

Land Use Change, Ethanol Production Expansion and Food Security in Brazil

Joaquim Bento de Souza Ferreira Filho and Mark Horridge

Abstract The concurrence of major increases in ethanol production and world commodity price increases were captured by the ‘food-versus-fuel’ dilemma around 2008. Brazil is the largest producer of ethanol worldwide and still has vast tracts of natural land available. This paper uses Brazil as case study to simulate food security and environmental impacts, especially on forests, of increased biofuel production. Results show that sugarcane production is concentrated in higher productivity regions so reaching the 2022 ethanol target would require only 0.07 Mha of new land, or 0.02% additional deforestation over baseline. Second, per-area production intensifies as land prices increase, indicating a nonlinear relationship between land area and production. Specifically, results indicate an average indirect land use change effect of 0.083 ha of new agricultural land for every 1.0 ha of additional sugarcane. Current discussions of biofuel expansion miss this critical point of intensification, which results from market forces and technological change. These results are assumed to be driven solely by cost-minimizing behavior, thus leaving significant room for policy to expand agricultural research resulting in greater per unit output and subsequent environmental benefits. Finally, results support historical data that land use change due to biofuel production has little impact on food security.

Keywords Land use Change · Ethanol production · Food security · Brazil

J.B. de Souza Ferreira Filho (✉)
Escola Superior de Agricultura “Luiz de Queiroz”, Universidade de São Paulo,
São Paulo, Brazil
e-mail: jbsferre@usp.br

M. Horridge
Centre of Policy Studies, Victoria University, Melbourne, VIC, Australia
e-mail: mark.horridge@gmail.com

1 Introduction

In 1975 Brazil engaged in a massive ethanol production program, in the aftermath of the first oil shock, through the launching of the Programa Nacional do Álcool (National Ethanol Program or Proálcool). Among the many policy measures adopted to stimulate the production and use of ethanol were: subsidized credit for investments; an increase in the at-pump ratio of ethanol to gasoline; guarantee of ethanol prices below gasoline prices; and a reduction of sales taxes on ethanol-engine cars. The production targets at that time were 3 billion liters of ethanol in 1980, and 10.7 billion liters in 1985 (BNDES 2008). The reduction in oil prices after 1985 caused a reduction in the production and use of ethanol in Brazil that lasted throughout the nineties. Ethanol use started to recover again in 2003, led by the introduction of the flex-fuel technology for car engines, which allows the use of either gasoline or ethanol, or any blend of those two fuels. Sugarcane area increased from 4.0 Mha (about 11% of total annual crops area) in 2000 to 9.8 Mha in 2012 (15% of total annual crops area).

The recent expansion of ethanol and sugarcane production in Brazil happened at the same time as world commodity price increases, raising concerns related to the fuel-versus-food dilemma worldwide (Yacobucci et al. 2007; Collins 2008; Elliot 2008; Babcock 2009, Trostle 2008), and the associated land use and environmental issues. As argued by Babcock (2009), “the debate about whether biofuels are a good thing now focuses squarely on whether their use causes too much conversion on natural lands into crop and livestock production around the world.” This debate is particularly important in Brazil, one of the few important agricultural producer countries in the world which still has a vast stock of natural land available. But the induced effect of biofuels expansion on natural land conversion is an indirect land use change effect (ILUC) and so has proved hard to observe directly, as can be seen in the works of Ferez (2010), Nassar et al. (2010), Lapola et al. (2010), Barona et al. (2010), Arima et al. (2011), and Macedo et al. (2012), in the Brazilian context.

In this paper we extend the results by Ferreira Filho and Horridge (2012, 2014) to discuss other aspects of Brazil’s ethanol and sugarcane expansion, using a simulation model to highlight the implications of an ethanol production expansion scenario in two main aspects: the food security impacts and the environmental impact, focusing on deforestation and the indirect land use change. First we present the recent pattern of sugarcane and ethanol expansion as a background for the ensuing discussions. Then we describe our methodology, which we apply to a scenario of future ethanol expansion in Brasil. Finally, we present results and conclusions.

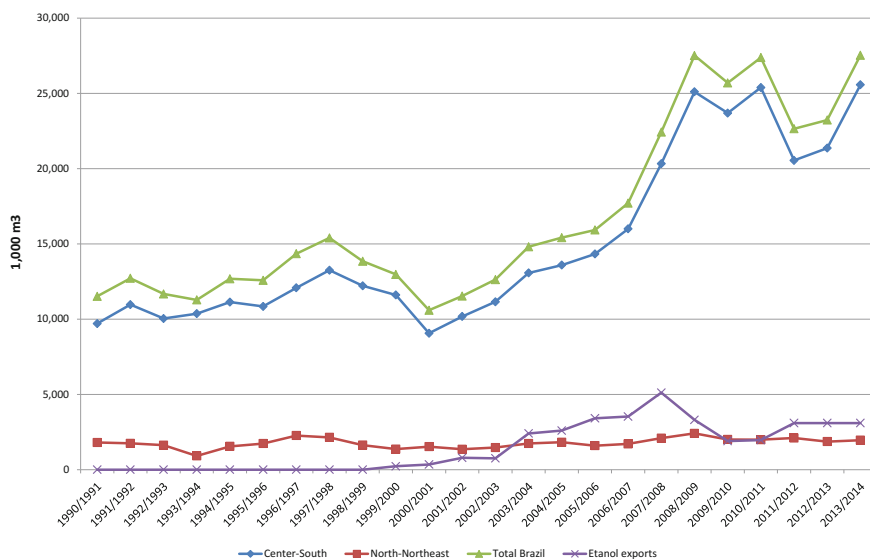


Fig. 1 Evolution of ethanol production and exports in Brazil (1000 m³). *Source* UNICA and Secretaria de Comércio Exterior do Brasil (SECEX)

2 The Recent Evolution of Ethanol and Sugarcane Production in Brazil

Ethanol production more than doubled between 1990 and 2008, and, as shown in Fig. 1, has been increasing continuously in the period 2000–2008, reaching a peak of around 27.5 billion liters in 2008. Adverse climatic conditions reduced production in 2008/2009 and 2011–2013 periods. The current Brazilian sugar/ethanol production industry has 437 production firms, among which 168 produce only ethanol, 16 only sugar, and 253 both ethanol and sugar. Notice that the increase in ethanol production came mainly from the Center-South region, which produces about 90% of the total.

