Luís Augusto Barbosa Cortez; Manoel Regis Lima Verde Leal;ré Meloni Nassar; Marcelo M. R. Moreira;
Sabrina Feldman; Miguel Taube-Netto;res da Silva. "LAND REQUIREMENTS FOR PRODUCING
ETHANOL IN BRAZIL", p.301-318. In Luis Augusto Barbosa Cortez (Coord.). **Sugarcane bioethanol — R&D
for Productivity and Sustainability**, São Paulo: Editora Edgard Blücher, 2014.
http://dx.doi.org/10.5151/BlucherOA-Sugarcane-SUGARCANEBIOETHANOL_30

11

LAND REQUIREMENTS FOR PRODUCING ETHANOL IN BRAZIL

Luís Augusto Barbosa Cortez, Manoel Regis Lima Verde Leal,
André Meloni Nassar, Marcelo M. R. Moreira, Sabrina Feldman,
Miguel Taube-Netto and *Andres da Silva*

INTRODUCTION

Biofuels production depends essentially of: solar energy, fertile land, water, atmosphere (with oxygen and carbon dioxide), in addition to human and financial resources as infrastructure and investment. From all factors, land usage may be the one that expresses the most limiting physical restriction on the planet. A study by Doornbosch and Steenblik (2007) on the land availability for bioenergy in the world (see Table 1 below) evidenced that the availability of proper land for bioenergy production is concentrated in two continents, South America and Africa.

The land areas shown as available indicate previous deduction of the areas required for future food agriculture, urbanization, and infrastructure, as well as areas having potential for agricultural use, but that are occupied by forests, and some reserved for grazing. The total 440 million hectares is a reasonable land area to supply future biofuel demands, as long as high-yield raw material options are selected, such as sugarcane, palm (*dendê*), and beets, as shown on Table 2 and in the following text. It is important to notice that from this total, 250 Mha are located in Central and South America, and 180 Mha are in Africa, comprising 90% of the total. In spite of its wide land availability for bioenergy production, Africa does not have the infrastructure, technology, and qualified labor, in addition to social and political instability that will hamper large-scale bioenergy production on the short to mid-term.

TABLE 1 Land available for producing biomass for energy in the world in 2050 (Gha).

Region	Total land	Rain-fed cultivation land	Adequate land, covered with forest	Plowable lands in use	Land that will be necessary in the future for buildings, food, and infrastructure	Additional available lands	Land for bioenergy
North America	2.1	0.4	0.1	0.2	0.0	0.00	0.00
South & Central America	2.0	0.9	0.3	0.1	0.1	0.25	0.25
Europe	2.3	0.5	0.1	0.2	0.0	0.08	0.04
Africa	3.0	0.9	0.1	0.2	0.1	0.44	0.18
Asia	3.1	0.5	0.0	0.6	0.1	-0.07	-0.07
Oceanía	0.9	0.1	0.0	0.1	0.0	0.04	0.04
Total	13.4	3.3	0.8	1.5	0.3	0.74	0.44

Source: DOORNBOSCH and STEENBLIK, 2007

TABLE 2 Land required to replace 10% of current world consumption of gasoline and diesel[1, 2].

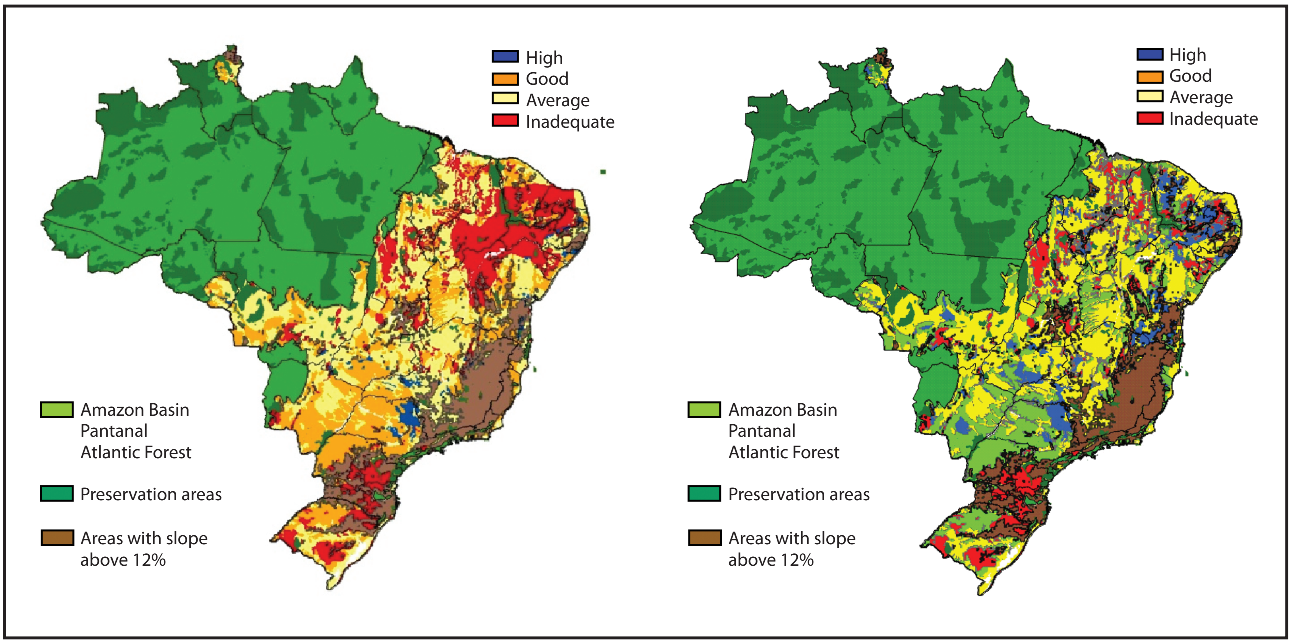
Biofuel	Raw material	Yield (t/ha)	Necessary land (Mha)
Ethanol	Sugarcane in Brazil	6,000	25
Ethanol	Sugarcane in the world average	4,550	33
Ethanol	Corn in the USA	3,500	43
Ethanol	Corn in the world average	1,960	77
Biodiesel	Soybeans	500	270
Biodiesel	Castor Beans	500	270
Biodiesel	Palm trees in Malaysia	4,700	29

[1] 150 billion liters (120 billion liters of gasoline)

[2] 135 billion liters (120 billion liters of diesel)

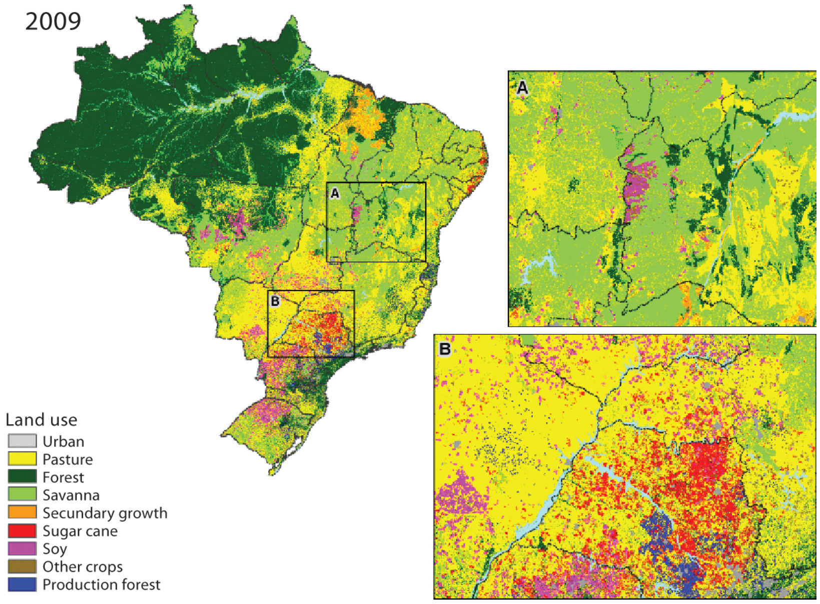
Source: prepared by the authors of this chapter. Data from world averages and other FAO countries, 2008.

