (BLUM) and by 'Debo Oladosu of ORNL on the ORNL version of the Global Trade and Analysis Project (GTAP) GTAP-DEPS (GTAP for Dynamic Energy Policy Simulations). The ORNL model incorporates US biofuel policies, estimates of cellulosic biofuel feedstock from the Billion Ton Study, sub-models for land use and supply, and dynamics. The need to clearly articulate assumptions and scenarios was emphasized. To interpret and assess the various efforts to simulate LUC related to bioenergy, it would be helpful to define a common set of standard assumptions and a reference case scenario.
Kristen Johnson and Michael Benton of OBP, and Keith Kline and Maggie Davis of Oak Ridge National Laboratory (ORNL), served as facilitators. Other labs with OBP-funded land-use change (LUC) projects were encouraged to take part in the webinar and were given the opportunity to briefly share their project overviews and join in a discussion of the various input parameters and assumptions within the datasets currently used for modeling. The webinar also featured a group discussion on input data and assumptions that may lead to different LUC results and the development of options to address differences and overcome DOE Sustainability barrier: "Representation of Land Use: The inability of existing data sources to capture the actual state of the landscape, a poor understanding of the processes that drive LUC, and the lack of knowledge about the environmental and social consequences of LUC associated with bioenergy production, have undermined efforts to assess the environmental and social effects of bioenergy."
Highlights:

- Causal attribution among diverse drivers of deforestation is lacking in LUC assessments.
- In Brazil, there is a lack of knowledge regarding factors driving recent deforestation. Deforestation appears to have increased partly due to the uncertainty caused by proposed changes to environmental regulations (Legal Reserve Areas, Areas of Permanent Protection).
- Future research with Brazil will include exchanging data and promoting consistency in modeling efforts by Brazil and US researchers to achieve consistent results related to Brazil LUC.

Future Research - Key Steps:

- Continue to improve data, especially regarding baseline trends
- Integrate local and global models
- Introduce more detail into LUC models for additional improvement
- Include common reference scenarios in LUC models
- Develop explicit definitions for scenarios and input assumptions (e.g., specific BT2 scenario)