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Sugarcane ethanol production in Brazil: an expansion model sensitive to socioeconomic and environmental concerns

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Abstract: Brazilian agriculture is characteristically dynamic; land and production resources have a skewed ownership distribution; and agricultural production is essential for small holders of rural poor regions. Also, the main agricultural land use is composed of pastures where extensive livestock production prevails. Because of increasing demand Brazil is expected to expand its sugarcane-based ethanol production. Addressing concerns about social and environmental impacts of such an expansion requires careful consideration of the complexity of Brazilian agriculture in general and specific local conditions in particular. This perspective outlines an expansion model for sugarcane ethanol production that is sensitive to socioeconomic and environmental concerns. Through integration with the prevailing land use, the model avoids the usual displacement of extensive livestock production to remote regions, causing leakage effects with deforestation and promotes milk and beef cattle intensification and investment opportunities for local society. The expansion model is feasible at current market conditions and should have good prospects for complying with sustainability criteria within various certification schemes presently under development. A case study, developed in the Pontal do Paranapanema region (state of São Paulo, Brazil) illustrates the model in agrarian reform settlements. © 2007 Society of Chemical Industry and John Wiley & Sons, Ltd

Keywords: Brazil; sugarcane; ethanol; environment; social

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Introduction

Brazil is the worlds' largest producer of sugarcane-based ethanol and is expected to expand its production due to a growing internal market and increasing import demand in the EU, USA, Japan and other regions. This can lead to both expansion of total cropland and intensification in traditional production areas by higher yields and changes in crop production patterns. Conservative estimates suggest that the area for sugarcane production in Brazil could double from 5.7 to 11 million hectares in the next ten years.[1] The Brazilian Federal Government hasn't yet defined a specific policy for this imminent expansion scenario. Legislation – for example, environmental, labor relations, expansion zones – and policy applicable to the currently cultivated regions are still the same as for new areas. Some minor initiatives at municipal and federal state level are on course, usually restricting the area allowed for sugarcane cultivation or suggesting additional environmental regulations, but with minor impact on social issues and with narrow comprehensiveness.

Considering that ethanol use for transport is motivated by, among other things, the desire to reduce emissions of greenhouse gases (GHGs) it is important to investigate whether the common understanding – that use of Brazilian ethanol for transport (in Brazil or importing nations) leads to substantial reductions in GHGs – holds also in the context of a substantially expanding sugarcane ethanol production. Besides the climate benefits, additional environmental and socioeconomic effects of expanding sugarcane ethanol production need to be assessed.

This perspective provides a background to the case of Brazilian ethanol by describing Brazilian agriculture in general and sugarcane ethanol production in particular. It also outlines an expansion model for sugarcane ethanol production that addresses socioeconomic and environmental – especially climate – concerns. The model integrates the sugarcane ethanol production with the existing local agriculture and stimulates productivity increases in livestock production. One thesis is that the expansion model can reduce the displacement of livestock production and thus the risk of indirect CO_2 emissions from off-site deforestation caused by new establishment of extensive cattle production in remote regions.

Agriculture in Brazil and prospects for sugarcane expansion

Recent trends in land use

Agricultural land-use change is still a dynamic process in Brazil. It occurs mainly in frontier regions, where cultivated pastures and to some extent cropland, for example, soybean, expand over rangeland, savannas or forests. (Cardille and Foley evaluated land-use changes in Brazilian Amazon between 1980 and 1995 using satellite and census data.[2] Over this period, they identified an increase of 15×10^6 ha of planted pasture and only 0.8×10^6 ha of cropland increase. Also, natural pastures, mainly composed of open savannas used as rangeland, decreased to 8×10^6 ha. In 1995, of the 25×10^6 ha deforested between 1980 and 1995, 7% was used as cropland, 54% as pasture and in 36% the forest was regrowing.)

Several factors combine in a complex and spatially dependent way to induce profound and diverse land-use changes in these regions according to specific climatic, soil and natural resources conditions as well as market, social and cultural factors. (The dynamic in Brazilian frontier areas has several underlying reasons. Caldas *et al.* pointed out demographic characteristics of households, market factors, and different motivations as to why poor families decide to settle in remote frontier areas.[3] Chomitz and Thomas suggested multivariate econometric procedures that considered climatic conditions as drivers for land-use changes and deforestation in the legal Amazon region, concluding that deforestation led overwhelming to the creation of extensive low-productive pasture concentrated in large holdings.[4]) Also, the more developed and intensively cultivated agricultural regions are dynamic but rather than expanding, the agricultural land uses change according to market conditions.