In another study carried out by Leite *et al.* (2009) the conclusion was that to replace the equivalent to 10% of all the gasoline to be consumed in the world in 2025, estimated in 1.7 trillion liters/year, 204 billion liters/year of ethanol would be required. To produce such volume from sugarcane in Brazil, about 34 million ha would be needed, considering an annual agro-industrial production of 6,000 liters of ethanol/ha. The same study mapped the Brazilian regions suitable for cultivating sugarcane according to their different productivity levels due to soil and climate (Figures 1 and 2). Even excluding the Amazon, Pantanal, and steep sloped areas, the study showed that there are areas with high yield (81.4 t/ha) 7.9 Mha; medium yield (71.3 t/ha) 113.9 Mha; low yield (64.8 t/ha) 149.2 Mha, totaling 271.0 Mha. This area could produce around 18.6 billion tons



Source: LEITE *et al.*, 2009.

FIGURE 1 Potential for sugarcane without irrigation (left) and with irrigation (right).



Source: GOUVELLO, 2009.

FIGURE 2 Use of land and changes in the use of land in Brazil.

of sugarcane. However, with salvage irrigation, the total of adequate land (303.6 Mha) could produce around 21.1 billion tons of sugarcane.

On the other hand, the quantity of land required to replace a fraction of the petroleum derivates consumption strongly depends – as it is known – on the raw material used and its agricultural yield. Table 2 makes it clear that sugarcane ethanol and palm tree biodiesel are the ones presenting the best agro-industrial yields. Here the importance of agricultural productivity is noticeable, strongly influencing the use of land, as well as the fact that some cultures, like sugarcane, are able to produce their own processing fuel (bagasse), still leaving the trash, with all its unexploited energy potential.

This demand for land for biofuel production has aroused some reaction, mostly from developed countries, markedly Europe and the USA, about a possible conflict in using fertile land around the world to produce food versus biofuels, on top of causing undesirable environmental impacts (SEXTON *et al.*, 2009; FAO, 2008).

It is worth mentioning that the use of land for agricultural purposes in the world is around 1.5 billion ha. Comparatively, the use of land for producing biofuels, including ethanol from corn in the USA, from cereals in Europe, and sugarcane in Brazil is around 25 million ha, i.e., about 1.6% of the total. Additionally, the land used today for pastures in the world are close to 3.5 billion ha, being 200 million in Brazil, i.e., almost 25% of the total area of the country.

Obviously, these points related to fertile land usage in the world are an issue that includes discussing the planet's support, i.e., how many we are and how many we will be, and what is the food consumption pattern for this population. A very important point to be considered is the improvement of pasture usage, as it has enormous potential for clearing lands adequate for agriculture; an increase of only 10% of pasture productivity would free 350 Mha for cultivating food or bioenergy.

It is important to stress the political and commercial features of this discussion, since there is a strong agricultural protectionism in the developed countries, which now see their markets threatened by "modern bioenergy", which can be exported. In this sense, it is important to mention that when bioenergy is not exported, like e.g., "traditional bioenergy", no further concern and criticism in the marketplace is given to it. Traditional bioenergy represented 10% of the energy consumed in the world in 2006, while modern bioenergy used in transportation represented only 0.3% (REN21, 2008). The exact quantity of land used for producing traditional biomass is unknown, also for its extractivism characteristics.

An estimate of breakdown of biomass use in 2006 was attemped by by Goldemberg (2007), and summarized in Table 3.

According to the table above, traditional biomass, and manure, used with extremely low efficiency) represents over 80% of the total biomass used for energy generation purposes; biofuels comprise only 1.5% of the total. The annual biomass production through photosynthesis is estimated at 3,000 EJ, hence little more than 1.5% of this total is exploited as a source of primary energy. The conversion of traditional biomass into modern biomass represents a major challenge, and is a tremendous opportunity to improve efficiency and sustainability in using this important source of primary energy.

This demand for land for bioenergy has raised considerable debate worldwide, also fueled by relatively new concepts such as direct land-use change (LUC), and more recently by indirect land-use change (ILUC). While methodologies for estimating LUCs have demonstrated a reasonable reliability level, determining ILUCs with minimum reliability remains a challenge. The mathematical models used in ILUC studies show a series of limitations and inconsistencies, presented in detail in ORNL, 2009.

TABLE 3 Biomass end use (2006).

	Mtep	EJ
Traditional biomass	950	40
Modern biomass	216	9.01
Bioethanol	16	0.67
Biodiesel	1.6	0.07
Electricity	32	1.33
Heat	166	6.94

Source: GOLDEMBERG, 2007.

USE OF AGRICULTURAL LAND IN BRAZIL

Soil in Brazil is considerably anthropized in this early 21st Century, i.e., its surface is considerably modified by human action, which removed most of the original vegetal topping/cover, exception made to the Amazon and the Pantanal. The only region in Brazil that preserves its original vegetation, at least by 80%, is the North Region, precisely where the Amazon is, the region with the widest biodiversity in Brazil, and precisely where the sugarcane culture is virtually inexistent.

Another point to be made is that sugarcane expansion for ethanol production will take place almost completely in lands currently taken up by pastures, but which were originally covered by medium complexity bushes (*"cerradão"*). This means that over more than a century ago these areas were deforested, today being occupied by low-productivity pastures. Therefore, the change in land use in Brazil for the sugarcane expansion will take place in Center-West regions, in either degraded pasture or low-productivity land (< 0.7 UA/ha).

Data from *Instituto Brasileiro de Geografia e Estatística* – IBGE, (Table 4) show sugarcane as the third agricultural activity in the country, after soybean with about 21 Mha, and corn with 14 Mha. Sugarcane today occupies about 7 Mha in Brazil. It should be noted that this area produces both sugar (Brazil is the world's largest producer and exporter) and ethanol. It may be said that ethanol fuel production in Brazil uses around 4 Mha, i.e., around 0.5% of the total country area, or about 8% of the total currently cultivated area.

Furthermore, sugarcane expanded over the past few decades without compromising the food industry; on the contrary, it is possible to say that being a high-yield culture and high income per hectare, sugarcane brings wealth to the countryside and fosters its production.

In a recent study by a working group coordinated by C. Gouvello (2009), sugarcane geography in Brazil (see the Figure 2) was again evidenced,

TABLE 4 Area occupied and yearly production by annual cultures in Brazil.

