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The sustainability of ethanol production from sugarcane

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ABSTRACT

The rapid expansion of ethanol production from sugarcane in Brazil has raised a number of questions regarding its negative consequences and sustainability. Positive impacts are the elimination of lead compounds from gasoline and the reduction of noxious emissions. There is also the reduction of CO_2 emissions, since sugarcane ethanol requires only a small amount of fossil fuels for its production, being thus a renewable fuel. These positive impacts are particularly noticeable in the air quality improvement of metropolitan areas but also in rural areas where mechanized harvesting of green cane is being introduced, eliminating the burning of sugarcane. Negative impacts such as future large-scale ethanol production from sugarcane might lead to the destruction or damage of high-biodiversity areas, deforestation, degradation or damaging of soils through the use of chemicals and soil decarbonization, water resources contamination or depletion, competition between food and fuel production decreasing food security and a worsening of labor conditions on the fields. These questions are discussed here, with the purpose of clarifying the sustainability aspects of ethanol production from sugarcane mainly in São Paulo State, where more than 60% of Brazil's sugarcane plantations are located and are responsible for 62% of ethanol production.

1. Introduction

Ethanol is produced through the fermentation of agricultural products such as sugarcane, corn, wheat, sugar beet and cassava, among others. The great majority of ethanol produced in the world is from sugarcane, mainly in Brazil, and corn in the United States (which together account for 35.4 million cubic meters, about 72% of the world's production) (UNICA, 2008; EIA, 2008).

The Brazilian Alcohol Program (Proalcool) was established in 1975 for the purpose of reducing oil imports by producing ethanol from sugarcane. Ethanol's production rose from 0.6 million cubic meters from that year to 18 million cubic meters in the 2006/2007 season, with increasing agricultural and industrial productivities. In Brazil, ethanol is used in cars as an octane enhancer and oxygenated additive to gasoline (blended in a proportion of 20%, E-20, to 26%, E-26, of anhydrous ethanol in a mixture called gasohol), in dedicated hydrated ethanol engines or in flex-fuel vehicles running with up to E-100. Only in the year 2003, the emission of 27.5 million tons of $CO_{2\,equivalent}$ in the atmosphere was avoided due to the gasoline replacement by ethanol (Macedo, 2005).

Since February 1999, ethanol prices are no longer controlled by the Government; hydrated ethanol is sold for 60–80% of gasohol's price at pump stations, and nowadays Brazilian ethanol is competitive internationally with gasoline at Rotterdam prices and there are no subsidies to producers, due to significant reductions in production costs (Goldemberg et al., 2003; Coelho, 2005).

However, the expansion of ethanol production from sugarcane envisaged in Brazil (particularly São Paulo) to supply an expanding market as well as exports to other countries has raised concerns on its sustainability.

Therefore here we will discuss the sustainability aspects of ethanol production, namely environmental and social aspects as well as sustainability criteria, as suggested by the Cramer Commission (Cramer et al., 2006).

2. Energy balance of ethanol production and use

To evaluate the merits of replacing gasoline with ethanol, an analysis of energy balance and greenhouse gas (GHG)-avoided emissions has to be performed using life-cycle analysis. Different feedstocks for ethanol production must also be compared in such terms, as well as their land use efficiency (tC/ha/yr) (Larson, 2006).

What makes ethanol from sugarcane attractive as a replacement for gasoline is that it is essentially a renewable fuel while

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Table 1
Energy and greenhouse gas balance of ethanol production from sugarcane

Energy output/input		GHG emission (kg/m^3)	
Average case: 8.3[a]	Best case: 10.2[b]	Average case: 389[a]	Best case: 359[b]

Source: Macedo et al. (2004).
[a] Average technology available: scenario based on the average values of energy and material consumption.
[b] Best technology available: scenario based on the best values being practiced in the sugarcane sector (minimum consumption with the use of the best technology in use in the sector).

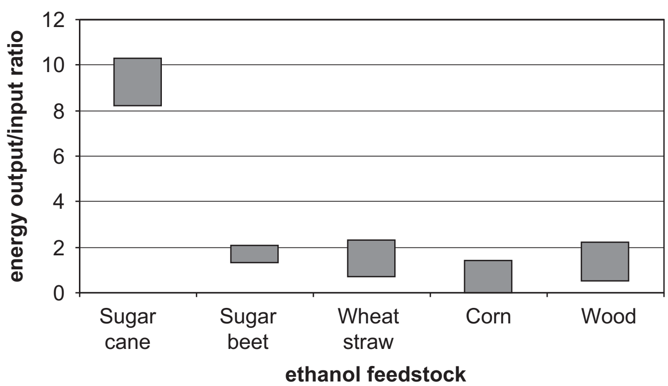


Fig. 1. Energy balance of ethanol production from different feedstocks. *Sources*: Macedo (2005); UK DTI (2003); USDA (1995).

gasoline derived from petroleum is not. The use of sugarcane-based ethanol does not result in significant net emission of GHGs (mainly CO_2). The reason for this is that CO_2 from the burning of ethanol (and the bagasse,[1] in boilers) releases are reabsorbed by photosynthesis during the growth of sugarcane in the following season. All the energy needs for its production (heat and electricity) come from the bagasse and excess bagasse is used to generate additional electricity to be fed into the grid. The direct consumption of fossil fuels is limited to transportation trucks, harvesting machines and the use of fertilizers. Indirect consumption of fossil fuels is low due to the fact that Brazilian Energy Matrix is mainly based on hydropower (MME, 2007).

Table 1 shows the energy and GHG balance of ethanol production from sugarcane ethanol produced from sugarcane.