Sugarcane accounts for a relatively small share in total annual crop area¹ (Fig. 2), although it is the third most important crop in terms of area in Brazil, occupying 9.7 Mha out of 63 Mha of annual crops area in 2012, or 15.3% of the total. The most important annual crops in area are soybeans, with 25 Mha cultivated in 2012, and corn, with 15 Mha. The area of pasture (not included in the figure) tripled between 1970 and 2006 to 160 Mha in 2006 (Brazilian Agricultural Census).

The increase in total cultivated area was accompanied by a steady increase in per-area productivity. The productivity index (tons/ha) grew from 100 in 1990 to

¹Permanent crops area accounted for 6.2 million hectares in 2012.

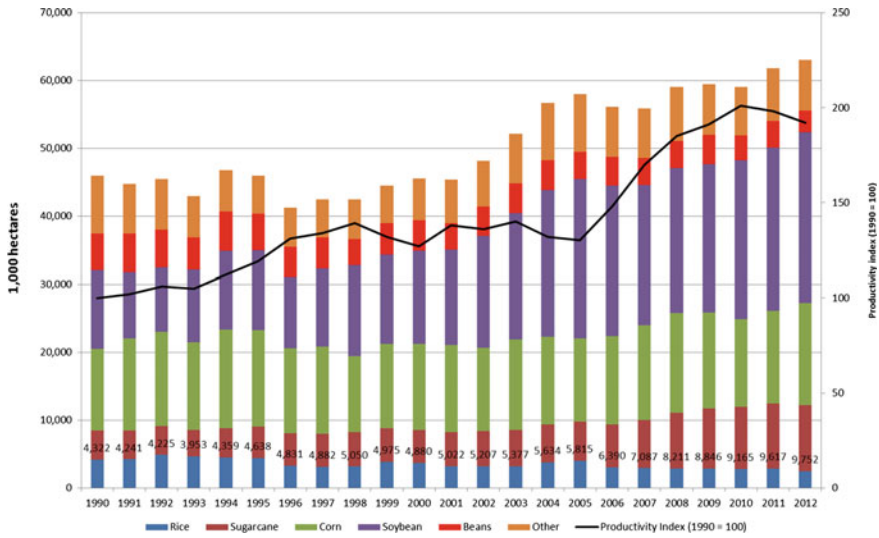


Fig. 2 Evolution of annual crops areas in Brazil and productivity index

192 in 2012, after peaking at 201 in 2010. Livestock productivity also increased, with important gains in animal performance and pasture productivity. As shown by Martha et al. (2012), 79% of the growth in beef production between 1950 and 2006 can be explained by productivity gains.

The regional concentration of ethanol and sugarcane production has important consequences for the points to be discussed in this paper. Looking at regional sugarcane planting over time, Fig. 3 shows that the bulk of the expansion of sugarcane area took place in the state of São Paulo,² which in 2013 accounted for 51% of total Brazilian ethanol production. São Paulo’s sugarcane area grew from 1.8 Mha in 1990 to 5.2 Mha in 2012, or 53% of total sugarcane acreage in Brazil.³ The Center-South region (which includes the state of São Paulo) accounted for 93% of total ethanol production and 87% of total sugarcane area.

These figures are central to the ILUC discussion. In São Paulo and most of Brazil’s Southern states, the stock of convertible land has basically run out, meaning that the supply of agricultural land is fixed. Hence sugarcane expands only at the expense of other land uses. However, around 18 Mha have been added to total national crop area (annual plus permanent crops) between 1995 and 2006 according to the Brazilian Agricultural Censuses of 1996 and 2006 (14 Mha between 1995 and 2009). An extra 1.8 Mha of planted pasture have been incorporated in the same period (Table 1). The expansion of agricultural area has taken

²São Paulo is the richest state in Brazil, with about 33.5% of national GDP in 2010.

³Sugarcane productivity is higher in São Paulo than in other states. Besides, the other Brazilian regions produce a higher share of sugar than ethanol when compared to São Paulo.

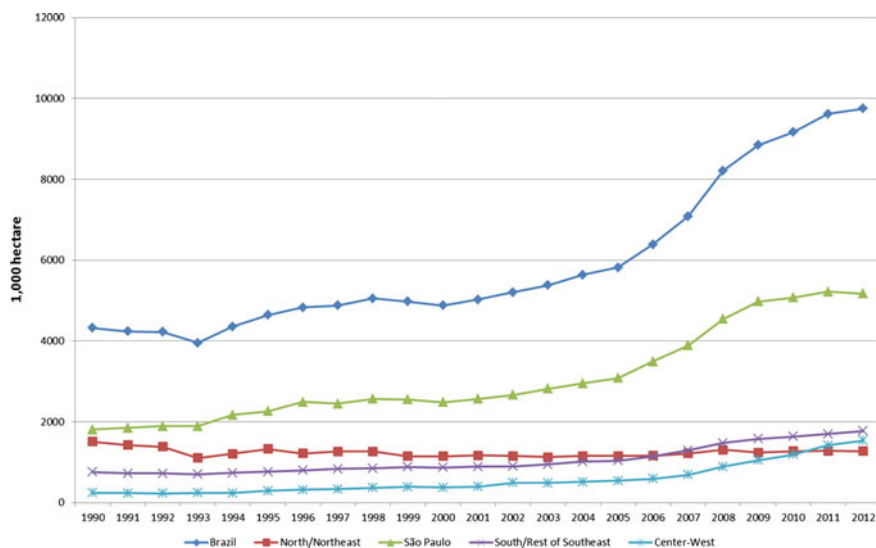


Fig. 3 Evolution of sugarcane planted area in Brazil, by region 1000 ha. *Source* IBGE—Produção Agrícola Municipal

Table 1 Land use variation in Brazil, (1970–2006 Thousands hectares)

	1970	1975	1980	1985	1995	2006	Difference 2006–1995
Perennial crops	7984	8385	10,472	9903	7542	11,612	4071
Annual crops	26,000	31,616	38,632	42,244	34,253	48,234	13,982
Natural pasture	124,406	125,951	113,897	105,094	78,048	57,316	–20,732
Planted pasture	29,732	39,701	60,602	74,094	99,652	101,437	1785
Planted forests	1658	2864	5016	5967	5396	4497	–899
Total var. 2006–1995	189,781	208,518	228,620	237,303	224,891	223,098	–1793

Source Brazilian Agricultural Censuses, various years

place mainly in some states in the Center-west, North, and Northeast, notably those closer to the Center-west Cerrados (tropical savanna) areas.