Culture	Cultivated area (10^6 ha)	Production (10^6 ton)
Soybean	20.6	58.0
Corn	13.8	51.3
Sugarcane	6.7	515.8
Beans	3.8	3.3
Rice	2.9	11.1
Wheat	1.9	4.1
Coffee	2.2	2.2
Other	5.9	–
Total	57.8	

Source: IBGE, 2008.

as well as the importance of the sugarcane-pasture relationship regarding sugarcane expansion and how all this can take place without jeopardizing meat production while reducing GHG emissions, considering that their integration may even free up land presently occupied with degraded pastures.

AGRO-ENVIRONMENTAL ZONING FOR SUGARCANE IN BRAZIL

From a recent study by the Ministry of Agriculture (MAPA, 2009), the so-called agro-environmental zoning of sugarcane, it may be drawn that there are about 65 million hectares adequate for cultivating sugarcane in Brazil (Table 5 and Figure 3). This land today has low socio-economical and environmental value and does not justify its use with the current productivity figures.

FUTURE DEMAND FOR SUGARCANE ETHANOL IN BRAZIL

From the data shown in Tables 2, 4, and 5, it is possible to state that Brazil is exceptionally able to produce a significant part of the world's future ethanol demand due to its availability of adequate land for cultivating sugarcane with low socio-economic impact (65 Mha), excellent agro-industrial productivity, human and infrastructure resources.

BRAZILIAN MODEL FOR LAND USE (BLUM)

In early 2008, the International Negotiation and Trade Studies Institute (Instituto de Estudos do Comércio e Negociações Internacionais – ICONE) set up a partnership with the University of Iowa's FAPRI-CARD (Food and Agricultural Policy Research Institute – Center for Agricultural and Rural Development), to work out a partial balance economic model that made it possible to analyze and project the dynamics of the major Brazilian agricultural industries on a 10-year window. The first version of the model was developed within

TABLE 5 Synthesis of areas for sugarcane expansion in Brazil, considering suitability of prevailing classification and land use types in 2002.

Brazil	Adequacy classes	Adequate areas by type of land use by adequacy classes (ha)				
		Ap	Ag	Ac	Ap+Ag	Ap+Ag+Ac
Total areas in Brazil	High (H)	11,302,343	600,767	7,360,310	11,903,110	19,263,420
	Medium (M)	22,863,866	2,126,395	16,496,736	24,990,261	41,486,996
	Low (L)	3,041,122	483,326	731,077	3,524,448	4,255,525
	H+M	34,166,209	2,727,162	23,857,046	36,893,371	60,750,416
	H+M+L	37,207,331	3,210,488	24,588,123	40,417,819	65,005,941

Note: Adequacy classes H: High; M: Medium; L: Low – Current use: Ac: Agriculture; Ag: Animal breeding; Ap: Pasture.

Source: MAPA, 2009.

Source: MAPA, 2009.

FIGURE 3 Areas suitable for sugarcane cultivation based on agricultural classification, currently used for pastures, animal breeding, or agriculture.

the scope of the "Study of Low Carbon for Brazil" project of the World Bank, which was interested in assessing GHG (greenhouse gas) emission scenarios in various Brazilian industries.

This was how BLUM – Brazilian Land Use Model, came to being. In just two years it matured and enabled ICONE to set up a wide intelligence network with specialists from various Brazilian and international universities and research centers. For example, the Federal University of Minas Gerais (UFMG), the Brazilian Agricultural Research Company (EMBRAPA), the National Space Research Center (INPE), the Alternative Energies Center (CENEA) in Fortaleza, the Brazilian Bioethanol Science and Technology Laboratory (CTBE), Luiz de Queiroz Agriculture School (ESALQ-USP) of the São Paulo State University, the Remote Monitoring Laboratory of the Goiás State Federal University (LAPIG), the Strategic Studies and Management Center (CGEE), all in Brazil, could be mentioned among others. International examples include the CARD and the World Bank itself.

Today BLUM has in its record two remarkable international accomplishments: 1) the results shown by US-EPA (Environmental Protection Agency) on GHG emissions from sugarcane ethanol, within the scope of the laws referring to the *Renewable Fuel Standard* (RFS 2), corroborate the results obtained by ICONE and submitted to that agency in 2009. Based on BLUM, ICONE has proven that sugarcane ethanol is an advanced biofuel, with lower GHG emissions than those initially suggested by EPA; 2) BLUM was integrated to the FAPRI model and included in its Outlook 2010,

TABLE 6 Projected global supply/demand of ethanol.

Billion liters	2009		2010		2015	
Country	**Offer**	**Demand**	**Offer**	**Demand**	**Offer**	**Demand**
World	83.4 (40.9)	82.2 (40.3)	101.4 (49.7)	99.4 (48.7)	168.6 (82.6)	147.3 (72.2)
USA	42.4 (20.8)	42.4 (20.8)	49.2 (24.1)	49.2 (24.1)	61.7 (30.2)	60.5 (29.6)
Brazil	27.5 (13.5)	22.0 (10.8)	29.7 (14.6)	25.9 (12.7)	54.0 (26.5)	47.2 (23.1)
European Community	3.4 (1.7)	4.8 (2.4)	4.4 (2.2)	6.0 (2.9)	6.0 (2.9)	9.2 (4.5)
China	3.1 (1.5)	8.5 (4.2)	3.4 (1.7)	8.8 (4.3)	12.8 (6.3)	11.5 (5.6)
India	1.7 (0.8)	0.8 (0.4)	1.8 (0.9)	1.6 (0.8)	9.3 (4.6)	2.1 (1.0)
Indonesia	0.7 (0.3)	0.18 (0.1)	2.2 (1.1)	0.6 (0.3)	6.5 (3.2)	1.1 (0.5)
Malaysia	0	0	0	0	0	0

Source: IEF, 2010.

executed for the first time with a model specific for Brazil integrated to the worldwide FAPRI models.

BLUM's major difference is its capacity to reflect the local reality of Brazilian agro-business using a methodology based on variables recognized by the academic community as determinants of the Brazilian agricultural industry dynamics. ICONE innovated in the model methodology for two reasons: 1) by suggesting geo-referenced information from remote monitoring analyses that contribute to embodying information on areas offering expansion potential for agro-business, considering physical, environmental, and legal constraints; 2) by projecting endogenous pasture areas, which were not considered by other land use models; 3) by differentiating first-harvest cultures (that require land for production) from mini-harvests and winter cultures (that require no additional land, as they are planted in the areas already used for first-harvest cultures); 4) for focusing on the national agricultural dynamics, dividing Brazil in six different regions with their respective peculiarities, which is essential for a more accurate land use analysis; 5) BLUM's structure, in its elastic features of price and competition, considers homogeneity, symmetry and add-ability economic conditions.

Several improvements are still needed in BLUM, such as the distribution of the demand for land at IBGE-level micro-regions, incorporating deforestation and deforested lands occupation data from the Amazon and *Cerrado* biomas, assessment of competition and replacement between productive uses, based on data from remote monitoring, and incorporation of transportation infrastructure improvements and their impact on agricultural production.