When compared to ethanol produced from other feedstocks, sugarcane ethanol has a very favorable GHG emissions balance, as shown in Fig. 1.

Also, a life-cycle assessment conducted by Ekos Brasil, in 2006, shows that for sugarcane ethanol replacing a share of the gasoline consumed in Switzerland, the energy balance is 5:6-1, since it considers also the energy consumed in the transportation of ethanol (Rodrigues and Ortiz, 2006). This means that even when ethanol from sugarcane is exported to other countries, the final energy balance is highly positive when compared to other crops.

Due to this positive energy balance, the sugar/ethanol sector avoids emissions equivalent to 13% of all Brazilian industrial, commercial and residential sectors.[2] In 2003, 33.2 $tCO_{2\,\mathrm{equivalent}}$ were avoided, being 82.8% due to the replacement of gasoline by ethanol and 17.2% due to the use of sugarcane bagasse in energy cogeneration in the mills, as well as supplying of electricity surplus to the grid (UNICA, 2007). This fact, together with the use of hydroelectricity, is responsible for the low carbon emissions in the country (most of the carbon dioxide emission of the country, 75% of all national emissions, is due to Amazonia Forest deforestation) (MCT, 2004).

In contrast, as can be seen in Fig. 1, the production of ethanol from corn and other crops requires considerable imports of fossil fuels into the producing plants, resulting in energy balances that vary from almost zero to only slightly higher than one (USDA, 1995).

For second-generation processes, the energy balance for production from cellulosic materials is expected to be better than the present methods from sugarcane or corn (Larson, 2006).

3. Environmental aspects

3.1. Air

3.1.1. Impacts to the air quality

Proalcool was created with the purpose of partially replacing gasoline due to the high prices of imported oil in 1975 and also to the revitalization of the sugarcane industry (Moreira and Goldemberg, 1999).

Initially, lead additives were reduced as the amount of alcohol in gasoline was increased and they were completely eliminated by 1991. Brazil was then one of the first countries in the world to eliminate lead entirely from gasoline.

The aromatic hydrocarbons (such as benzene), which are particularly harmful, were also eliminated and the sulfur content was reduced as well. In pure ethanol cars, sulfur emissions were eliminated. The simple addition of alcohol instead of lead in commercial gasoline has dropped the total carbon monoxide (CO), hydrocarbons and sulfur transport-related emissions by significant numbers.

Due to the ethanol blend, lead ambient concentrations in São Paulo Metropolitan Region dropped from 1.4 $\mu g/m^3$ in 1978 to less than 0.10 $\mu g/m^3$ in 1991, according to CETESB (the Environmental Company of São Paulo State), far below the air quality standard of 1.5 $\mu g/m^3$ (Coelho and Goldemberg, 2004).

Also, ethanol hydrocarbon exhaust emissions are less toxic than those of gasoline, since they present lower atmospheric reactivity.

One of the drawbacks of pure ethanol combustion is the increase in aldehyde emissions as compared to gasoline or gasohol. Total aldehyde emissions from ethanol engines are higher than those of gasoline, but it must be observed that these are predominantly acetaldehydes and for gasoline they are mainly formaldehydes. Also, aldehyde ambient concentrations in São Paulo present levels quite below the reference levels found in the literature.

Recently, aldehyde emissions from high-content ethanol blends have been measured in Brazil and reach low levels. Typically, 2003 model-year Brazilian vehicles fueled with the reference blend for governmental certification (a blend with 22%v/v ethanol—E22) emit 0.004 g/km of aldehyde (formaldehyde+acetaldehyde), a concentration that is about 45% of the strict California limit that is required only for formaldehyde. On the other hand, emissions of aldehydes are not limited to ethanol use. Combustion of gasoline, diesel, natural gas and liquefied petroleum gas also generates aldehydes as well. Automotive use of diesel oil can be a more important source of aldehydes than gasoline–ethanol blends. Data from diesel vehicle aldehyde measurements show that emissions (formaldehyde+acetaldehyde)

[1] Bagasse is the byproduct of sugarcane crushing.
[2] Base year 1994, MCT (2004).

are 5.6–40.2 higher than those from vehicles running on E22 (Abrantes, 2003).

Ambient aldehyde concentrations were also measured in Denver, CO, USA, for the winters of 1987–88 through 1995–96 (before and after the introduction of E10) and no statistically significant differences were observed for both ambient acetaldehydes and formaldehydes. A study conducted by the California Air Resources Board predicted for E10 uses virtually no increase for acetaldehyde ambient concentrations in 2003, relative to 1997 (when no E10 was used). Additionally, a reduction of about 10% for formaldehyde, 30% for benzene and 45% for 1,3-butadiene was predicted. Rather, the California study identified aromatic compounds and olefins, basic constituents of gasoline, as being primarily responsible for the formation of formaldehyde and acetaldehyde in the air (Coelho et al., 2006).

Besides the increase of acetaldehyde, there is also concern about the increase on peroxyacetyl nitrate (PAN) concentration, caused by the combustion of ethanol when compared to gasoline. PAN is an eye irritant noxious to plants, which is a byproduct of combustion.

Several studies were conducted to determine the air quality impact of ethanol blends. One of these studies, conducted in California, noticed a small increase in acetaldehydes and PAN concentrations with ethanol blends, and the conclusion of a study conducted in Canada is that the risks of increased aldehyde pollutants are insignificant (IEA, 2004). Some studies concluded that the impacts on pollution levels are quite similar for high-level (E85) and low-level blends (IEA, 2004).