The simultaneous increase in areas of crops and pasture is possible, of course, due to the increased total area available for agriculture, caused by the expansion of the agriculture frontier through deforestation. We underline the enormous availability of pasture areas in Brazil. Area under planted pasture represents 61% of total

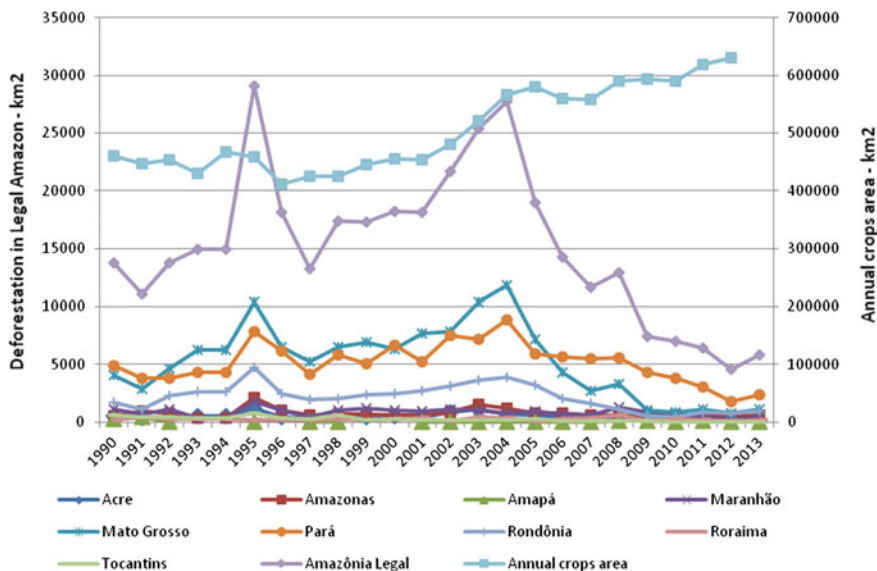


Fig. 4 Deforestation in Legal Amazon and annual crops area evolution (total) 1991–2013. *Source* PRODES (INPE) and Pesquisa Agrícola Municipal (IBGE)

area under production, and the land use change between pasture and crops is traditionally important for agricultural expansion.

In spite of the increase in land used for agriculture and livestock, the rate of deforestation has been reduced considerably in the recent period. Figure 4 shows that the rate of deforestation fell markedly from 27,772 square kilometers (2.77 Mha) in 2004 to 5843 square kilometers (0.58 Mha) in 2013 (IBGE/PRODES).⁴ The deforestation values in Fig. 4 refer to the Legal Amazon, an administrative region that includes nine out of the 26 Brazilian states (Rondônia, Acre, Amazonas, Roraima, Pará, Amapá, Tocantins, Maranhão and Mato Grosso). The agricultural frontier, however, is mainly located in Mato Grosso, Rondônia, and Pará, the states on the so-called “Arch of deforestation”.

As seen before, however, the incorporation of new areas and the agricultural expansion do not match exactly in geographical terms, giving birth to the ILUC problem. How much of the agricultural frontier expansion in North and Center-west, for example, is caused by the sugarcane expansion in Southeast Brazil? Furthermore, if one goes deeper into details and looks inside the crops aggregate, how does the sugarcane expansion affects the supply of other types of agricultural products? As showed by Rudorff et al. (2010) using satellite imagery,

⁴ Available at <http://seriesestatisticas.ibge.gov.br/series.aspx?vcodigo=IU12&t=desflorestamento-na-amazonia-legal-3-desflorestamento-bruto-anual-na-amazonia-legal>.

for example, almost all the land use change for sugarcane expansion of crop year 2008/2009 occurred on pasture and annual crop land. The modeling approach used to analyze these issues is presented next.

3 Methodology⁵

A multi-period computable general equilibrium model of Brazil, based on previous work by Ferreira Filho and Horridge (2014), is used to analyze the ILUC effects of projected sugarcane expansion. The model includes annual recursive dynamics and a detailed bottom-up regional representation, which for the simulations reported here distinguished 15 aggregated Brazilian regions. It also has 38 sectors, 10 household types, 10 labor grades, and a land use change (LUC) model which tracks land use in each state, to be described below. The core database is based on the 2005 Brazilian Input–Output model, as presented in Ferreira Filho (2010).

The model's recursive dynamics consist basically of three mechanisms:

- a stock-flow relation between investment and capital stock, which assumes a 1 year gestation lag;
- a positive relation between investment and the rate of profit; and
- a relation between wage growth and regional labor supply.

With these three mechanisms it is possible to construct a plausible base forecast for the future, as well as a policy forecast—because policy instruments shock variables to different values from the base (e.g., the ethanol expansion scenarios). This difference can be interpreted as the effect of the policy change. The model is run with the aid of RunDynam, a program to solve recursive-dynamic CGE models.

3.1 Modeling Regional Land Use

Increased production of biofuels may arise from technical progress, or using more inputs, such as capital, labor, or land. The last of these, land, is in restricted supply. In order to analyze the importance of an expansion of ethanol production in Brazil, land use has to be explicitly modeled, as described in this section.

For this paper, agriculture and land use are modeled separately in each of 15 Brazilian regions with different agricultural mix, which allows the model to capture a good deal of the differences in soil, climate, and history that cause particular land to be used for particular purposes.

Brazilian land area statistics by the Instituto Brasileiro de Geografia e Estatísticas (IBGE) distinguish three types of agricultural land use, Crop, Pasture, and

⁵The methodological description is based on Ferreira Filho and Horridge (2014).