FEATURES OF BLUM

BLUM encompasses soybean, corn (first and second harvest), cotton, rice, beans (first and second harvest), sugarcane, wheat, barley, raising cattle for meat and dairy, poultry and eggs, and swine, and is based on two large modules: supply and demand, and land use.

In the first module, demand is projected nationwide, and is composed by domestic demand, net exports (exports less imports), and final inventory (only milk, eggs, and meat demands do not include the final inventory variable), which respond (negatively) to price, as well as exogenous factors, such as GNP, population, and exchange rates. The supply is composed by domestic production (sum of the production in all six regions) and the initial inventory (this one only for cereal, sugarcane, and its derivates), and gives the profitability of each commodity, which on its turn depends on the respective cost, productivity, and price of each product.

Prices are determined from the demand and supply balance, which interact dynamically until simultaneous balance is achieved in all markets considered.

The land use module comprises two effects: scale and competition. The scale effect is the one that determines the fraction of the total area available in each region (estimated by remote monitoring) actually taken by agriculture. It is assumed that the higher average agricultural profitability, the higher will be the scale effect. The competition effect is the one that divides the total area occupied by the various specific production uses (types of culture and pasture) in each region, as a function of the profitability of the activity itself and its competitors. The distributed area and productivity compose each individual product's production in each region which, added to the initial inventory, determine the national supply of that product. This relationship ensures the interaction between the land use and the supply/demand modules in the model.

In addition to the competition for land, there are interactions between the sectors analyzed, as well as between a product and its by-products. For instance, between the meat and cereal sectors, the demand for animal foodstuff from the supply of meat, milk, and eggs (basically corn and ground soybeans) is one of the components of the domestic demand for corn and soybeans. In the case of the soybean complex, ground soybeans and soybean oil are components of the demand for soybeans, which is determined from the grinding ratio. Likewise, ethanol and sugar are components of the demand for sugar.

MAJOR BLUM APPLICATIONS

The results obtained by BLUM are long-term projections, at national level, for domestic demand, net exports, inventories, prices and, at regional level, for planted area, pasture area, production, productivity, and stratified bovine and swine herds. The model is a tool that allows to quantitatively assess the change in land use and GHG emissions from the growth of the demand for foods, biofuels, and fibers.

Periodically, baseline scenarios will be generated, and various alternative scenarios may be simulated, both from different macroeconomic scenarios (changing variables exogenous to the model) and by different technology and domestic demand or export scenarios for one or more products (changing variables endogenous to the model).

Furthermore, the model may simulate the response of the Brazilian agricultural industry to international price projections. Thus, BLUM can be used as a tool for multiple purposes and analyses by public policy developers, the private sector, and the international scientific community.

For the private sector, various scenarios may be simulated in order to serve as a tool for defining long-range strategic plans, and for decision-making in investments. From the results obtained with the model, it is possible to forecast the demand for fertilizers, pesticides, as well as agricultural machinery, to define location and production capacity of industrial plants as a function of regional agricultural production and technology to be adopted, to make decisions regarding international trade, private policies related to sustainability, to assess impacts of agricultural and environmental policies on the Brazilian agri-business, among others.

For the public sector, the results of long-range projections serve for formulating agricultural policies related to infrastructure (particularly logistics), investments in regional rural education, in research and technology (making it possible to simulate various technological scenarios), to the environmental impact of agricultural expansion, to climate changes, to agricultural credit, to environmental legislation, to food safety, to regional incentives to agricultural development, to international negotiations, and to sustainability, among others.

Finally, as the model presents area allocation results in six different regions, each of them predominantly located in one bioma, it is possible to determine the kind of natural vegetation converted into agriculture. This means that the model is capable of projecting which type of native vegetation will be converted, in case an increase in the total area used by agriculture is forecasted. Breakdown by regions and the inclusion of pasture areas in the model are extremely important advantages in comparison to the other leading economic model projections available, and it may allow to significantly improve the consistency and accuracy of analyses on the direct and indirect effects of land use, hence, on the greenhouse gas emission calculations.

FINAL REMARKS

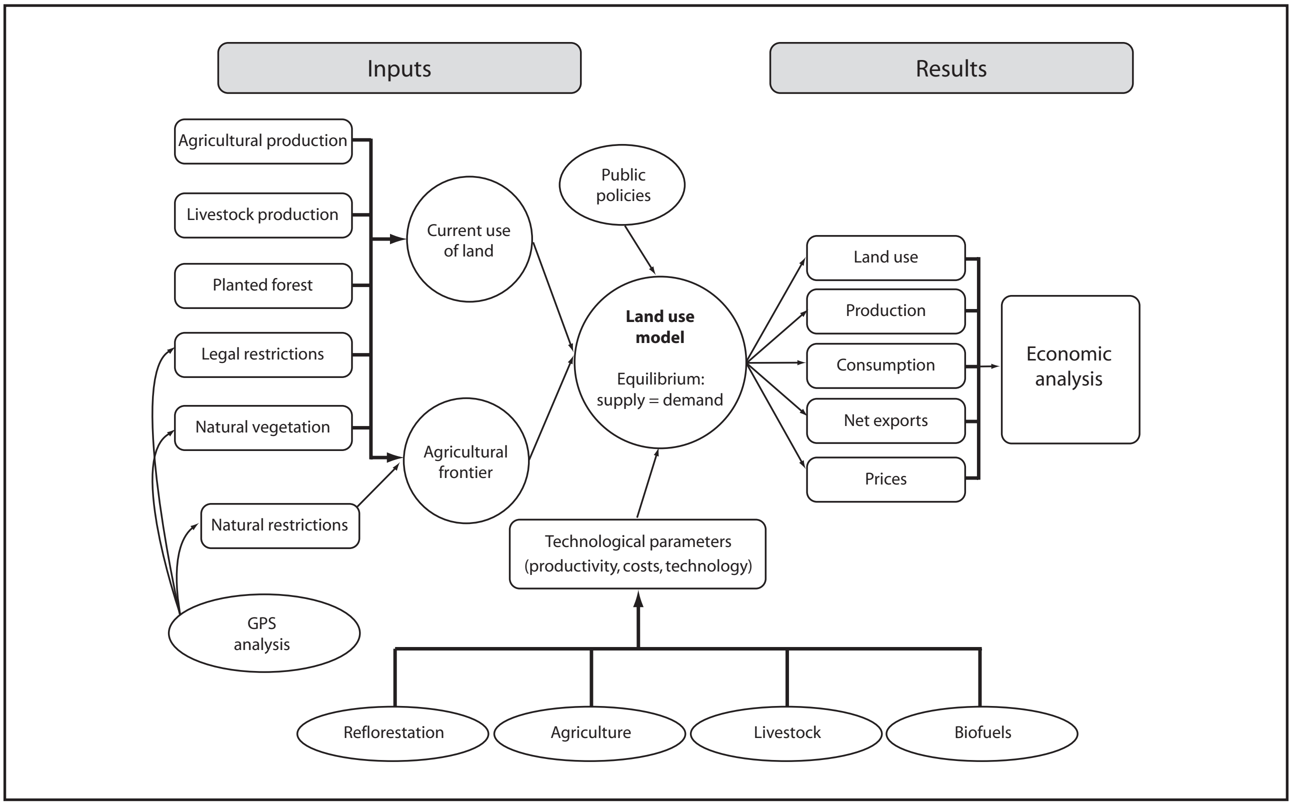
Regions in which Brazil was divided into in the BLUM

South (Paraná, Santa Catarina, and Rio Grande do Sul), Southeast (São Paulo, Rio de Janeiro, Espírito Santo and Minas Gerais), Center-West, *Cerrado* (Mato Grosso do Sul, Goiás, and part of Mato Grosso within the *Cerrado* and *Pantanal* bioma), North Amazon (part of Mato Grosso within the Amazon bioma, Amazonas, Pará, Acre, Amapá, Rondônia, and Roraima), MAPITO and Bahia (Maranhão, Piauí, Tocantins, and Bahia), Coastal Northeast (Alagoas, Ceará, Paraíba, Pernambuco, Rio Grande do Norte, and Sergipe).