Figure 1 shows recent land-use changes in Brazil and Table 1 presents the latest available land uses. (The sources for this data are annual surveys made by IBGE (National Institute for Geography and Statistics), the Government agency responsible for national census surveys. The area of agricultural production (crops) is updated by opinion surveys every year, but the area covered by pastures and rangeland (natural pasture) is not. For these, the latest reliable information is the National Agricultural Census of 1995/96.[5] In the year 2006/07 a new National Agricultural Census is being

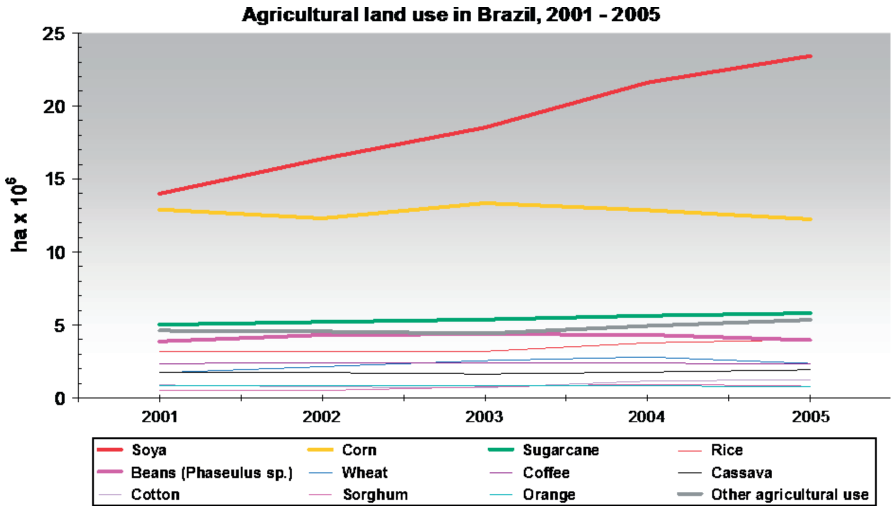

Figure 1. Recent crop dynamic in Brazil.

conducted, but data collection is still running and no results are currently available. The 2006/07 Census will improve the quality of the opinion-based data and allow an update on pastures distribution, thus potentially changing the values of Table 1 significantly.)

Table 1. Latest available data of agricultural land use in Brazil.

Land Use	Area	Part of Ag. Use	Part of Territory
	ha 10^6	%	%
Cultivated pasture[a]	99.7	41.2	11.7
Rangeland[a]	78.0	32.2	9.2
Soya[b]	23.4	9.7	2.8
Corn[b]	12.2	5.1	1.4
Sugarcane[b]	5.8	2.4	0.7
Rice[b]	4.0	1.7	0.5
Beans (*Phaseulus sp.*)[b]	4.0	1.6	0.5
Wheat[b]	2.4	1.0	0.3
Coffee[b]	2.3	1.0	0.3
Cassava[b]	1.9	0.8	0.2
Cotton[b]	1.3	0.5	0.1
Sorghum[b]	0.8	0.3	0.1
Orange[b]	0.8	0.3	0.1
Other Agricultural use[b]	5.4	2.2	0.6
Total	242	100	28.5

[a] Source: 1995/96 Census of Agriculture (IBGE, 1998).

[b] Source: Municipal agriculture production (IBGE, 2005).

Pastures occupy large extensions in Brazil, when compared to any other land use. Most of these pastures sustain extensive and low-productive beef cattle production. The cattle economy and the interaction between cattle production and other land uses are essential determinants of the land-use dynamic in Brazil. (Walker *et al.* explained deforestation in the Amazon region based on specific beef cattle conditions of large-scale and small farmers; they observed different intensities and driving forces towards deforestation according to each group.[6] They conclude that any forest-conservation initiative must consider and address the specific underpinnings of the cattle economy). A sugarcane expansion model that aims to address land-use-related social, economic, and ecological effects therefore needs to consider how the new sugarcane fields interact with the major agricultural land use in Brazil: cultivated and natural pastures. These interactions may involve displacement, competition, coexistence or integration, or a combination thereof. In each case, the environmental, social and economic effects will differ.

Actors in Brazilian agriculture

Land concentration started in Brazil during the Portuguese colonization, aiming to deny access to land by non-elite members of the white poor. Since then, Brazil has had one of the most skewed land ownership structures in the world, which has prevailed during independence (1822), the end of slavery (1888), the inauguration of the republic (1889),

Table 2. Family and industrial agriculture profile in Brazil.

	Unit	Family	Industrial	Ratio (larger/smaller)
Farms[a]	#	4,291,300	568,564	7.5
Area[a]	10^6 ha	110	244	2.2
Part of territory[a]	%	12.9	28.7	total = 41.6
Area per farm[a]	ha	26	429	16.8
Production value[a]	10^9 R$	18	29	1.6
Productivity[a]	R$ ha^{-1}	168	121	1.4
GDP (ag. production)[b]	%	3.6	5.7	1.6
GDP (agribusiness)[b]	%	10.1	20.5	2.0

[a] Source: 1995/96 Census of Agriculture (IBGE, 1998).

[b] Source: Guilhoto *et al*., 2005.

democratization (1945), the military coup and regime (1964–1985), and finally the restoration of democratic principles under a neoliberal and globalized logic (1986–present). Also, in the period after World War II, Brazil developed from a rural-based economy to an industrialized nation. The consequent urbanization and strong migration from remote rural areas to the industrialized centers was also reflected in agricultural production: a productive industrial agricultural sector was established as large land holders adopted mechanization and modern green-revolution supplies – for example, machines, fertilizers, pesticides and improved genetic material. Because of this history in rural development, industrial and family agriculture coexist in Brazil under different arrangements – competitive, exclusive, integrated – and technological levels.[7]