A recent paper (Jacobson, 2007) draws attention to the potential negative effects of ethanol versus gasoline vehicles on cancer and mortality in the US, but it does not consider the benefits of the reduction of aromatic hydrocarbons in the atmosphere due the use of ethanol. The paper also does not take into consideration the effect of particulate matters (PMs) and other volatile organic compounds (VOCs) that are also reduced due to the use of ethanol (Saldiva, 2007).

Nowadays NO_x and VOCs (frequently referred to as hydrocarbon) may have negligible or even null increase with ethanol. Modern vehicle technology allows efficient NO_x control, reducing ground-level ozone. Depending on engine characteristics, reduction of exhaust emission of VOCs, potent precursors of photochemical smog and noxious substances, can also be accomplished. A very comprehensive Australian study (Apace Research Ltd., 1998) found that the use of E10 decreased hydrocarbon emissions by 12%, noxious emissions of 1–3 butadiene by 19%, benzene by 27%, toluene by 30% and xylene by 27%. The decreased carcinogenic risk was by 24%. CO emissions were reduced by 32%.

The most obvious pollution reduction effects associated with blends containing up to 10% ethanol by volume (E10 blends) include reduction of CO, harmful hydrocarbons (such as benzene and 1–3 butadiene that are known carcinogens), sulfur oxides (SO_x) and PM. However, modern catalytic converters help significantly in the reduction of emissions (Coelho et al., 2006). CO transport-related emissions were drastically reduced: before 1980, when gasoline was the only fuel in use, CO emissions were higher than 50 g/km and they decreased to less than 1 g/km in 2000.

The use of E10 blends to reduce harmful wintertime CO emissions has proven to be a very effective strategy in the USA. Tests at the National Center for Vehicle Emissions Control and Safety at Colorado State University document a 25–30% reduction in CO when automobiles burn E10. It is important to note that CO, in addition to being an important air pollutant by itself, also contributes to the formation of photochemical smog. Therefore, the reduction of CO may actually contribute to the lower formation of ground-level ozone (Coelho et al., 2006).

3.1.2. Air emissions in sugarcane and ethanol production

3.1.2.1. Air emission in the ethanol production process. As already mentioned, all the energy needs in the sugar/ethanol process are supplied by the sugarcane bagasse (30% of sugarcane in weight). In the past, the bagasse was burned very inefficiently in boilers. However, old boilers of low pressure (21 bar) are being replaced by new and more efficient ones (up to 80 bar) and new plants have high-efficiency boilers.

Emission from bagasse boilers are mainly PM and NO_x. These emissions are controlled by the São Paulo State Environmental Agency (CETESB) and recently a new Resolution from the National Council for the Environment (CONAMA Resolution, 382/2006) has established limits for such pollutants, as shown in Table 2.

3.1.2.2. Air emissions due to sugarcane burning. Sugarcane burning before harvesting is a practice used to facilitate the manual harvest of the stalks and also repel poisonous animals, such as spiders and snakes. On the other hand, cane burning can damage the cell tissue of the cane stem, and thus increase the risk of diseases in the cane, destroy organic matter, damage the soil structure due to increased drying, and increase the risks of soil erosion. Harvesting method of burning sugarcane also results in risks of electrical systems, railways, highways, and forest reserves. Beside these impacts, there are harmful atmospheric emissions such as CO, CH_4, non-methane organic compounds and PM. The burning of sugarcane is also responsible for the increase of troposphere ozone concentration in sugarcane producer areas.

However, existing studies did not report a direct relationship between cane burning and damage to health (Smeets et al., 2006). On the other hand, studies performed in Brazil by the University of São Paulo Medical School led to the conclusions that air pollution from biomass burning causes damage to the respiratory system, increasing respiratory diseases and hospital admissions. Children and elderly are the most affected, and the effect is similar to people exposed to industrial and vehicle emissions in urban areas (Cançado et al., 2006). Results also show that health effects are determined not just by high pollution levels but also by the length of time exposure (Bates and Koenig, 2003).

According to Macedo (2005), the health consequences of burning sugarcane waste was the subject of many papers in the 1980s and 1990s (in Brazil and other countries); but these studies were unable to conclude that the emissions are harmful to human health. Table 3 presents the health problems related to atmospheric emissions.

The Brazilian Agricultural Research Corporation (EMBRAPA) together with the University of São Paulo (USP), University of Campinas (UNICAMP) and ECOFORÇA (a local NGO) conducted research to assess chronic respiratory diseases in some regions of São Paulo State that are producers of sugarcane as well as some others that are not. The conclusion was that Ribeirão Preto, in the middle of the most important producing region in the State, has the same risk of respiratory diseases as Atibaia, where there are no sugarcane plantations and has a very good air quality (Miranda et al., 1994 In Macedo, 2005).

Table 2
Emissions from bagasse boilers

Thermal power (MW)	PM[a]	NO_x (as NO_2)[a]
Lower than 10	280	Not applicable
From 10 to 75	230	350
Higher than 75	200	350

Source: CONAMA Resolution (382/2006).
[a] Figures in mg/N m^3, dry basis and 8% of excess oxygen.

Besides the reduction of local pollutant emissions, the mechanical harvesting of green cane also reduces carbon emissions, avoiding the emission of 183.7 kg of carbon per year per square kilometer (Cerri, 2007).

Harvesting burning practices, which result in intense air pollution, are being phased out, resulting in energy benefits of mechanization due to higher surpluses of electricity that can be produced from sugarcane byproducts corresponding to 30% more in terms of biomass availability (State Law 11,241/2002). Also, harvesting burning practices are controlled/authorized by São Paulo State Secretary for the Environment according to atmospheric conditions. Fig. 2 shows the timetable for progressive elimination of manual harvesting in São Paulo.