Factors that may lead to a lesser use of land for bioenergy in Brazil and factors that may contribute to increased food production associated to the sugar-alcohol industry in Brazil

Study of bioethanol and animal breeding integration dynamics in Brazil

This text refers to a study carried out to explore the integration potential between sugar-alcohol, animal breeding, and agriculture industries with sugarcane field reforms. For this purpose, available technology in a mill with a certain grinding capacity per harvest is considered, with capacity for processing bagasse for producing hy-



Source: ICONE.

FIGURE 4 Methodology diagram of the Brazilian Land Use Model – BLUM.

drolyzed bagasse and animal foodstuff preparation to supplement feeding bovines in pasture areas of the mill and/or sugarcane suppliers, and for confined cattle. The study considers the production of soybean and corn in sugarcane field reform areas that normally occur 5-6 years after planting, and that represent 15% of the total area utilized for planting sugarcane. These grains are considered in producing animal foodstuff together with natural bagasse, hydrolyzed bagasse, yeast, and molasses.

At the outset, the following situation was studied: Given an area of 100,000 hectares occupied with cattle breeding (reproduction and meat), low-tech (typically 0.7 animal unit per hectare), is it possible to implement a distillery processing 2 million t/year of sugarcane, occupying 28,000 hectares of this area, and still produce, with the benefits from integration, the same quantity of meat per year. It was shown that with pasture supplementation, confinement, soybean and corn planting in reform area, without any additional external input, the response is positive.

The positive answer to the question above can be built with simple calculations on spreadsheets, involving experimental data available in the technical literature. However, another question was posed: Which methodology allows analyzing the interactions between the production of bioethanol, grain, and meats, taking into account the technology and economic change dynamics over time?

It was shown, by means of a mathematical programming model, the evolution over time of activities such as calf acquisitions, use of pastures for breeding and gaining weight, use of food supplements, use of confinement for gaining weight and selling cattle, in a way to maximize meat production. Also represented in the model were the formulation of the foodstuff for pasture supplementation and confinement using hydrolyzed bagasse, natural moist bagasse, yeast, ground soybeans from the soy planted during the reform, and corn also from the reform areas. Calf acquisition costs and cattle sales were obtained from historic series of the Brazilian domestic market.

TABLE 7 Indicators *versus* bagasse availability.

Item										
Available bagasse (%)	1%	2%	3%	4%	5%	6%	7%	8%	9%	10%
Pasture area (ha)	72,000	72,000	72,000	72,000	72,000	72,000	72,000	72,000	72,000	72,000
Confined capacity (c.g)	2,425	4,850	7,275	9,699	12,130	14,549	16,974	18,600*	18,600*	18,600*
Supplementation capacity (c.g)	3,889	7,778	11,667	15,556	19,450	23,333	27,222	31,111	35,000	38,889
Average occupancy (U.A./ha)	0.68	0.69	0.71	0.72	0.74	0.76	0.78	0.79	0.79	0.80
Annual meat production (ton)	14,444	15,450	16,537	17,929	19,325	20,714	22,089	23,104	23,104	23,115
Average meat production (kg/ha)	200.62	214.58	229.68	249.01	268.40	287.69	306.79	320.89	320.89	321.05
Average profitability (R$/ha)	123.69	129.21	134.66	140.04	145.43	150.73	155.97	159.45	159.45	159.45
Average slaughter age (months)	34.49	33.70	32.95	32.14	31.44	30.83	30.29	30.00	30.00	30.01
% Traditional handling	87.75	76.88	67.45	59.52	52.65	46.67	41.34	38.35	38.35	38.36

Key decision variables represents calf quantity acquired in month m for sale in month n, being sent for confinement in month i, if convenient (to be determined by the model), being that, on a specific month of the planning horizon (typically 120 months for a better representation of breeding dynamics), the total of pasture areas being used is less or equal to the area available for cattle breeding (72,000 hectares, in the aforementioned study). Typical animals weight gain figures are drawn from literature, for each month, in extensive breeding, in pastures with food supplementation and in confinement.

Table 7 shows the use characteristics of a 100,000 hectares area, with 28,000 hectares taken by sugarcane, remaining 72,000 hectares for

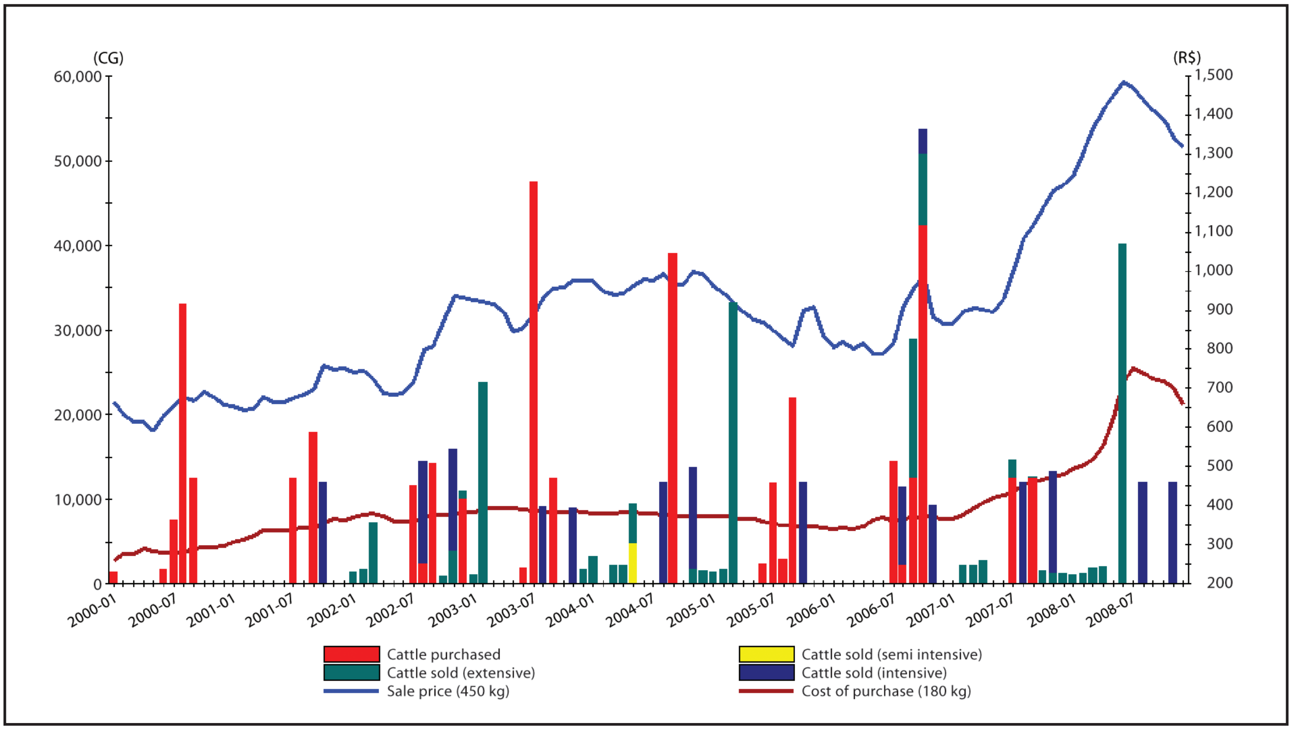


FIGURE 5 Calf purchase cost and cattle sales price dynamics, and buy/sell activities.