Both family- and industrial-based agriculture forms a continuum, ranging from extensive and low-productive to highly technological and productive, reflecting regional natural resources, economic conditions and cultural values. Table 2 provides a brief account of family and industrial agriculture sector profiles and Figure 2 shows the spatial distribution of production value ratio – production value of family agriculture divided by production value of industrial agriculture. Despite the fact that family agriculture takes place on 7.5 times more farms than industrial agriculture, the latter occupies 2.2 times more land. However, family

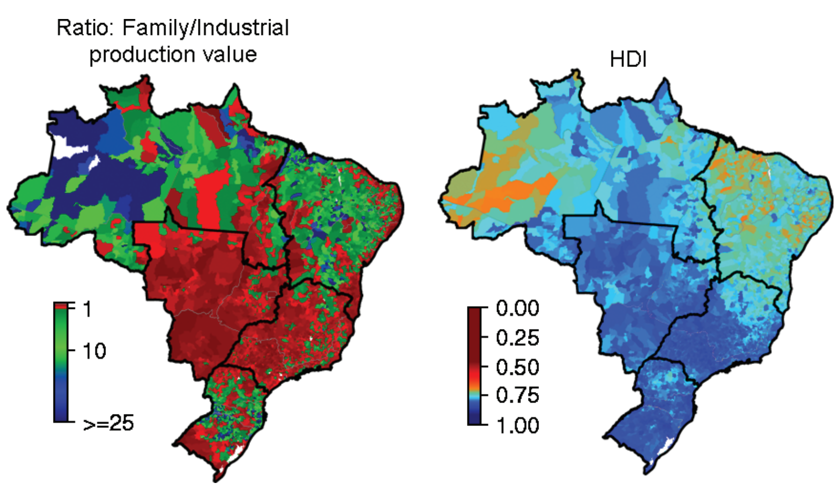

Figure 2. Family and industrial agriculture distribution and Human Development Index (HDI).

agriculture is more land-use efficient and both production value and GDP contribution are more equally shared than the skewed land distribution. Also, the spatial distribution (Fig. 2) shows a predominance of family agriculture production value in the less developed Brazilian regions, mainly noticeable in the North-East and North regions.

Any analysis or development strategy for Brazilian agriculture has to consider the diversity in social function, range of actors, labor use, spatial distribution, production strategy, intensity and productivity, and the historical origin of land concentration – especially if externalities and social aspects are in focus – since they both influence the access to production resources and conditions, and also the social relevance of agricultural production in itself.

Spatial distribution and organization of agriculture

Sugarcane production in Brazil is located in four separated regions. Most production comes from the South-East state of São Paulo and neighboring areas. Other two traditional regions are the North-East costal areas (*Zona da Mata*) and Campos (close to Rio de Janeiro). More recently, sugarcane has been expanding into the fourth region in the Central-West (the Brazilian *cerrados* or savannahs).

The major land uses surrounding these regions are cultivated pastures, which are composed of cleared (deforested) land that has been planted with exogenous grass species after soil tillage. Rangeland, or natural pastures, composed of open natural vegetation – for example, open savannahs, semi-arid vegetation or *caatinga* – may also to some extent surround the sugarcane growing areas. These two land uses together comprise the major agricultural land use in Brazil, with the exception of the North region where forests prevail (Fig. 3).

Pastures and crop production are spatially not coincident in more developed regions. Livestock production – especially beef cattle – is traditionally an extensive low-input activity, using minor labor. It is characterized by low productivity, income and profit. This combination makes it suitable for and adapted to remote areas, because of the limited infrastructure requirements – electricity, paved roads, specialized labor, machines. The need of large land areas (*latifundia*) and low profit per area makes it viable only where land prices are low. As a consequence, when infrastructure improves and more intensive land uses start to predominate – for example, grain crops, sugarcane, and orange trees – the extensive beef cattle production is displaced. Figure 4 shows an example for the case of the state of São Paulo, evidencing a mirror picture between extensive livestock production and other more intensive agricultural land use – in the case of São Paulo predominately sugarcane. The increase in land prices attracts cattle ranchers to sell or rent out their land and move to remote areas where the conditions for extensive production are more favorable. Migration will predominantly be to the border of the Amazon or regions in the Central-West *cerrados* where the infrastructure is less developed; such displacement will likely lead to deforestation and ecosystem degradation.

Prospects for and expected impacts of conventional sugarcane ethanol expansion

Due to high logistic costs, sugarcane cannot be transported over long distances for processing; sugarcane needs to be produced close to an ethanol production facility – <100 km. Sugarcane-based ethanol production, therefore, takes place in regions having a dense paved-road network, a supply market for industrial needs (for example, machines, services, labor), and if possible, high electricity demand to allow co-generation using surplus bagasse. Also, climatic, topographic and soil conditions have to be favorable, allowing sugarcane cultivation without supplementary water irrigation, and a well-defined dry season is needed to permit maturation and sugar concentration. (Moreira and Goldemberg detail the rationale for launching the national Ethanol Program (Pro-álcool) in the mid-1970s, and the development, under government subvention, until the 1990s.[9] The increased productivity gains, cost reductions, and large-scale production made the use of ethanol as a biofuel feasible under market (or near-to-market) conditions. Von Lampe suggests that Brazil is the only country that would be able to produce ethanol economically even if crude oil prices fell to $39 per barrel.[10] Thus, from the 1990s to the present, government support and regulation was reduced, and market orientation drove the sector's development under the new organization experienced by Brazilian society after 1995 with the end of the military regimes. Bressan describes the macroeconomic characteristics of this period for the development of sugar and ethanol industries in Brazil.[11])