According to Fig. 2, in 2007, 40% of the sugarcane was harvested green in the State of São Paulo, and in 2010 this will reach 50%. This Law was enacted only in the State of São Paulo, but there is strong pressure to extend it to other sugarcane-producing regions in the country.

In 2007, the São Paulo Secretariat for the Environment and UNICA (Sugarcane Agro industry Association) signed a voluntary environmental agreement, which aims at rewarding good practices in the sugarcane sector. About 140 mills (78% of the mills associated with UNICA) have already adhered to this agreement. One of the main guidelines of this agreement is to anticipate the timetable for sugarcane burning phase-out.

In the State of Minas Gerais, where sugarcane expansion is taking place, a technical group of the Secretariat for the Environment is preparing a law to phase-out sugarcane burning. The State of Minas Gerais has already made an Environmental-Ecological Zoning, which is one of the tools used to evaluate environmental risks and vulnerable areas. The regions of *Triângulo Mineiro* and *Alto Paraná* appeared to be the most suitable regions for sugarcane crops, not only because of the high-quality soil but also due the logistical infrastructure already existing (Sepúlveda, 2007).

Table 3
Health problems related to atmospheric emission

Gases	Disease
CO	Respiratory problems, poisoning, cardiovascular problems
	Long-time exposure: increase of spleen volume, bleeding, nausea, diarrhea, pneumonia, amnesia
PM	Respiratory problems, eye irritability and cardiovascular diseases
NO_2	Respiratory problems
O_3	Eye irritation
	Respiratory problems (inflammatory reaction of the respiratory system)
Pb	Cumulative toxic effect
	Anemia and brain tissue destruction
SO_2	Respiratory problems, eye irritation and cardiovascular problems

3.2. Water

3.2.1. Water availability

Water is used in two ways in the production of sugarcane and ethanol:

- *Use of water for cane production*: the evapotranspiration (transpiration that occurs in the leaves, corresponding to the water losses; higher evapotranspiration means higher losses) of sugarcane is estimated at 8–12 mm/tons of cane and the total rainfall required by sugarcane is estimated to be 1500–2500 mm/yr, which should be uniformly spread across the growing cycle (Macedo, 2005). The use of crop irrigation is very small in Brazil, mainly in the northeastern region, due to climate conditions. Sugarcane production is mainly rain-fed in the rest of Brazil. Nearly the whole of the São Paulo sugarcane-producing region does not make use of irrigation (Matioli, 1998). So, unlike other parts of the world, sugarcane irrigation is a minor problem in Brazil (Rosseto, 2004).
- *Use of water for sugarcane to ethanol conversion*: conversion of cane to ethanol requires large amounts of water. The total use of water was calculated to be 21 m^3/ton of cane in 1997, of which 87% was used in four processes: cane washing, condenser/multijet in evaporation and vacuum, fermentation cooling and alcohol condenser cooling. However, most water used is recycled, as discussed later (Macedo, 2005).

Water consumption and disposal for industrial use have substantially decreased in the last years, from around 5.6 m^3/ton of sugarcane collected in 1990 and 1997 to 1.83 m^3/ton of sugarcane in 2004 (figures from a sampling in São Paulo). The water reuse level is very high, and the release treatment efficiency is more than 98%.

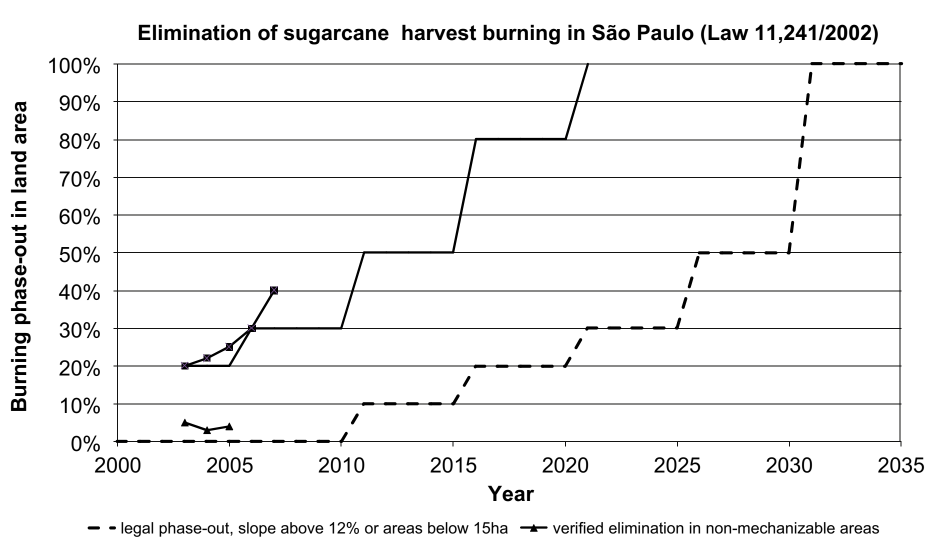


Fig. 2. Sugarcane harvest burning phase-out.

Also, a dry cane washing process is replacing the standard wet cane washing process, which uses 5 m^3 of water/ton of cane. The dry washing process recycles most of the water, representing a much lower net water use (Macedo, 2005).

Modern agricultural practices include the recycling of washing water and ashes to the crops via fertirrigation, together with the vinasse (pollutant byproduct from ethanol distillation).

3.2.2. *Water pollution*

Environmental problems related to water quality, which result from irrigation (water run-off, with nutrients and pesticides, erosion) and industrial use, have not been reported in São Paulo. In this respect, EMBRAPA rates sugarcane as Level 1 (no impact on water quality).

Regarding wastewater issues, there is the problem of organic and inorganic pollutants.