Table 2 Transition matrices for land use change (Mha), (Average annual changes)

MatoGrosso	Crop	Pasture	Plant forest	Unused	Total 1996
Crop	8.7	0.2	0	0.1	9
Pasture	1	20.6	0	0.1	21.8
Plant forest	0	0.1	0	0	0.1
Unused	0	0.9	0.1	58.4	59.4
Total 2005	9.7	21.8	0.1	58.7	90.3
Brazil	Crop	Pasture	Plant forest	Unused	Total 1996
Crop	59.2	1.6	0	2	62.9
Pasture	5	153	0.4	2.1	160.5
Plant forest	0	0.9	3.6	0.1	4.7
Unused	0.1	3.7	0.6	619	623.4
Total 2005	64.3	159.2	4.6	623.3	851.5

Source Primary data from IBGE

Plantation Forestry. Each industry in the model is mapped to one of these types. Within each region, the area of “Crop” land in the current year is predetermined. However, the model allows a given area of “Crop” land to be reallocated among crops according to a Constant Elasticity of Transformation frontier, and the same mechanism is used to distribute Pasture land between Livestock cattle and Milk cattle uses. Forestry land has only one use. The total area of each region, of course, considerably exceeds the amount used for agriculture. The difference, called “Unused” in the model, accounts for 73% of Brazil’s total area. It includes land which could be used for crops or grazing, but is not yet so used. The North and West of Brazil contain large areas both of cultivable savanna and of forests that could be felled for grazing.

Over time the model allows land to move between the Crop, Pasture, and Forestry categories, or for Unused land to convert to one of these three. Based on the information collected from the Brazilian Agricultural Censuses of 1996 and 2006 (which shows land use changes between 1996 and 2005), a transition matrix approach is used, as illustrated in Table 2. The transition matrices show land use changes in the first year of our simulation. Row labels refer to land use at the start of a year, column labels to year end. Thus the final, row-total, column in each sub-table shows initial land use, while the final, column-total, row shows year-end land use. Within the table body, off-diagonal elements show areas of land with changing use between two consecutive periods. For brevity, the table shows only results for one state, Mato Grosso, and for all of Brazil, but there is one such transition matrix for every region in the model.

In Table 2, row and column values reflect current land use and the average rate of change of land use during the between Census period of 11 years (1996–2005), drawn from the Brazilian Agricultural Censuses of 1996 and 2006. Numbers within the table bodies are not observed but reflect an imposed prior: that most new Crop land was formerly Pasture, and that new Pasture normally is drawn from Unused

land (see, for example, Arima et al. 2011; Macedo et al. 2012). The prior estimates are scaled to sum to data-based row and column totals. The transition matrices could be expressed in share form (i.e., with row totals equaling one), showing Markov probabilities that a particular hectare used today for, say, Pasture, would next year be used for Crops.

In the model, these probabilities or proportions are modeled as a function of land rents, subject to a sensitivity parameter. Thus, if Crop rents rise relative to Pasture rents, the rate of conversion of Pasture land to Crops will increase. In the scenario the amount of Unused land was allowed to decrease only in selected frontier regions, namely Rondônia, Amazon, ParaToc (Pará plus Tocantins), MarPiaui (Maranhão plus Piauí), Bahia, MtGrosso (Mato Grosso), and Central (Goiás plus the Federal District). In the other, mainly coastal, regions total agricultural land was held fixed.

In summary, the model allows for sugarcane output to increase through:

- assumed uniform primary-factor-enhancing technical progress of 1.5% p.a. (baseline assumption);
- increasing non-land inputs;
- using a greater proportion of Crop land for sugarcane, in any region;
- converting Pasture land to Crops, if Crop rents increase, in any region; and
- converting Unused lands to Pasture or Crop uses, in frontier regions.

The last three mechanisms above characterize the indirect land use change (ILUC) examined in this paper.

4 Model Baseline and Scenario Simulation

As stated before, the model database is for year 2005. The model was run for seven years of historical simulations, using observed data to update the database to 2013, followed by annual runs to simulate the ethanol expansion scenario until 2022. The baseline assumes moderate economic growth until 2022, a 2.5% increase in real GDP per year, with projections for population increase by state by IBGE.⁶ As for deforestation, the model is calibrated to give a deforestation path close to the annual average observed values for the period 2009/2013 by PRODES, around 670 thousand hectares per year.⁷

To analyze the ILUC effects of an expansion of ethanol production, we compare the moderate scenario above with a more aggressive one, analyzing the differences in land use in both situations. With this in mind, the baseline projections for ethanol

⁶This simulation differs from that in Ferreira Filho and Horridge (2014) in two main ways: the baseline historical simulation was updated to 2013, and a revised scenario is used.

⁷The actual average deforestation for 2009/2013 by PRODES is 626 thousand hectares. We have used a value slightly higher because PRODES figures does not include some areas in Piauí state.

entail a moderate expansion in exports (average of 5.5% per year from 2014 to 2022) as well as in household use (around 2.5% per year from 2014 to 2022). These projections result in an average 2.8% per year increase in ethanol production in Brazil in the same period. This inertial growth would result in a baseline production of 37.1 billion liters of ethanol in 2022, or a 133.3% increase above the 2005 production of 15.9 billion liters.

The policy scenario, on the other hand, is based on projections by EPE⁸ (2013) in the Plano Decenal de Expansão de Energia 2022 (Decennial Energy Expansion Plan 2022), and comprises an approximate 7.5% per year increase in total ethanol production in Brazil between 2013 and 2022,⁹ to reach a total production of 54 billion liters of ethanol in 2022. This scenario is justified mostly by the continuous increase in sales of flex-fuels engine cars in the coming years, which will tend to increase domestic ethanol demand. The policy scenario, then, will be compared to the baseline scenario, which does not incorporate this extra change in the composition of flex-fuels/gasoline engine cars in the Brazilian fleet from 2013, and will allow the identification of the effects of ethanol expansion on the economy. No exogenous technological change was considered for the simulations.