pastures (used for breeding and/or breeding and weight gain), with variable percentages of bagasse being made available for animal foodstuff.

In these years, the limiting factor is the availability of grains, not bagasse.

It is noticeable that production in confinement reaches the limit of 18,600 cattle heads at the level of 8% of natural bagasse available, because the limiting factor is the production of grains, as we are assuming that grains supply is solely from reform areas. This hypothesis ensures favorable conditions for life cycle analysis (LCA) and direct land-use change (LUC)/indirect land-use change (ILUC). Obviously, the study may be expanded to include the supply of other ingredients to compose animal foodstuff. Also noticeable are the gains in the meat production per year, in the average slaughter age and, consequently, in the profitability.

The methodology analysis considered a calf purchase cost and cattle sale price dynamics over a period from 2000 through 2009, shown in the Figure, where the total meat production is maximized by buying and selling at optimum quantities and times (months).

This methodology may be used in more complex situations, such as the one shown on Figure 6 which considers a sugar, ethanol, and electricity plant, enlarged to optimize its economic performance by integrating grains and cattle production activities.

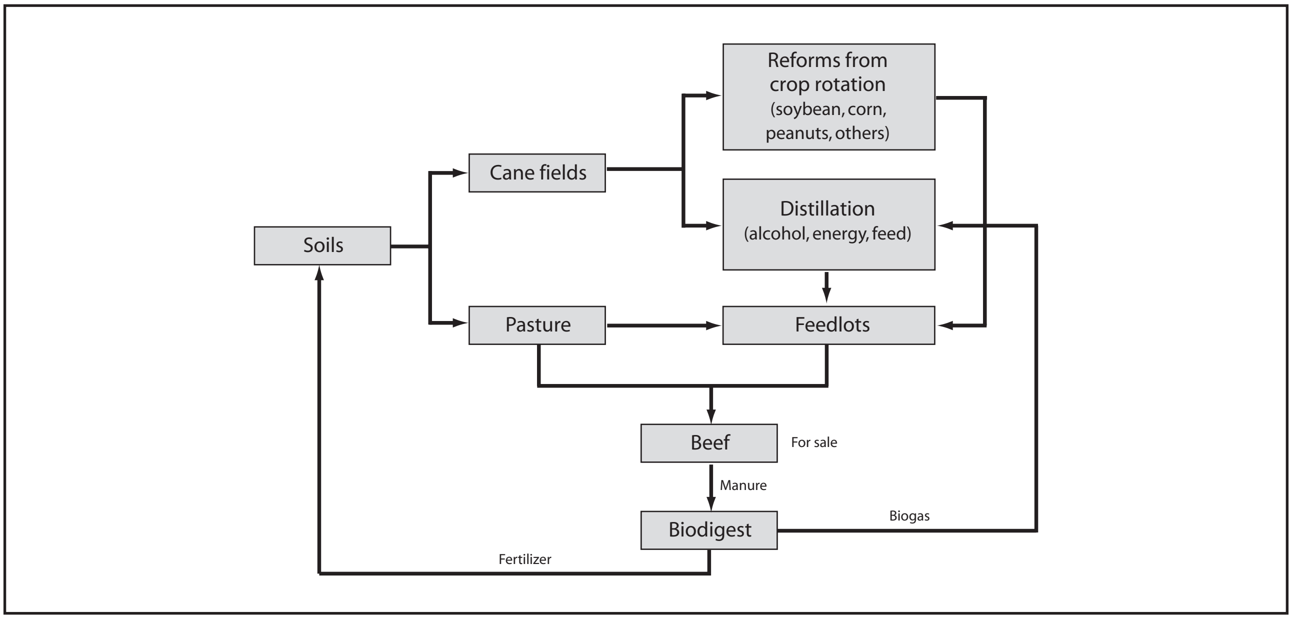
It is also possible to study the interactions between the interests of mill owners, cattle breeders, and meat packers at the level of one single plant or a cluster of them, considering logistic, technological, economic, and environmental aspects.

The mathematical model was programmed using the algebraic language AIMMS-Advanced *Integrated Multidimensional Modeling Software* which includes the CPLEX solver, thus facilitating the development of systems for Supply Chain Planning usually associated to ERP – Enterprise Resources Planning environments currently used by mid – and large-sized companies, as in several sugarcane processing mills.

Spin-offs from this project shall introduce interesting issues for the bioethanol sustainability agenda in its micro and macro aspects.

Development of second-generation technology (hydrolysis)

The average agro-industrial ethanol productivity, measured in liters per hectare per year, in Brazil was 6,000 l/ha/year, and increases slightly more than 1% per year (Table 8). It may be in-



Source: UNISOMA.

FIGURE 6 Schematics indicating the integration of sugarcane-pasture exploiting waste.

TABLE 8 Expected productivity of agro-industrial yields, considering the possible contribution from cellulosic ethanol.

	2005	2015	2025
Sugarcane productivity (tons/ha/year)	70	82	96
Pol (%) sugarcane	14.5	15.9	17.3
Industrial efficiency (%)	83.5	90.0	90.0
Liters ethanol/ha/year	6,000	8,200	10,400

Source: LEITE *et al.*, 2009.

creased by the addition of the expected productivity from second-generation technologies, such as enzymatic hydrolysis, which may – as soon as in 2015 – have commercial processes for converting cellulose, and in 2025, hemicellulose. Hypothetically, considering these contributions, the agro-industrial productivity may reach 8,200 l/ha/year in 2015 and up to 10,400 l/ha/year by 2025.

It should be noted that the impact of the contribution from second-generation technologies on land use is important and, therefore, the adopted hypothesis, in spite of being a little optimistic, fully justifies an ambitious research program that includes collection of trash, and the full exploitation of the energy resources from sugarcane.

Integration of Bioethanol Plants with Agricultural Greenhouses

The incorporation of new areas to sugarcane production will require, likewise, restructuring other agricultural production sectors in Brazil. In this sense, the sheltered cultivation of food cultures is a segment of the Brazilian agri-business that could benefit more from this tremendous challenge. Just as an example, sheltered culture, or plasticulture, in the São Paulo state occupies an area of only 1,450 ha, concentrated in three definite areas: **silviculture** (production of seedlings), **ornamental** culture where the participation of the Holambra Cooperative (São Paulo) represents over 30% of the total sector sales (R$ 1.3 billion); and a blossoming sector in **fruit culture and vegetables**. In the latter, São Paulo state holds an important share, comprising over 70% of the total fruits and vegetables production, with R$ 6.6 billion turnover.