3.2.2.1. Organic pollutants. The main liquid effluents of ethanol production are the vinasse and the wastewaters used for cleaning sugarcane stalks.

Vinasse disposal represents the most important potential impact due to the large amounts produced (0.011–0.014 m^3 per m^3 of ethanol), its high organic loads (biochemical oxygen demand and chemical oxygen demand) and its pH of 4–5 (Rodrigues and Ortiz, 2006).

Disposal costs are high, mainly in the northeast of Brazil, and the vinasse were released into rivers, polluting the water in each harvesting season. Nowadays such disposal is prohibited all over the country and fertirrigation uses vinasse in the sugarcane crops together with wastewaters.

Also, a number of studies on leaching and possibilities of underground water contamination with vinasse indicate that there are, in general, no damaging impacts for applications of less than 30,000 m^3 of vinasse/km^2. A technical standard by CETESB (2005) regulates all relevant aspects, namely risk areas (prohibition), permitted areas and adequate technologies.

Ways to reduce the amount of organic pollutants in wastewater include the mechanical removal of suspended particles, aerobic treatment, anaerobic treatment and recycling (Smeets et al., 2006).

3.2.2.2. Inorganic pollutants. Agrochemicals such as herbicides, insecticides, mitecides, fungicides, maturators and defoliants are some of the inorganic pollutants applied in ethanol production.

There is adequate Federal legislation, including rules and regulations from production to use and disposal of materials: Federal Law 7082/89, Federal Decree 4074/02 and São Paulo State Law 4002/84 (Tomita, 2005). Moreover, pesticide consumption per square kilometer in sugarcane crops is lower than in citrus, corn, coffee and soybean crops, hence the low use of insecticides and fungicides.

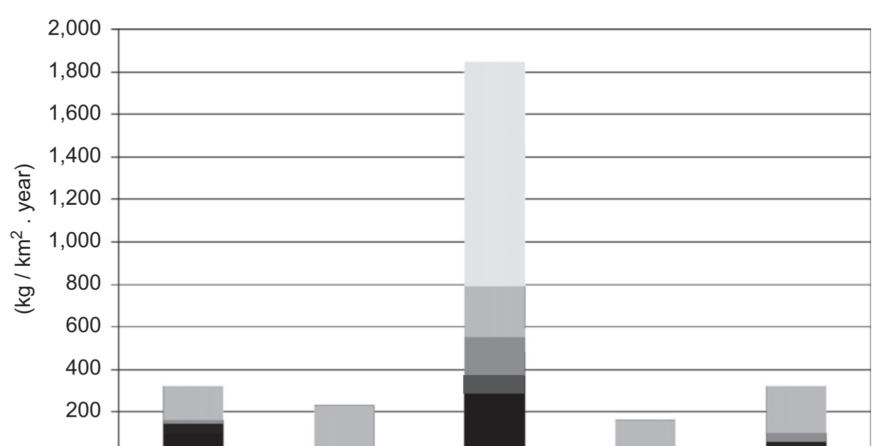
Genetic researches allowed the reduction of sugarcane diseases through the selection of resistant varieties, such as the mosaic virus, the sugarcane smut and rust, and the sugarcane yellow leaf virus. Genetic modifications (at the field-test stage) have also produced plants resistant to herbicides, fungus and the sugarcane beetle (Macedo, 2005). In fact, there are more than 500 commercial varieties of sugarcane.

According to Marzabal et al. (2004) in Macedo (2005), the consumption of agrochemicals in sugarcane production is lower than that in coffee crops. On the other hand, sugarcane uses more herbicides per square kilometer than coffee. Fig. 3 compares the average amount of agrochemicals consumed in different crops.

Also, among Brazil's large crops (areas larger than 10,000 km^2) sugarcane uses smaller amounts of fertilizers than cotton, coffee and orange, and is equivalent to soybean crops in this respect. The amount of fertilizer used is also small compared to sugarcane crops in other countries (48% more is used in Australia) (UNICA, 2007).

Nevertheless, some small producers of fruit complain that the herbicides used on these crops spread from airplanes are damaging the fruit trees (Souza, 2007).

The most important factor is nutrient recycling through the application of industrial waste (vinasse and filter cake), considering the limiting topographic, soil and environmental control conditions. So, substantial increases in productivity and in the potassium content of the soil have been observed. Nutrient



	coffee	sugarcane	citrus	corn	soy
mitecide	4	-	1,053	-	1
herbicide	161	220	239	141	220
other pesticides	17	4	182	7	46
insecticide	46	11	86	15	43
fungicide	99	-	286	1	16

Fig. 3. Average agrochemical consumption in different crops. *Source*: CTC (2007).

Table 4
Sugarcane expansion forecast

	Season 2006/2007	Season 2012/2013	Increase
São Paulo	147	182	35
Minas Gerais	25	43	18
Goiás	15	25	10
Paraná	27	31	4
Mato Grosso do Sul	9	18	9
Mato Grosso	10	10	0
Rio de Janeiro	8	9	1
Espírito Santo	6	6	0
Rio Grande do Sul	1	1	0
Total	248	325	77

Source: CTC (2007).