4.1 Closure

An important detail in any CGE model is the closure. Broadly speaking, the closure conditions how the model determines the new solution after a policy shock, establishing the rules for achieving the new equilibrium. In the closure used in this paper, labor is free to move between regions and activities, driven by real wages changes, but not to move between labor categories. Capital accumulates between periods driven by profits, as discussed before. In order to properly approach the sugarcane expansion, a few other closure rules were used in the simulations:

- Capital in the ethanol industry was allowed to accumulate only in some regions, where ethanol expansion is expected to occur (Ferreira Filho and Horridge, 2009). These regions are Minas Gerais (MinasG), São Paulo, Paraná, Mato Grosso do Sul (MtGrSul), Mato Grosso (MtGrosso), and Central. This choice is based on those region's climate aptitude, as well as on their proximity to the most important ethanol consumption regions.
- Exports of agricultural raw products, food, textiles, and mining were kept fixed in the simulations at the baseline levels.

⁸The Empresa de Pesquisas Energéticas (EPE) is a research center linked to Brazil's Ministry of Mines and Energy.

⁹This value is a weighted average of the EPE forecasts for anhydrous and hydrous ethanol. The value used in the paper is slightly below the EPE forecast, which is around 9.6% per year from 2013 to 2022.

5 Results

As mentioned before, the goal of this paper is to address the potential consequences of increasing ethanol production in Brazil for land use change effects and the food security. Below we discuss the model’s results to gain insight about those issues.

The baseline scenario results in a 2.2% increase in deforestation accumulated to 2022 (13.2 Mha), matched by 6.5% increase in total area of crops (5.5 Mha), a 6.1% increase in area of pasture (7.9 Mha), and 3.6% fall in planted forests areas (0.2 Mha). The increase in deforestation, of course, would occur in the frontier states, where the natural stocks of land are still available. The main changes occurred in the states Mato Grosso (-2.3 Mha), Pará and Tocantins (-3.5 Mha aggregated), Rondônia (-0.7 Mha), and Maranhão and Piauí (-1.2 Mha, aggregated).

The increase in ethanol production leads to an increase in sugarcane acreage above the baseline, increasing the total agricultural land required for production. The variation in the broad land use categories is shown in Fig. 5.

Total crops area would increase by 0.16 Mha compared to the baseline, while pasture and planted forests areas would decrease by 0.07 Mha and 0.02 Mha, respectively. The expansion would still require an extra 0.07 Mha of new agricultural areas coming from deforestation. This would imply an average ILUC effect of 0.083 ha of new land for each extra hectare of sugarcane, a result close to that

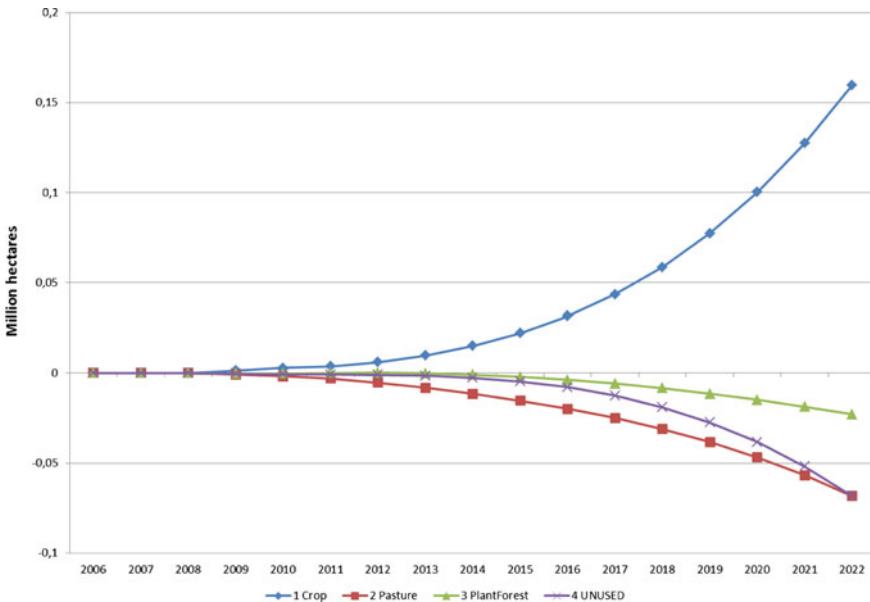


Fig. 5 Simulation results. Land use variation in Brazil. Deviations from baseline, accumulated

obtained (0.14) by Ferreira Filho and Horridge (2014), and slightly higher than the value (0.08) found by Nassar et al. (2010).

The above results show an important point regarding agricultural expansion, which is the advance of sugarcane into pasture areas. As discussed before, Brazil has an enormous area of low productivity pasture, which constitutes a land reserve that can be used for agricultural expansion. The expansion of sugarcane predominantly on pasture was noticed before by Homem de Melo et al. (1981), during the first period of the Proalcool program in the late seventies.

A further analysis into the transition matrix used in the model is useful to clarify the projected land use change pattern. As explained before, the transition matrix was calibrated with data from two Brazilian Agricultural Censuses between 1995 and 2006. There is one transition matrix for each region in the model. The transitions incorporate an important stylized fact of Brazilian agriculture, which is the sequence of transitions from natural forests to pasture first, and then from pasture to crops. This is the more common sequence, although transitions directly from natural forests to crops can also be observed, but in a much lesser extent and in particular biomes. The possibilities of transitions between those broad land use categories, then, are determinant for the results, and can be seen in Fig. 6. In the figure, only transitions from pasture and unused land to crops and from unused land to pasture are presented, to save space.

As Fig. 6 shows, most of the land substitution in the sugarcane expansion regions (MinasG, SaoPaulo, Paraná, MtGrSul, MtGrosso, and Central) comes from the transition of pasture to crops. The regions of MinasG, SaoPaulo, Paraná,