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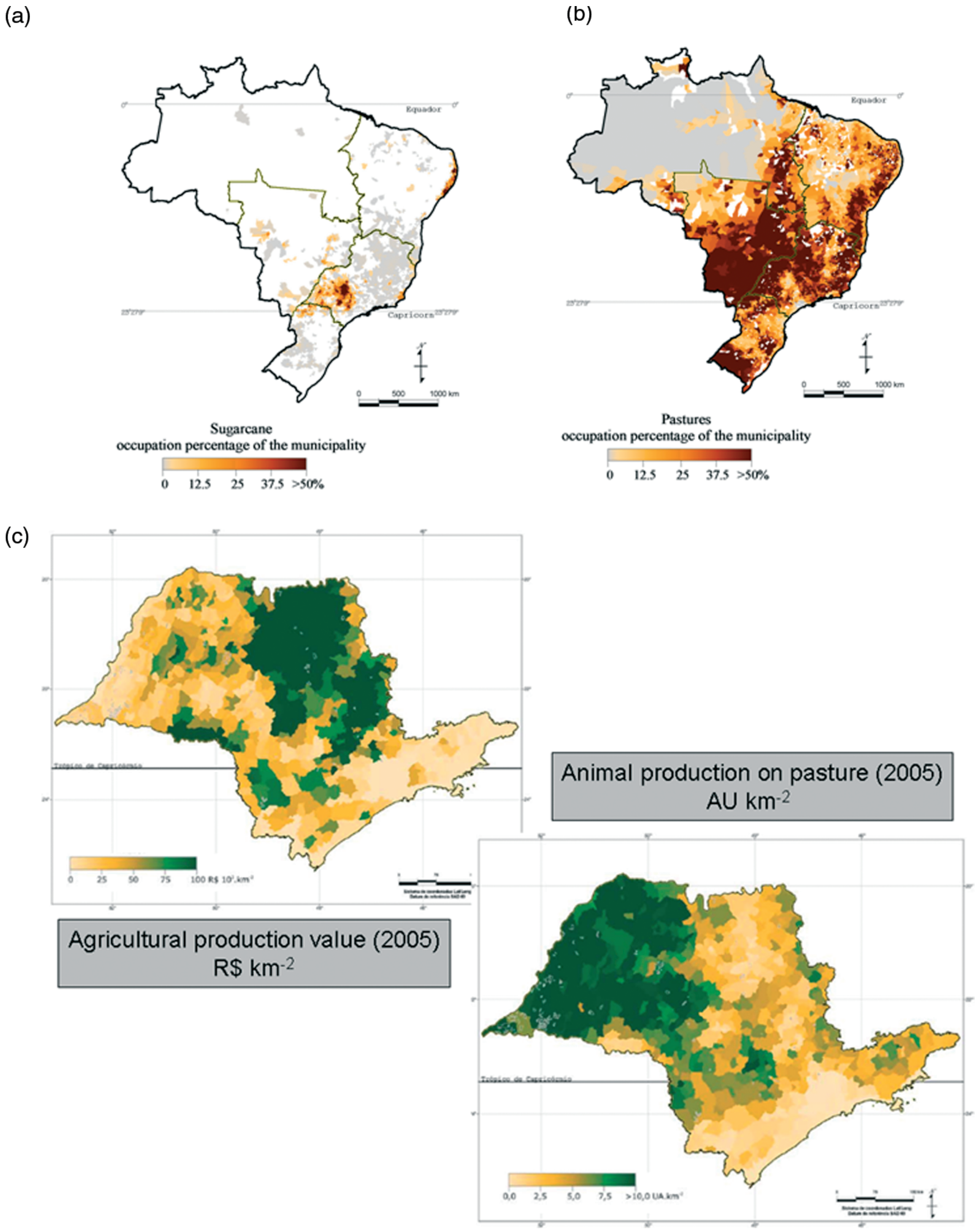

Figure 3. a) Sugarcane distribution in Brazil (percentage of the municipal area); b) pasture distribution in Brazil (percentage of the municipal area); c) Livestock and agricultural (annual and permanent crops) production in the state of São Paulo.

Because of these conditions, suitable areas for sugarcane expansion are limited and the most probable scenario is expansion along the existing frontiers in traditionally producing regions. Expansion in the North-East and Campos regions is less likely due to climate and soil restricting conditions. In these regions the most favorable areas are already cultivated with sugarcane. In the main production region (the state of São Paulo and surroundings), and in the new *cerrados* Central-West region, expansion is more likely to take place. In these two regions, pastures with extensive livestock production still surround the existing sugarcane fields and climate or soil conditions appear not to be limiting. Long-term performance of sugarcane varieties is not known and the adjustment of agronomic technology is not complete in the Central-West region, thus increasing the risks for investments. Also, the dryer climate may restrict rain-feed production in this region and thus lead to increasing costs or environmental impacts due to the need for water irrigation.