Sheltered cultivation in Brazil still has little structure, both in technology and in marketing. The best example may be the consumption of vegetables in Brazil. The average Brazilian consumes around 40 kg per year (excluding potatoes), i.e., less than half the average of the USA or Europe, or close to one-third of the average in Asia. The lack of consistent quality and high prices, if compared to other foods, explain this low consumption and point out the high potential for this segment's growth.

Modern production technologies in agricultural greenhouses are a solution for these problems. Sheltered cultivation solves the problem of between-harvests production, offers improved quality with less agrochemicals, and its high productivity allows for competitive prices to the consumers, as well as reduced losses. In modern greenhouses it is possible to obtain productivities of 650 tons/ha of salad tomato (over 10 times the national average, including industrial tomatoes).

The inherent high investment and high operating costs are the leading factors preventing the development of such technology. To reduce these costs, the solution would be adding value to the by-products of bioethanol production. The use of the CO_2 from the fermentation vats (to increase the photosynthesis rate) and the recovery of low-temperature (35 to 65 °C) residual heat (for greenhouse heating and demoisturizing), the use of bagasse, and the use of stillage (to prepare nourishing solutions), would render the necessary investments in this segment viable.

A standard mill processing 12,000 ton/day of sugarcane with a daily production of 1 million liters/day of ethanol can provide all the heat and CO_2 necessary for producing 60 ha of hydroponic tomatoes. This greenhouse complex would produce the equivalent to 36,000 tons of tomato per year (R$ 43 million in sales at CEAGESP 2009 prices), on top of opening over 900 direct permanent jobs. In environmental terms, GHG sequestration would be around 15% of the total produced by fermentation vats. Finally, this project would stimulate the development of a new corporate image, as this integration would represent an innovative response of the sugar-alcohol industry to Brazilian agriculture, especially in the production of food and the generation of new, sustainable jobs.

Integrating land use, water use, and CO_2 emissions issues in expanding the ethanol production in Brazil

Among the themes linked to sustainability in the production of biofuels, CO_2 emissions are discussed due to direct land use change (LUC) and indirect land use change (ILUC), use of agricultural water (Hydrologic flows), as these are themes that have a strong impact on the biofuels production viability analysis.

For instance: taking the case of a basin in the Center-West region, sufficiently large to encompass several mills (cluster) and a large sugarcane field, we could consider the following:

- on CO_2 emissions: assuming that sugarcane will expand over degraded pastures, a widely accepted hypothesis nowadays, changing the soil use from degraded pasture to sugarcane will incorporate C in the soil, in this case, improving the emissions balance due to LUC.

Carbon stock in soil dynamics is a very complex subject for involving a large number of variables, such as: soil use history, type of soil, current agricultural handling, local climate, and others. Macedo and Seabra (2008) present the Brazilian situation in terms of sugarcane expansion to produce ethanol, reminding that from 1985 through 2002, there was no sugarcane expansion for ethanol, since the production of this biofuel remained practically constant throughout this period. Nassar *et al.* (2008), MAPA and CONAB studied the sugarcane expansion in recent years, based on satellite images, field researches, and EIA/RIMA studies of new production plants, showed that the expansion (Macedo and Seabra, 2008) of sugarcane took place over areas with established cultures (mostly soybean and corn) and pastures, and that areas covered with (natural or planted) trees represented less than 1.5% of the lands used. In pastures, occupation by sugarcane occurred mostly in degraded or low-productivity areas (abuse by stampede, no fertilization).

A literature study by Amaral *et al.* (2008) allowed a preliminary assessment of carbon stock in the most common types of soil in the new sugarcane areas, both in the soil as well as above it. Tables 9 and 10 present these figures for clayous soils with high and low activity (HAC and LAC, respectively), and the IPCC default values.

These figures are preliminary, and many experimental measurements must be taken in a more controlled and systematic way to offer additional reliability. However, they are much more adequate to represent the sugarcane culture expansion in the recent past, and probably within the next few years, than those used by various authors (e.g. Searchinger *et al.*, 2008, and Fargione *et al.*, 2008).

An estimate of GHG emissions by the change of land use was made by Macedo and Seabra (2008), considering that at least 70% of the pastures replaced by sugarcane fields were natural (not planted), and having various levels of degradation, that the sugarcane will be harvested unburned, and various alternative cultures, is shown on Table 11. The situation in 2006 (partial burned sugarcane) and 2020 (unburned sugarcane and collecting 40% of trash to general surplus electric power, supplementing bagasse) are also shown to indicate the expected trends.

From Table 11, within the hypotheses considered, sugarcane expansion in the new frontier is causing, and will continue to cause, a net gain in carbon stocks in the soils involved.

However, this demand for lands for bioenergy has raised considerable debate worldwide, also fueled by relatively new concepts such as direct land use change, and more recently by ILUC. While methodologies for estimating LUCs have demonstrated a reasonable reliability level, determining ILUCs with minimum reliability remains a challenge. The mathematical models used in ILUC studies show a series of limitations and inconsistencies, presented in detail in ORNL, 2009.

TABLE 9 Stock figures in the soil for different cultures (tC/ha).

Culture	Default IPCC		Experimental		Selected values
	LAC	HAC	HAC	Other	
Degraded pasture	33	46	41	16	41
Natural pasture	46	63	56	–	56
Cultivated pasture	55	76	52	24	52
Soybean	31	42	53		53
Corn	31	42	40		40
Cotton	23	31	38		38
Cerrado	47	65	46		46
Open field	47	65	72		72
Cerradão	47	65	53		53
Burned sugarcane	23	31	35-37	35	36
Unburned sugarcane	60	83	44-59		51

Source: MACEDO and SEABRA, 2008.

TABLE 10 Soil carbon stock figures above ground (tC/ha).

Degraded pasture	1.3
Cultivated pasture	6.5
Soybean	1.8
Corn	3.9
Cotton	2.2
Strictly cerrado	25.5
Open field	8.4
Cerradão	33.5
Unburned sugarcane	17.8

Source: MACEDO and SEABRA, 2008.

- On a second hypothesis, admitting that there was no "domino effect", whereby the pasture occupied with sugarcane would move elsewhere (ILUC), but that this occupation of the pasture by sugarcane would be absorbed by the activity itself, since the use of 25 Mha of pasture by sugarcane would simply increase density from 0.7 UA/ha to 0.8-0.9 UA/ha, making the average distance between cattle heads in Brazil drop from 100 m to something like 97 m. Another possibility would be higher integration of pasture with sugarcane, freeing a significant area of land, maybe half (100 Mha) of it. Estimating biofuels need around 30 Mha, some 70 Mha would be made available for other uses. In other words, even the Amazon and other environmental sanctuaries could be recomposed, in this case making a reverse ILUC, i.e., instead of the ILUC causing a supposed increase in emissions, with the pasture-sugarcane integration, there would be a likely increase of the C stock, thus considerably improving the emissions balance, making it less negative.
- In this same hydrographic basin, previously occupied by degraded pastures and having an equally degraded hydric balance (it is important to keep in mind that the hydrologic damage was done by deforestation, over a century ago), there would also be, with the introduction of sugarcane, an increase in the level of underground water, reduced soil erosion, and a more regular river flow.