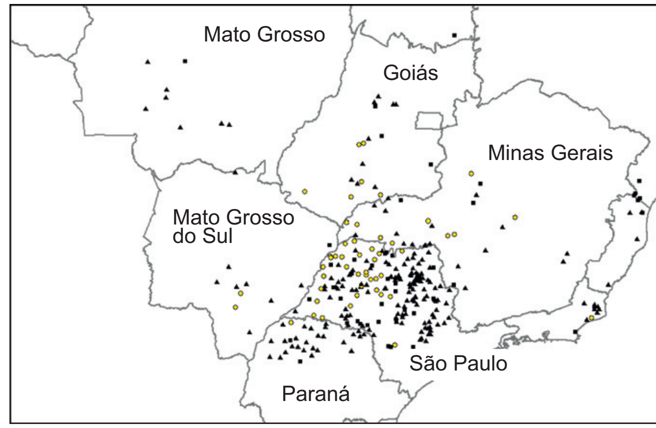


Fig. 4. Location of new mills as expected in the expansion plan (December 2005) *Note*: the dark triangles represent existing mills, the light circles the planned new mills. *Source*: Leal (2007).

recycling is being optimized, and trash utilization is yet to be implemented.

3.3. *Land use*

3.3.1. *Expansion of sugarcane*

Table 4 shows the expected expansion of ethanol production in Brazil, but it must be noted that not all the projects might be implemented.

The biggest threat posed by expanding the amount of land under cultivation for energy or any other use is the irreversible conversion of virgin ecosystems. Deforestation, for example, causes the extinction of species and their habitats, and the loss of ecosystem functions. Studies reveal that wide-scale destruction of forests can affect the hydrologic cycle and the climate, reducing regional precipitation and increasing temperatures.

In Brazil, the expansion of sugarcane is limited by the quality of the soil, pluviometric precipitation (as already discussed) and logistics.

Sugarcane is not a particularly demanding crop in terms of soil, adapting reasonably to soils of average fertility and high porosity/permeability-sandier soils. More fertile soils implicate in higher productivity levels, and/or smaller demand for fertilizers and corrective products, but are more expensive. The areas in the northeast region that demand financial resources for irrigation purposes are more problematic, in view of the considerable initial investments and the cost of the energy used in irrigation.

The areas of cane expansion with greater future potential are those that combine the three conditions mentioned above, with perspectives of a positive evolution in terms of logistics. Among the areas that stand out in the short term are *Triângulo Mineiro* (Minas Gerais State), northwest of São Paulo State, Mato Grosso do Sul State, Goiás State and the north of Espírito Santo State. In the medium term there is potential for development in the areas of west of Bahia State, south of Maranhão State and south of Tocantins State. Attention should be given, however, to areas in which pluviometric precipitation is practically zero for 3–5 months per year, demanding investments in rescue irrigation. In these cases, the lower cost of land might compensate the additional cost of irrigation, which needs to be taken into account for each specific case. Most of the Amazon is not suitable for agricultural reasons, besides the fact that it would lead to further undesirable deforestation.

The problem could be indirect pressure because of the expansion of existing crops/cattle areas in the above regions. Most expansion on existing sugarcane crops is taking place on degraded and pasture lands (Lora et al., 2006). Fig. 4 shows where new mills are being installed.

Fig. 5 shows the percentage of sugarcane crops in Brazilian municipalities. The light gray spots represent the municipalities with small percentage of sugarcane crops (up to 20%) and the black spots represent municipalities with up to 85% of sugarcane crops in its territory.

Land in the State of São Paulo is becoming more expensive; costs increased on average 113.66% from 2001 to 2006, with regions such as Ribeirão Preto, Bauru and Franca showing a growth in a range of 160–170%. However, there is a lack of infrastructure in these states to deliver the production of ethanol to consumer centers or to harbors for export (Brito, 2007).

A large portion of Brazilhas conditions to economically support agricultural production, while preserving vast forest areas with different biomes. From 1955 to 2006, the sugarcane area in Brazil increased steadily from 10,000 to 60,000 km^2. From this total, the most important cane-producing state is São Paulo, with an area of 19,000 km^2 in 1993 that increased to 42,700 km^2 in 2006 (19% of state's total area) being used for sugarcane crops. In 2006, 34,500 square kilometers were harvested, half of it dedicated to ethanol production and the other half for sugar. An expansion of 8200 km^2 of sugarcane plantations is currently taking place in the state (IEA, 2007).

The Brazilian environmental legislation is based on the National Forestry Code (Federal Law 4771/65), and the Environmental Crime's Law (Federal Law 9605/98); there is also legislation for licensing and recovery projects. A legal reserve of 80% is required for rural properties in the Amazon region, 35% in the Amazonian Cerrado (savannas) and 20% for the rest of the country, including São Paulo State.

Hence, sugarcane plantations (or other crops) in São Paulo must guarantee at least 20% forestry cover on native trees (or reforested with native trees), and São Paulo State Decree 50,889 from June 16, 2006 establishes rules to the execution of the legal reserve in the state. São Paulo has also special requirements on riparian forests maintenance for environmental licensing, since there is, in the state Secretariat for the Environment, a special program funded by World Bank/Global Environment Facility (GEF), launched in 2005, on recuperation of the 10,000 km^2 of riparian forests.

3.3.2. *Land competition: ethanol versus food crops*

In the 1970s and 1980s, ethanol caused a shift in land-use patterns from food crops to sugarcane. In São Paulo, from 1974 to 1979, the expansion replaced food crops. Maize and rice had the