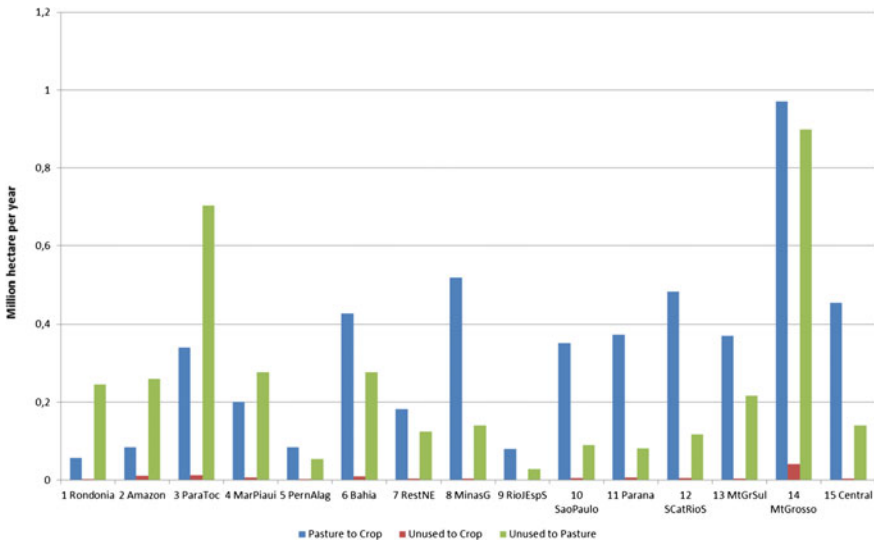


Fig. 6 Land use transitions in Brazil. Million hectares per year. Average between 1995 and 2006

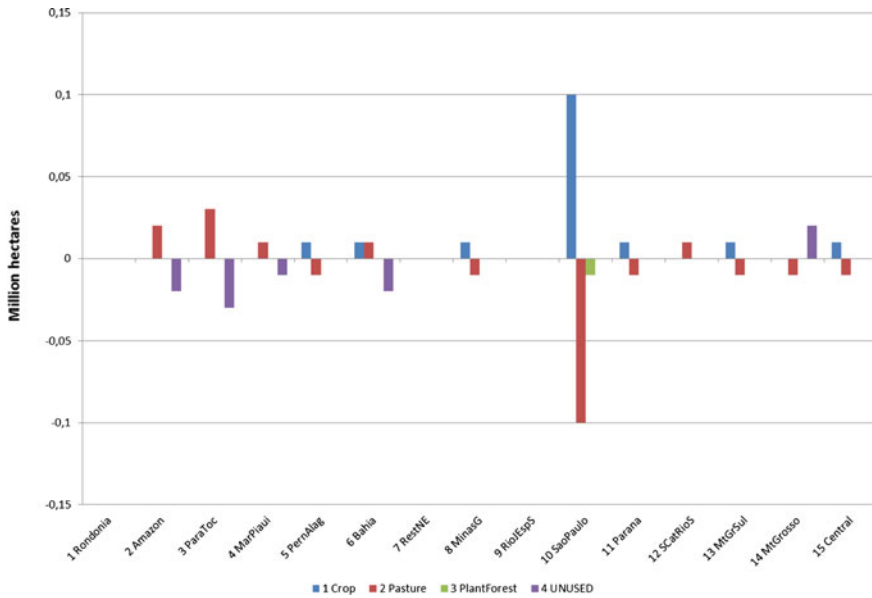


Fig. 7 Broad land type changes caused by increased ethanol production. Million hectares. *Source* Model results

MtGrSul, actually, are regions where no land conversion from natural forests to any other use can occur, since the natural stocks in those regions is already exhausted.¹⁰

The expansion of sugarcane in regions not located in the agricultural frontier, then, would require both land from pasture for crops expansion and a change in composition of production between different crops, with sugarcane taking over land previously in other uses. This process triggers a complex pattern of substitution and indirect land use change tracked in the model, summarized in the results in Fig. 7.

In the sugarcane expansion regions (MinasG, SaoPaulo, Paraná, MtGrSul, and Central) the increase in crops area happens mostly on pasture—see Fig. 7. Model results show that in São Paulo state, for example, the 0.1 Mha increase in crops area (accumulated in year 2022) would be almost exactly matched by the fall in pasture area.

The exception for this pattern is the state of Mato Grosso (MtGrosso), a frontier state, where an increase in areas converted to forests is actually observed in the simulation; this is caused by a particular feature of that state’s transition matrix. In this case, the transition from pasture to crops (0.971 Mha per year) is higher than the transition from unused to pasture (0.899 Mha per year). The expansion of sugarcane in this state takes more land from pasture (compared to the baseline), but

¹⁰Notice that some transition from unused to pasture appears in the matrix in the non-frontier regions, since it’s calibrated from past data. In the simulations, however, no deforestation is allowed in those regions, as discussed before.

Table 3 Changes in agricultural production, land use, and productivity per hectare (Cumulative percent deviation from the baseline, 2022)

	Production	Land area	Production/ha
Rice	-0.19	-0.27	0.07
Corn	-0.15	-0.83	0.68
Wheat	-0.62	-1.06	0.45
Sugarcane	20.54	12.44	8.11
Soybean	-0.09	-0.30	0.21
Other agric	-0.61	-1.30	0.69
Cassava	0.13	-0.41	0.54
Tobacco	0.20	-0.10	0.30
Cotton	-0.25	-0.07	-0.18
Citrus fruits	-0.53	-2.08	1.55
Coffee	0.02	-0.53	0.55
Forestry	-0.51	-0.54	0.03
Livestock	0.08	-0.07	0.15
Raw milk	0.11	-0.11	0.22
Other livestock	0.00	0.00	0.00

Source Model results

requires proportionately less forests to be converted to new pasture (compared to the baseline).¹¹ The increase in pasture will happen elsewhere, in states where the conversion from pasture to crops is smaller than that from unused to pasture, as is the case of ParaToc region (Pará and Tocantins states).

Table 3 summarizes national results for production in crops and livestock, as well as for land use. The increase in ethanol production would require a 20.5% increase [above baseline] in sugarcane production, but only a 12.4% increase in sugarcane area.

Table 3 shows that land use is not proportional to production. The production of sugarcane, for example, increases more than the increase in its area. Sugarcane production is concentrating in Southeast Brazil, where the productivity per hectare is the highest in the country. In this case, each additional hectare of sugarcane adds to production more than the national average or, conversely, less land is required for each ton of sugarcane.

Likewise, in the cases where a fall in cultivated area is observed, the pattern is that production falls less than area. This difference is caused by an induced increase in productivity per hectare, caused by (limited) substitution of land by other inputs in the simulations: as land prices increase more fertilizer and other inputs would be used per unit of area, increasing productivity.

¹¹This means that some land previously under pasture would be set aside, as is indeed observed from the data. A different (observed) transition matrix in the Second Brazilian Communication to the United Nations Convention Frame (Brasil 2010) estimates that 1.3 Mha of land was set aside between 1994 and 2002 in Brazil, 0.27 Mha of which was in the state of Mato Grosso.