In any case, the more likely expansion in the state of São Paulo and especially in Central-West will occur predominantly in areas currently occupied by extensive pastures: i) such areas are largely available in these regions; ii) land prices or rent payments are low; and iii) cattle ranchers find it economically rational to sell or rent out their land to increase income. Thus, livestock production can be expected to decrease or be displaced to local marginal areas, and also the land-market dynamic will increase and concentrate: small properties will merge into larger and more feasible units for large-scale sugarcane production. Local environmental effects can be expected – due to higher rates of pesticide and chemical fertilizer use, industrial residue disposal in soils (for example, vinasse, filter cake), and increasing soil tillage with consequent increases in erosion and physical soil degradation – and also indirect impacts (described earlier) related to the displacement of extensive cattle farming to remote regions.

Without regulation or interference, the changes will occur based on market logic and previous experience in expanding regions. Sugarcane will monopolize land use and economic activities as a result of local industrialization; although regulation or certification procedures may alleviate impacts and better sustain expansion. The interference in the above-described scenario should aim at a less aggressive and more integrated expansion. Coexistence instead of hegemony (sugarcane monoculture), integration instead of displacement, welfare return for affected communities, and reduction of local and off-site environmental impacts should drive intervention.

Social aspects of ethanol production: a comparison with biodiesel production

After a short subvention period in the beginning of the 1970s (Pro-álcool project), sugarcane production – mainly ethanol, sugar and co-generation – developed under market (or close-to-market) conditions. Besides taxes and a government-defined mixture rate of anhydrous ethanol in gasoline, no major market regulation is currently present.

In the case of biodiesel, the Brazilian Government created the National Program for Production and Consumption of Biodiesel (PNPB) in December 2004. PNPB provides a market for stimulating the inclusion of family farmers, aiming at social benefits and increasing income based on oilseed crops. PNPB defines an increasing amount of biodiesel mixture in petrol-based diesel. (Law # 11,097/05 January 13, 2005 rules the introduction of biodiesel in the Brazilian energy matrix. Starting January 2008, a mixture of 2% of biodiesel in petrol-based diesel is obligatory over the entire Brazilian territory. In January 2013, the percentage increases to 5%. A resolution (National Council of Energy Police) issued September 3, 2005 anticipated this percentage (5%) to January 2006 for production units that aim for the 'Social Fuel' certificate.) Several other governmental support actions (for example, fiscal incentives by reduced taxation) stimulated oilseed corps (for example, palm-oil *Elaeis guineensis* Jacq, castorbean *Ricinus communis* L.) adapted to low-quality land and family agriculture. Also, a 'Social-Fuel' certificate, issued by the Government, insures a specific share of family agriculture production for biodiesel, with greater amounts in the rural poor Brazilian North-East region, and offers credit for production units that blend diesel with prime matter from family farms. The certified companies may also use the Social-Fuel seal for advertising.

With PNPB, elements of social responsibility were incorporated into contracts between farmers and the industrial sector. Rural workers' unions represent family farmers, and the industries supply technical assistance that allows the small farmer to produce according to the industrial needs. The Federal Government catalyzes the institutional arrangements between family farm associations and industries, and provides subsidized production credits (*Pronaf biodiesel*).

These mechanisms do not guarantee that, in the future, one single crop, for example soybean, produced in the more developed regions in large industrial farms will supply the volumes needed to achieve the legislation targets. Although, the large geographic dispersion over which the new industrial production units are operating is a primary indication that the arrangements around biodiesel production in Brazil are achieving its goals.

The PNPB poverty alleviation approach of targeting and promoting family agriculture and rural poor regions, at least in part, makes sense and is theoretically feasible. Logistic issues for oilseed plant products are not so restricting – long-distance transport is possible – and the industrial facilities may be smaller and are not so complex. Also, a large variety of crops adapted to low-quality soils and restricting climates is available under known agronomic technology. PNPB has a real social component created by regulations, an institutional local market, and the Government provides specific credits for family agriculture in rural poor regions.

The same policy cannot be adopted for sugarcane-based ethanol production. Logistic costs tend to transform the surroundings of industrial facilities into intensive monocultures, and favor the formation of industrial clusters. A suitable region with favorable soils, topography and climate, provided with adequate supply market and infrastructure, will attract several investors. Remote areas are not attractive for expansion.

Considering that sugarcane expansion is expected to occur over extensive pastures, the prospects for integration with the prevailing land use is a key determinant of resulting expansion pattern and impacts. It is desirable that such integration leads to: i) local development, ii) no (or minimal) land-use displacement, and iii) unaffected land tenure: the land property structure is kept intact by avoiding small holders selling land for the establishment of larger producing units.

The expansion model: integration of sugarcane with prevailing land use

How is integration feasible?

The ideal integration will provide enough area around the industrial plant for intensive sugarcane cropping, while stimulating the traditional land use at the surroundings of the plant and even regionally. Sugarcane can, to some extent, be integrated with other agricultural land uses. However, it is a semi-perennial crop, standing in the fields for five to seven years. During renewal (on typically 20% of the cultivated area) the fields are idle only for a short period of three to four months, usually at the beginning of the rainy season because most sugarcane is planted at the end of the rainy season. Thus, only short-season crops such as peanuts, soybean and green manure are suitable: extensive livestock production cannot exploit this integration opportunity.