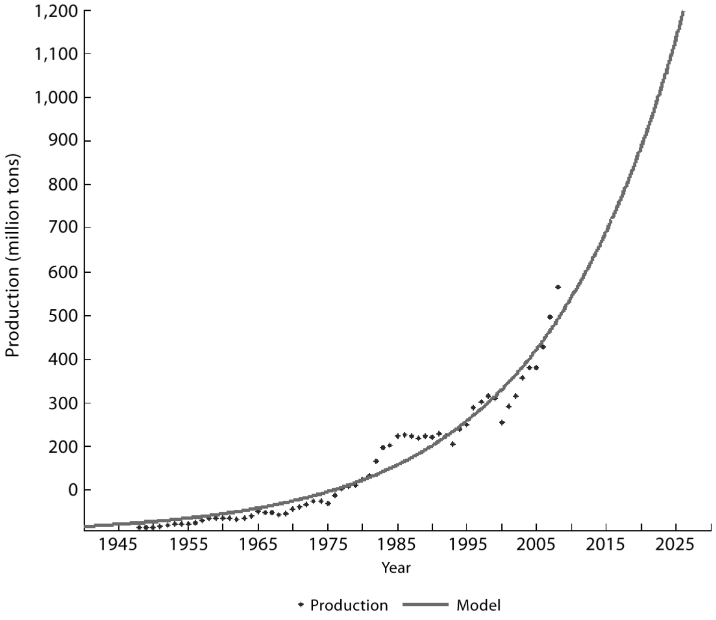
TABLE 11 GHG emissions due to the replacement of various cultures with unburned sugarcane.

Replaced Culture	Change in carbon stock	Emissions (kg CO_2eq./m³)	
		2006	2020
Degraded pasture	10	-302	-259
Natural pasture	-5	157	134
Cultivated pasture	-1	29	25
Soybean	-2	61	52
Corn	11	-317	-272
Cotton	13	-384	-329
Cerrado	-21	601	515
Open field	-29	859	737
Cerradão	-36	1,040	891
GHG emissions due to LUC		-118	-109

Source: MACEDO and SEABRA, 2008.

FINAL CONSIDERATIONS

Among other positive socio-economic impacts, ethanol production in Brazil, and the outlook of its expressive expansion in the next few years, also posed the need for rural and agricultural zoning, which at the same time preserved environmental sanctuaries (Amazon, Pantanal, Atlantic Forest among others), and protected indigenous reservations as well as food production in the country.



Source: MAPA, 2009.

FIGURE 7 Projected sugarcane production growth in Brazil, up to 2025.

The rapid growth of the sugarcane culture in Brazil (see Figure 7), motivated by both the international demand for sugar/ethanol and the domestic demand for ethanol has been nurturing this industry, which is undergoing change at both technological and corporate levels. It may be said that these good times may last for some decades yet, in view of the considerable international interest in really sustainable biofuels, the possible future domestic demand for bioelectricity, and also the growing demand for green plastics. Even under a significant increase in the agro-industrial activity, that may reach some 11,000 liters/ha/year, the demand for new areas for sugarcane in Brazil should take place almost wholly in pasture areas; hence, the urgent need to know thoroughly the situation of areas taken by pastures in Brazil.

Therefore, it may be said that this significant expansion of sugarcane, with the correspondent use of land, will lead the country not only to improve the sustainability indicators related to the sugar-alcohol industry, but also to other agricultural activities, mostly cattle breeding for meat, a large user of lands in Brazil, still having productivity indicators far below what is expected.

Thus, sugarcane expansion may actually be a milestone in land use in Brazil, considering the high likelihood for further expansion, its good productivity and sustainability indicators, as well as the perception of both Brazilian and international society that biofuels production should follow much stricter criteria than those currently used by the food industry.

REFERENCES

CGEE, 2009, **Bioetanol combustível:** uma oportunidade para o Brasil, Relatório preparado pelo Nipe/Unicamp para o CGEE, Coordenado por Rogério Cerqueira Leite.

CORTEZ, L. A. B. (Coord.). Projeto Nipe/Unicamp-CGEE. **Sustentabilidade Fases 1 e 2**. Relatório Final. Campinas, SP 2009 e 2010.

DOORNBOSCH, R.; STEENBLIK, R. **Biofuels:** is the cure worse than the disease?, Report to OECD SG/SD/RT(2007)3, Paris, Setembro de 2007, 57p.

FAO 2008 – Food and Agriculture Organization – **The State of the Food and Agriculture 2008:** Biofuels, prospects, risks and opportunities.

GOLDEMBERG, J. Etanol for sustainable energy future, **Science** 315, p. 808-810, 2007.

GOUVELLO, C. de. **Potential Mitigation of GHG Emissions in Brazil**. The World Bank. Presented at COP15. Available at: <http://siteresources.worldbank.org/EXTCC/Resources/LCG_Brazil.pdf>, 2009.

IEF. **Assessment of Biofuels Potential and Limitations**. International Energy Forum Report by Claude Mandil and Adnan Shihab-Eldin. Feb 2010.

LEITE, R. C. C.; LEAL, M. R. L.V.; CORTEZ, L. A. B.; GRIFFIN, W. M.; SCANDIFFIO, M. I. G. **Can Brazil Replace 5% of the 2025 Gasoline World Demand with Ethanol?** Energy vol 34/5 (655-661) 2009, 7p.

MACEDO, I. C.; SEABRA, J. E. A. Mitigation of GHG emissions using sugarcane bioetanol. Em: P.Zuurbier and J. van de Vooren (editores) Sugarcane Ethanol, Wageningen Academic Publishers, Wageningen, The Nederlands, p.95-111, 2008.

NASSAR, A. M.; RUDORFF, L. B.; ANTONIAZZI, L. B.; AGUIAR, D. A.; BACCHI, M. R. P.; ADAMI, M. Prospects of sugarcane expansion in Brazil: impacts on direct and indirect land use changes. In: ZUURBIER, P.; Van de VOOREN, J. (Eds.), **Sugarcane Ethanol**, Wageningen Academic Publishers, Wageningen, The Nederlands, p. 63-93, 2008.

MAPA – Ministério da Agricultura, Pecuária e Abastecimento. Zoneamento Agroecológico da Cana-de-Açúcar, 2009

ORNL – Oak Ridge National Laboratory, Workshop on Land Use Change, May 11-14, 2009, 64 p., 2009.

REN21 – Renewable Energy Policy Network for the 21st Century. Available at: <http://www.ren21.net/>.

SEXTON, S.; RAJAGOPAL, D.; HOCHMAN, G.; ZILBERMAN, D.; ROLAND-HOLST, D. Biofuel policy must evaluate environmental, food security and energy goals to maximize net benefits. **California Agriculture** 63(4):191-198. DOI: 10.3733/ca.v063n04p191. October-December 2009.