The exception to this rule is cotton: productivity actually falls, due to a particular regional combination of results. Cotton is mostly cultivated in the state of Mato Grosso more productively than elsewhere in Brazil. Our simulation shows a decrease in cotton area in that state, causing a fall in productivity not compensated by the increase in other states where the culture expands, like Minas Gerais and Bahia, for example.

Thus the ethanol expansion scenario proposed by EPE (2013) would be easily accommodated, in terms of land use change. The ethanol production target of approximately 54 billion liters in 2022 would be met with an extra 0.07 Mha of new land, representing just 0.02% more deforestation than the amount projected in the baseline.

And finally it is important to analyze also the impacts of the projected ethanol expansion on Brazilian food supply. The expansion of biofuels production worldwide has been associated with recent food price increases by many authors (Yacobucci et al. 2007; Collins 2008; Elliot 2008; Babcock 2009; Trostle 2008). The issue has been analyzed also in relation to the welfare and poverty impacts in Brazil, by Ferreira Filho (2010) and Ferreira et al. (2011).

Table 3 shows that the increase in ethanol production would cause a small reduction in the area of land used for other agricultural products. This would affect their market prices, with potential impacts on household welfare. Notice, however, that incomes would also change with the policy shocks, and the net result on household consumption will depend on the balance between incomes and the consumption bundle prices changes, as shown in Fig. 8. In this figure the variation in real consumption of the 10 different households in the model is displayed, where POF1 stands for the poorest household and POF10 for the richest.

The ethanol expansion raises consumption levels for the poorest households (relative to the baseline). This result is driven by the increase in real incomes, which can be understood by analyzing the relation between household incomes and the labor wages of different occupations. The expanding agricultural sector is intensive in less skilled workers, who mostly come from the poorest households. When sugarcane expands, besides expanding labor demand (and wages) directly in the activity, an increase in land prices occur, inducing a change in input demand in all land-using activities, away from land and toward labor and capital. This further increases wages in agriculture, increasing the wages of the poorer households. Model results point to a positive net effect on real incomes, increasing real consumption of most of the household groups.¹²

¹²The reduction in consumption of the richest household is linked to the fall in production of activities intensive in more skilled labor, like the oil industry (gasoline), whose consumption would fall when ethanol consumption increases (substitutes).

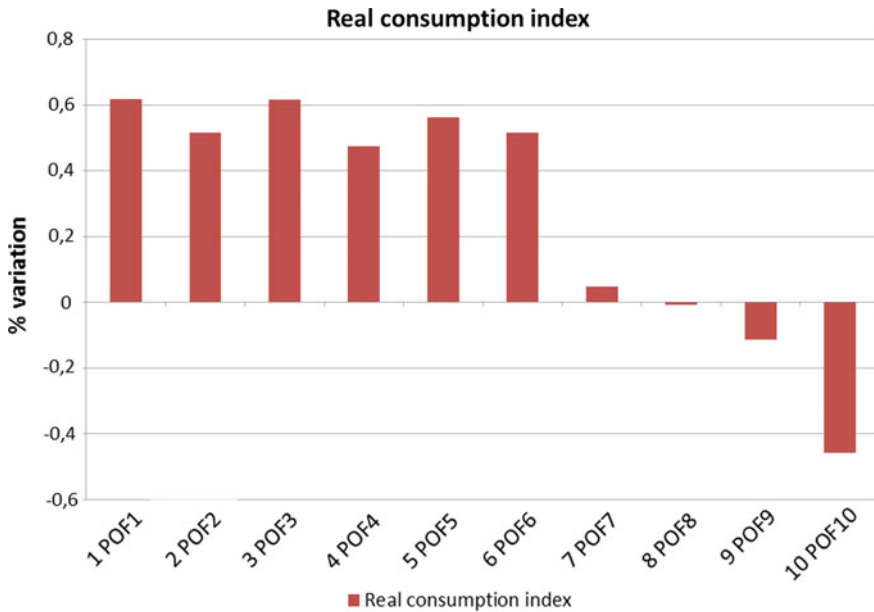


Fig. 8 Model results. Real consumption by household group, accumulated in 2022. Percent deviation from baseline.

6 Final Remarks

The expansion of biofuels worldwide fueled a debate recently about its consequences for deforestation and food security. In this paper we argue that none of those issues represent serious challenges in the case of the Brazilian economy.

The concentration of sugarcane in regions with higher productivity (the Southeast region) is one of the first aspects to be taken into consideration when analyzing the associated land use change issues. Each hectare of sugarcane in regions with above average productivity reduces the induced need for new areas drawn from natural forests, or ILUC. Considering that most of the modern ethanol production units are already located in the Southeast region, this seems to be the trend for the expansion. The recent spillover of sugarcane areas to the center-west regions is happening with the same technological standards observed in Southeast Brazil, what means that the trend for land use discussed here is likely to be stable in time.

The second important point raised by the simulation results is the endogenous intensification of per-area production induced by land prices increases, suggesting a nonlinear relation between the reduction in land areas and production levels, a point frequently misunderstood in discussions about biofuels expansion. This means that one extra hectare of biofuel crop does not require one extra hectare of cleared forest. Actually, in the Brazilian case this effect combines with a high availability of low productivity pasture to generate a low ILUC effect on natural forests, which in this

paper was estimated to be around 0.084 ha of cleared forests for each additional hectare of sugarcane.

Our results also suggest that the LUC impacts on food security in Brazil are very small; this is supported by historical data. On the contrary, the expansion of agriculture-based activities which use high shares of low skilled labor is likely to have positive distributional impacts, with potential to increase the real consumption level of the poorer households.