Integration of sugarcane ethanol production with livestock production can instead be based on opportunities to produce animal feed at the ethanol plant: minor adaptations of an industrial plant designed for sugarcane processing for sugar and ethanol – using proven, commercially available technology – makes it possible to produce animal feed based on steam cooked (hydrolyzed) bagasse pulp.

Factory bagasse contains about 45% cellulose, 35% hemicellulose and 10% lignin. This raw material has a very low digestibility (about 30%). However, improvements can be brought about by high-pressure steam (18 kg/cm^2, 250°C) which, through acid hydrolysis, solubilizes the hemicellulose component increasing digestibility to 65%. In Brazil, rations based on steam-hydrolyzed bagasse are produced for beef cattle production in several industrial plants. Until 1995, 120 plants were equipped with such facilities. This number is currently reduced to about 30 due to the emergence of other similarly profitable uses of the surplus bagasse; for example, co-generation of electricity. However, the technology is fully developed and the equipment for hydrolysis and ration production is commercially available; thus it is feasible for large-scale implementation in the short term. (Peterson describes several alternatives for animal feeding in tropical regions, referring to Basile and Machado for steam-treated sugarcane bagasse; both are from the University of São Paulo, where the concept was first developed experimentally in Brazil.[12, 13, 14] Steam-treated bagasse specifically for beef cattle finishing is also described by Osorio *et al.*[15]) The complete ration based on bagasse utilizes other sugarcane residues – molasse, filter-cake, vinasse, yeast, and factory bagasse – and grains and vitamins. This complete ration has a very low production cost when compared to other feeding options, but cannot be stored for long periods – except as silage – because of high water content. Currently, with few exceptions, the ration facilities are used to produce free-stall confined beef cattle for the sugarcane industries, and not for other local producers.

The integration of the industrial plant as a main source of animal feed may benefit not only the areas where sugarcane fields will expand, by allowing its coexistence with livestock production (beef cattle, milk, sheep, pork, or horses), but also spread out over a larger region. The design of such an integration scenario is outlined below.

Who may benefit from integration and in which way?

Animal production

In regions with a dry winter – a climate type also suitable for sugarcane cropping – extensive livestock productivity is restricted because of the low availability of pasture in winter time. Sugarcane is harvested during winter, and therefore the complete ration can be produced and delivered at cost-price to the ranchers during this shortage period. The expected outcome is a roughly 30% reduced amount of non-integrated land needed to sustain the same herd – estimated based on the land suitable for agricultural production. During the rainy season no ration can be produced – because no sugarcane is harvested at this time and the industry is not operating – but pastures are highly productive, thus also allowing the reduction in area. The remaining 70% of the area – based on the land suitable for agricultural production – used previously to spare pastures for the winter or produce silage during the summer, can now be utilized for sugarcane production. The productivity of livestock tends to increase. Solving the winter feed problem is the key aspect for production intensification under seasonal climate conditions.

Considering this integration, sugarcane is still possible at the surrounding of the industrial plant, except on the 30% of land used by the ranchers as summer pastures. Ranchers' income will increase not only because of higher productivity, but also because of income generated from sugarcane production on the remaining land, or from renting out the land for this purpose. The increased productivity and income may also reduce the migration of ranchers to remote regions. This integration is possible for any farm scale. Involvement of family agriculture in the integration also reduces the likelihood of farm aggregation into larger units, thus maintaining tenure structure.

Local economy

Integration will allow not only expansion of sugarcane, but will also stimulate intensification of the previous extensive land use. The dependence on one economic sector is reduced: diversity helps to equilibrate the local economy and reduces the vulnerability to varying profits in one or other sector. Native farmers and ranchers are more likely to use their increased income for local investments, thereby stimulating other sectors regionally. Additionally, not only the sugarcane sector will demand labor, but also the more intensive livestock production. The local economy will grow and become more dynamic, relying not only on one product, but on a more diverse range of production chains and services that are stimulated by livestock intensification in cooperation with sugarcane expansion.

Local social structures

Initially the need for specialized labor, services and goods for sugarcane production and industrial processing will in part be supplied by external sources or by migration from other regions, thus limiting positive local effects. With integration, the existing social structures and productive arrangements will be less impacted, and even expanded. Considering that livestock producers will not move, but intensify production locally, the actual existing supply markets for goods and services have a tendency to improve and grow. So, even assuming that the more complex and specialized needs from the expanding sugarcane business is supplied from elsewhere, local social structures will also benefit, and have more time to adapt to the new situation.

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Environment

As has been explained earlier, when sugarcane ethanol expands in a conventional way, displacement is intrinsic for economic reasons, because of the impossibility to maintain extensive and low-productive livestock production close to the sugarcane fields. The increased productivity and income induced by the expansion model based on integration may reduce the migration of ranchers to remote regions. If accomplished with a socio-environmental certification, an expansion model may define targets for displacement and indicators for effective monitoring. Considering Brazilian political and social organization, a near-to-market reason to avoid the displacement of extensive livestock production, and the consequential off-site deforestation impacts of sugarcane expansion, may be more effective than enforcement by law or the creation of a comprehensive official, state-led monitoring action.

Environmental impacts intrinsic to a more intensive agricultural land use – that makes use of chemical fertilizers, pesticides, soil tillage, and residue management – are difficult to avoid, but certification and adoption of best management practices may reduce these impacts to tolerable levels and suggest mitigation measurements.