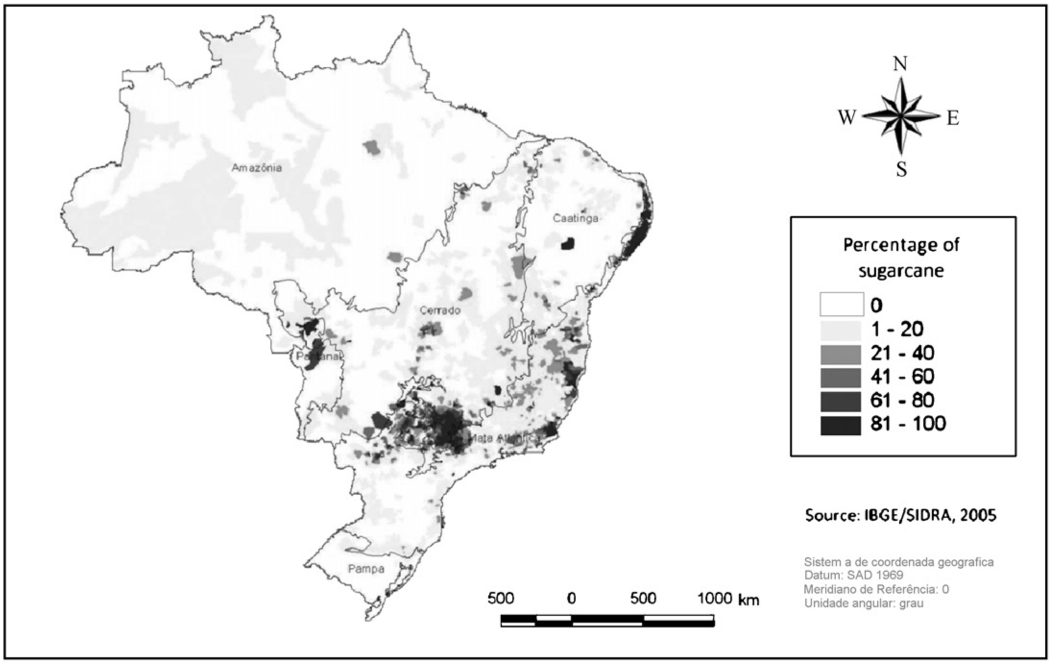


Fig. 5. Percentage of sugarcane in Brazilian municipalities.

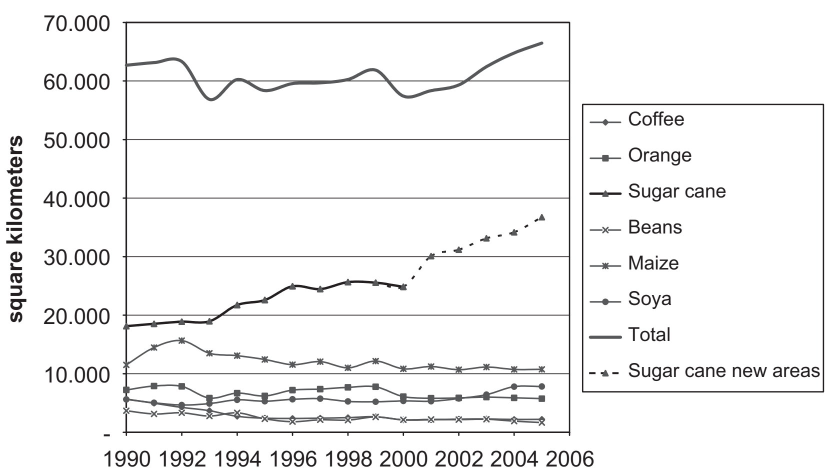


Fig. 6. Main crops in São Paulo State (IBGE and IEA).

highest decrease, with the planted area declining by 35% (Saint, 1982 in ESMAP, 2005). The present use of agricultural land in São Paulo is shown in Fig. 6.

Fig. 6 shows that sugarcane growth does not seem to have an impact in food areas, since the area used for food crops has not decreased. The expansion in the state is taking place over pasturelands.

Besides the expansion of sugarcane area, the increase on ethanol production in the state was also due to the growth of overall productivity (both agricultural and industrial) in the country.

Brazil has achieved a sugarcane agricultural productivity average of around 6500 ton/km^2. In the State of São Paulo the productivity can be as high as 10,000–11,000 ton/km^2. An enhancement of 33% in the State of São Paulo since Proalcool started can be related to the development of new species and to the improvement of agricultural practices.

Also, genetic improvements allow cultures to be more resistant, more productive and better adapted to different conditions. Such improvements allowed the growth of sugarcane production without excessive land-use expansion.

Recently there are plans to increase sugarcane areas in São Paulo State by 50% until 2010, a process that is being followed closely by the environmental licensing authorities. Existing assessments show that there could be space for it, without significant environmental impacts (Coelho et al., 2006; Macedo, 2005). Excluding urban and infrastructure areas, the State of São Paulo has 220,000 km^2, distributed as shown in Table 5.

As mentioned, sugarcane expansion during the period 2002–2006 occurred in São Paulo mainly on land previously used for cattle feed (Lora et al., 2006), thus not pressuring food crops. Also because the rotation system is used for the sugarcane crops, during every harvesting season 20% of the sugarcane crop is removed and replaced with other crops like beans, corn, peanuts,

Table 5
Land use in São Paulo State, 2006 (in thousand square kilometers)

Sugarcane	43.4	19.70%
Other cultures	35.7	16.21%
Sub-total cultures	*79.1*	*35.91%*
Natural forests	32.0	14.53%
Reforesting	11.4	5.17%
Sub-total forests	*45.4*	*20.61*
Pasture land	97.8	44.39%
Total	*220.30*	*100%*

Source: IEA (2007).

Table 6
Land use in Brazil

Area (million ha)	Distribution in relation to	
	Agriculture areas (%)	Agriculture and pasture lands (%)
Soy (21)	35	7
Corn (12)	20	4
Sugarcane (5.4)	9	2
Other cultures (17)	36	6
Total agriculture (60)	100	20
Pastureland (237)	–	80
Agriculture+pastureland (297)	–	100

Source: CTC (2007).

Box 1–Expanding into Brazilian Cerrado (Brazilian Savannah).