Finally we stress that no additional exogenous technological change was assumed for the policy scenario analyzed in this paper. The productivity increases due to intensification were assumed to arise from cost-minimizing behavior with given production functions. The continuous expansion of ethanol and sugarcane production above the levels analyzed in this study may eventually start to reduce the average sugarcane productivity, a point which certainly deserves attention for the future. Public policies toward agricultural research are likely to have a higher payoff not only in terms of agricultural output, but also in terms of land sparing, with corresponding environmental benefits.¹³

References

- Arima, E.Y., P. Richards, R. Walker, and M.M. Caldas. 2011. Statistical confirmation of indirect land use change in the Brazilian Amazon. *Environmental Research Letters* 6, 024010 (7 pp) doi:[10.1088/1748-9326/6/2/](https://doi.org/10.1088/1748-9326/6/2/).
- Babcock, B. 2009. Measuring unmeasurable land-use changes from biofuels. Iowa Ag Review. *Center for Agricultural and Rural Development. Summer* Vol. 15, no. 3.
- Barona, E., N. Ramankutty, G. Hyman, and O.T. Coomes. 2010. The role of pasture and soybean in deforestation of the Brazilian Amazon. *Environmental Research Letters* 5, 024002 (9).
- BNDES 2008. Bioetanol de cana-de-açúcar: energia para o desenvolvimento sustentável. Organização BNDES e CGEE—Rio de Janeiro. 316 p.
- BRASIL 2010. Segunda Comunicação Nacional do Brasil à Convenção-Quadro das Nações Unidas sobre Mudança Global do Clima. Brasília: MCT, 2010. Available at: <http://www.mct.gov.br/index.php/content/view/326751.html>. Access in February 13, 2012.
- Collins, Keith. 2008. The Role of Biofuels and Other Factors in Increasing Farm and Food Prices: A Review of Recent Developments with a Focus on Feed Grain Markets and Market Prospects. Supporting material for a review conducted by Kraft Foods Global, Inc. of the current situation in farm and food markets, June 19. Available at http://www.globalbioenergy.org/uploads/media/0806_Keith_Collins_-_The_Role_of_Biofuels_and_Other_Factors.pdf.
- Elliott, K. 2008. Biofuels and the Food Price Crisis: A Survey of the Issues. Center for Global Development. Working Paper no. 151. August.
- EPE. Plano Decenal de Expansão de Energia 2022. Ministério de Minas e Energia. Empresa de Pesquisa Energética.

¹³Silva et al. (2014) discussed the land sparing importance of technological changes in agriculture and livestock production in Brazil, concluding in favor of the “Borlaug hypothesis” for technological improvements in livestock production.

- Ferez, J. 2010. Produção de etanol e seus impactos sobre o uso da Terra no Brasil. 48º. Congresso da Sociedade Brasileira de Economia, Administração e Sociologia Rural. Campo Grande, MS. Anais (CD-ROM).
- Ferreira Filho, J.B.S., and M.J. Horridge. 2009. "The world increase in ethanol demand and poverty in Brazil." In *Twelfth Annual Conference on Global Trade Analysis*.
- Ferreira Filho, J.B.S., and M. Horridge. 2014. Ethanol expansion and the indirect land use change in Brazil. *Land Use Policy* 36 (2014): 595–604.
- Ferreira, F.H.G., A. Fruttero, P. Leite, and L. Lucchetti. 2011. Rising Food Prices and Household Welfare: evidence from Brazil in 2008. Policy Research Working Paper 5652. The World Bank.
- Ferreira Filho, J.B.S. 2010. World food prices increases and Brazil: an opportunity for everyone? In: Carlos de Miguel; José Durán de Lima; Paolo Giordano; Julio Guzmán; Andrés Scuchny; Masakazu Watanuki (orgs). Modeling Public Policies in Latin America and the Caribbean. 1 ed. Santiago, Chile: United Nations Publications. VI. P. 231–253.
- Ferreira Filho J.B.S., J.M. Horridge. 2012. Endogenous land use and supply and food security in Brazil. In: 15th Annual Conference on Global Economic Analysis. Geneva.
- Homem de Melo, F.B., and E.G. Fonseca. 1981. *Proálcool, energia e transportes*. Pioneira: São Paulo.
- IBGE—Instituto Brasileiro de Geografia e Estatística. *Pesquisa Agrícola Municipal*.
- INPE—Instituto Nacional de Pesquisas Espaciais. *Projeto PRODES: Monitoramento da Floresta Amazônica Brasileira por Satélite*.
- Lapola, D.M., J.A.R. Schaldach, J. Alcamo, A. Bondeau, J. Koch, C. Koelding, and J.A. Priess. 2010. Indirect land-use changes can overcome carbon savings from biofuels in Brazil. In *Proceedings of the National Academy of Sciences* 107 (February (8)), 3388–3393.
- Macedo, M.N., R.S. DeFriesa, D.C. Mortonb, C.M. Sticklerc, G.L. Galfordd, and Y.E. Shimabukuroe. 2012. Decoupling of deforestation and soy production in the southern Amazon during the late 2000s. *PNAS* 109(4):1341–1346.
- Martha Jr, B. Geraldo, Elisio Contini, and Eliseu Alves. "12. Embrapa: its origins and changes." *The regional impact of national policies: the case of Brazil* (2012): 204.
- Nassar, A.M., L.B. Antoniazzi, M.R. Moreira, L. Chiodi, and L. Harfuch 2010. Contribuição do Setor Sucroalcooleiro para a Matriz Energética e para a Mitigação de Gases do Efeito Estufa no Brasil. Available at <http://www.iconebrasil.org.br/pt/?actA=8&areaID=7&secaoID=20&artigoID=2109>.
- Rudorff, B.F.T., D.A. Aguiar, W.F. Silva, L.M. Sugawara, M. Adami, and M.A. Moreira. 2010. Studies on the Rapid Expansion of Sugarcane for Ethanol Production in São Paulo State (Brazil) Using Landsat Data. *Remote Sensing* V.2, 1057–1076; doi:10.3390/rs2041057.
- Silva, J.G., J.B.S. Ferreira Filho, M. Horridge 2014. Greenhouse gases mitigation by agriculture and livestock intensification in Brazil. In *17th Annual Conference on Global Economic Analysis*. Center for Global Trade Analysis. Dakar.
- Trostle, R. 2008. Global Agricultural Supply and Demand: Factors Contributing to the Recent Increase in Food Commodity Prices. WRS-0801. Economic Research Service. USDA.
- Yacobucci, Brent D., and Randy Schnepf. 2007. "Selected Issues Related to an Expansion of the Renewable Fuel Standard (RFS)." CRS Report No. RL34265. Washington: Congressional Research Service, December.