Sugarcane industries

Sugarcane industries will initially have to invest in the construction and operation of the feed ration factories. To gain local support for the integration concept and to guarantee the participation of ranchers, this ration should be sold at a low price, implying a long period of investment amortization. More sensitive and certified markets may enforce integration, so configure a *sine qua non* condition in this context.

Another advantage is related to the diversification of the industry itself that becomes engaged in intensive beef cattle farming in marginal areas or in confined free-stall facilities. The same is applicable for milk production. Diversification may be a strategy for the industries to sustain business.

Sugarcane sector

Integration as a driver for sugarcane expansion at institutional level will allow the industrial sector to promote tangible regional development in the expansion regions. This would help the industry's public image and be beneficial from a political perspective: a better social insertion will result in support by the state and society in general.

Prospects and barriers for a large-scale implementation of the expansion model

The initial implementation of the expansion model is manageable with local arrangements and can avoid scale problems by a careful selection of the areas most suitable for the integration concept. Implementation on a larger scale requires that less suitable areas are included and non-ideal conditions may raise additional difficulties related to: i) technical restrictions for intensification in marginal areas; ii) technology adoption resistance by ranchers; iii) lacking capacity for adequate assistance; iv) markets for the increased livestock production; and v) competition from traditional extensive livestock production in remote areas.

Another obstacle for large-scale implementation of the integration model is concurrent use for the surplus bagasse. Current uses of bagasse, for example, co-generation, may be stimulated in the future by higher prices; new applications may be commercially available in a near future. This is the case of using bagasse – and other lignocellulose materials – for direct fuel ethanol production.

Prospects for overcoming these barriers and the impact of concurrent use of bagasse on its market price will determine the longer-term scope for the expansion model. Reliable projections of these are difficult to establish before the integration model is tested more comprehensively in practice and with prediction models, and are thus out of the scope of this paper.

A final example: the case study of Pontal

The expansion potential for sugarcane in the state of São Paulo is primarily found in the Pontal do Paranapanema region (Pontal) as shown in Fig. 4. Several sugarcane companies have at present received the environmental license to operate in Pontal and a near expansion period is expected. In this section, we briefly present main results from a case study where the integrated expansion scenario was evaluated in Pontal. More detailed information about the case study can be obtained from the corresponding author.

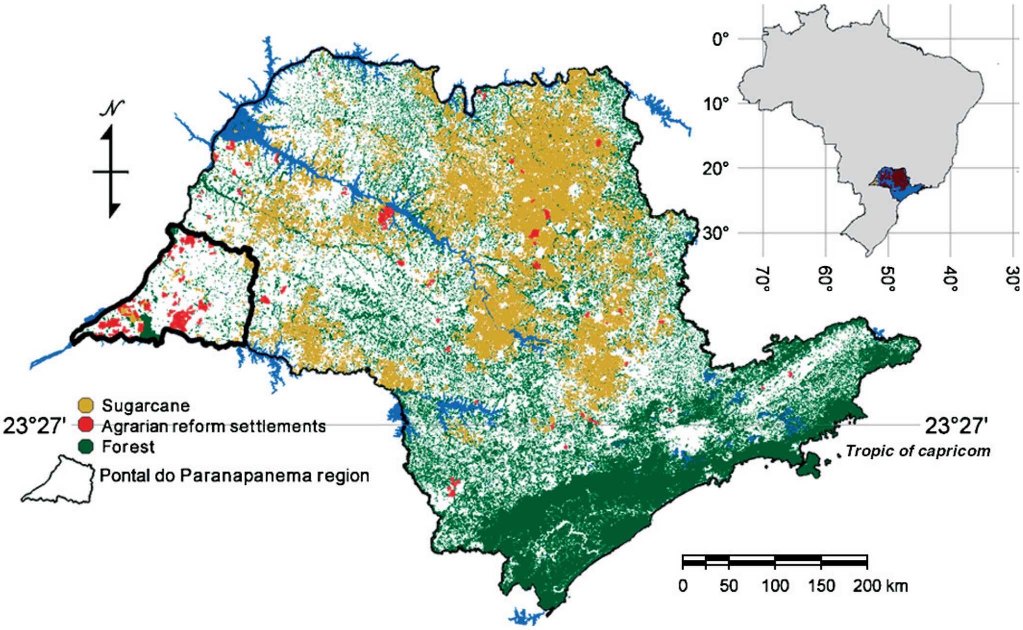

Figure 4. Geographic location of Pontal. The map also presents the distribution of sugarcane, forests and agrarian reform settlements in the state of São Paulo.

Pontal in the state of São Paulo

Pontal is the second-poorest region in the state and extensive beef cattle farming dominates land use: 55% of the 1.4 million ha large area is presently composed of extensive pasture, and 4% is used for sugarcane production. There are two main groups of land owners: i) *Ranchers* often own areas larger than 1,000 ha and their main income comes from extensive beef cattle farming; ii) *Settlers*, who received land by agrarian reform, own small properties of approximately 20 ha used for milk production and subsistence. The prevailing milk production in Pontal – extensive, low-productive cows and limited pasture management – restricts income growth for settlers. Food production for subsistence also consumes part of the land leaving little space for other cash crops.

Half of the total area in Pontal is suitable for growing sugarcane and approximately 12% of the suitable land is located within settlements. Some settlers already grow sugarcane for local industries but this activity presently claims less than 1% of the suitable areas. The contracts established with the sugarcane industry bind the settlers to a fixed price for sugarcane over a three-year period. The settlers lack capital to invest in equipment for sugarcane production and have to pay the industry for crop management. For the settlers, the average income from sugarcane production in Pontal is less than one-third of that in other similar regions. Often, sugarcane production does not lead to increased income for the settlers. Thus, if the expected sugarcane expansion follows the observed pattern, negative socioeconomic impacts may arise.

The expansion model evaluation

The evaluation of the expansion model for the case of Pontal compared an integration scenario – with intensification of milk production based on a complete ration produced in the industries – with the currently observed sugarcane production in the settlements, and focused on two central issues:

1. Socioeconomic effects of the integrated production system compared to expansion of current sugarcane production.
2. Change in GHG emissions due to pasture conversion to sugarcane, intensification of milk production in the settlements, and substitution of the produced ethanol for gasoline in the EU transportation sector.

The evaluation focused on settlers. Ranchers in Pontal would also be affected by expanding sugarcane production, but this aspect was beyond the scope of the case study.

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Methodological approach

The study combined interviews with scenario construction and modeling. In total 74 interviews were conducted during two weeks in October 2006. The questions concerned the settlers' income, cash crop production, milk production system, and expectations about growing sugarcane.

Two scenarios were constructed for the modeling. The *sugarcane exclusive* scenario focused completely on sugarcane, which becomes the only source of income: 80% of total land is assumed to be used for sugarcane production. The remaining land is used for growing food for family consumption and to keep milk cattle in order to stay self-sufficient. The *sugarcane integration* scenario represents the expansion model where sugarcane is integrated with and stimulates intensified milk production based on a complete ration provided by the industry during the winter.

Two models were developed: one model for assessing socioeconomic aspects, considering costs and incomes connected to the milk production; and one model for assessing the GHG emissions in relation to six different activities: i) sugarcane and ethanol production and manufacturing; ii) change of livestock production in Pontal; iii) conversion of pastures to sugarcane plantations leading to soil carbon loss; iv) transport of ethanol to EU; v) substitution of gasoline by ethanol in the transportation sector in the EU; and vi) substitution of oil-based electricity on the margin with electricity from bagasse in Brazil.

Major findings from the case study

The main result from the modeling was that increased production of sugarcane ethanol from Pontal can lead to decreased GHG emissions globally and increased income for settlers, but both effects occur only in the *sugarcane integration* scenario.

After 15 years, the intensified milk production leads to a stable net annual income that is 10 times higher than that currently obtained from milk production. In addition, sugarcane production on 30% of the land might further increase the income. However, the support from the ethanol plants providing non-profit feed is crucial for economic viability: cattle feed is the largest cost component in milk production.

The climate benefits differ depending on scenario. In the *sugarcane exclusive* scenario, where the farmers focus mostly on sugarcane production, more ethanol is produced and used to replace gasoline in the EU with larger reductions of GHG emissions in the EU. On the other hand, substantial volumes of additional milk are produced in the *sugarcane integration* scenario, substituting milk production (and related GHG emissions) elsewhere.

The modeling revealed that the total net climate benefit obtained in the two scenarios is sensitive to several aspects. One important aspect is the relative importance of manual vs. mechanical harvesting of sugarcane, where mechanical harvesting allows cycling of additional sugarcane biomass to the cropland. This addition can eliminate soil carbon losses as a consequence of sugarcane cultivation on former pastures with high soil- carbon content. Such soil carbon losses can drastically reduce the net climate benefit of the expanding sugarcane ethanol production.

The Brazilian law – stating that the practice of burning the cane-leaves before harvest (which is necessary in manual harvesting) should be totally phased out by 2031 – was established because burning leads to severe air pollution during the harvest season. But, given that a shift to mechanical harvesting – due to the phase-out of burning – also leads to carbon accumulation in soils, the law can clearly contribute to improved climate benefit of expanding sugarcane ethanol production.

While the relative importance of mechanical vs. manual harvesting is determined by factors other than those differing in the two scenarios, *sugarcane integration* may reduce the displacement of extensive cattle production and stimulate intensive milk production. This expansion model can reduce leakage – indirect CO_2 emissions from off-site deforestation – caused by new establishment of cattle production elsewhere. In this case study, the empirical basis for linking sugarcane expansion in Pontal with land-use change in remote areas was too weak to support any definite conclusions about this aspect. But the climate benefits of expanding sugarcane ethanol production in Pontal are clearly highly sensitive to the occurrence of such second-order effects.

The possibility of leakage warrants close attention and strategies for expanding sugarcane production on pastures may need to include instruments countering such land-use change effects. Market (or close-to-market) mechanisms, such as integration of livestock with the industrial plants providing feed for intensification of beef cattle and milk production – possibly regulated within certification schemes – may be effective in countering leakage. Concerns in Brazil and in importing regions about indirect CO_2 emissions, environmental impacts in general and negative socioeconomic effects for the rural poor are a strong motive for further investigations of the prospects for a large- scale implementation of the expansion model presented in this perspective, as an alternative to conventional production and expansion schemes.

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