In Brazil, the cultivation of sugarcane for ethanol is increasing the agricultural pressure, which has also been increased in order to meet the rising demand for sugar and soy in food and feed markets. The expansion of sugarcane production has replaced pasturelands and small farms of varied crops. Plantations for sugar and ethanol production have expanded predominantly into areas once used for cattle grazing, as cattle are mainly confined to cattle ranching and in a small scale to new pastureland (which may include cleared rainforests).

It must be considered that 50% of *cerrado* is not adequate for sugarcane plantation or has low suitability for it. This region (24% of the territory) has been extensively utilized for agriculture and cattle breeding over the past 40 years. In fact, the expansion of sugarcane crops in areas covered by the *cerrado* vegetation has been very small so far, and has replaced other covers that had previously replaced the *cerrado* (usually pastures) (Macedo, 2005).

Despite the existing forecast of expanding areas of sugarcane up to 850 thousand square kilometers (NIPE/Unicamp, 2005), considering that it is much less than the areas currently used for cattle (2.37 million km^2), more conservative forecasts indicate 120,000 km^2 up to 2020.

However, in the State of São Paulo, expansion of sugarcane was mainly over pasture lands, with cattle density growing from 128 to 140 heads per square kilometer. On the other hand, in Brazil, the density is 100 heads/km^2, with a large area for sugarcane expansion without pressurizing native forests (Lora et al., 2006).

etc. In order to allow the soil recovery, this practice is being used throughout the country.

Considering the replacement of cattle areas, it is important to notice that the number of animals in the pasturelands presently has very low densities in Brazil (100 head/km^2) when compared with developed countries' average. Also, as mentioned in Box 1, in São Paulo, cattle population has been rising, even with the reduction of pasture land, increasing the density from 128 heads/km^2 (2004) to 141 heads/km^2 (2005) (Lora et al., 2006), which is still very low.

So, in Brazil there are large areas for pastureland, which can be used for sugarcane expansion, as shown in Table 6.

3.4. Soil

The sustainability of the culture increases due the protection against erosion, compacting and moisture losses and correct fertilization. In Brazil, there are soils that have been producing sugarcane for more than 200 years, with ever-increasing yield.

CETESB set the standards that must be followed by potentially polluting emissions released by any sort of activities. Below is the CETESB Technical Rule P4.231 (2005), which sets:

- Sensitive areas in which vinasse use remains prohibited.
- Standards for vinasse storage according to the Rule NBR 7229—ABNT.
- All areas formerly used for vinasse disposal (sacrifice areas) should be immediately closed, and after that they should be assessed according to procedures of CETESB no. 023/00/C/E. Results should be compared with standards set by CETESB no. 014/01/E and a Directive from Ministry of Health 518/04.
- For any area, at least 4 monitoring wells should be installed according to the rule ABNT/NBR13.895 and CETESB-06.100, for checking standards of pH, hardness, sulfate, manganese, aluminum, iron, nitrate, nitrite, ammonia, Kjeldahl nitrogen14, potassium, calcium, dissolved solids, conductivity and phenols.
- A legal responsible contracted by working for the sugar mill company will then undertake the monitoring, sending the samples for examination to an accredited lab, which will determine whether the samples meet CETESB standards.

According to Smeets et al. (2006), the prevention of soil erosion and nutrient depletion can be reduced through special management procedures related to erosion, avoiding plantations on marginal or vulnerable soils, or with high declivity, monitoring soil quality and nutrient balance.

The sugarcane culture in Brazil is in fact well known for its relatively small soil erosion loss, mainly when compared to soybean and corn (Macedo, 2005).

3.5. Biodiversity

Direct impacts of sugarcane production on biodiversity are limited, because new cane crops are established mainly in pasturelands. As mentioned, these areas are far from important biomes like Amazon Rain Forest, *Cerrado*, Atlantic Forest and *Pantanal* (Smeets et al., 2006).

According to the state Secretariat for the Environment, there are 10,000 km^2 of degraded riparian areas in São Paulo; of this total, 1500 km^2 are in the sugar/ethanol sector as shown in Table 7. It must be stressed that in this study 7.4% of this area was still covered by sugarcane crops, possibly because the cane cycle of 4–5 years was being finished. The implementation of riparian areas, as mentioned, in addition to the protection of water sources

Table 7
Permanent protection areas and sugarcane crops

Permanent protection areas (APP)	% of sugarcane area
APP with natural forest	3.5
APP with reforestation	0.8
APP with natural recovery	2.9
APP with sugarcane crops	0.6
APP total	8.1

Source: Ricci (2005) in Macedo (2005).

and streams, can promote the restoration of biodiversity in the long run.

During sugarcane burning, some animals that cannot run away from the fire die; unfortunately, in general these animals are not able to return to wild life and are sent to zoos.

4. Social aspects

4.1. Social impacts

Regarding socioeconomics impacts of the agribusiness, the most important is regarding job and income creation for a very wide range of workface capacity building programs, with the flexibility to support local characteristics using different technologies. It should also be remembered that the industry fosters substantial foreign currency savings by avoiding oil imports, and the business and technological development of a major equipment industry.

Labor conditions' compliance with International Labor Organization (ILO) standards and social responsibility are partially implemented in São Paulo State.

Brazil's labor legislation is well known for its advances in workers protection; the labor union is developed and plays a key role in employment relationships. For sugarcane, the specific aspects of employment relations in agriculture are better than other rural sectors, with formal jobs mainly being in São Paulo State. Compared to the Brazilian 40% mean rate of formal jobs, the sugarcane industry's agricultural activities now have a rate of 72.9% (from the 53.6% of 1992), reaching 93.8% in São Paulo (2005) and only 60.8% in the north/northeast region.

However, local problems still exist. In Sao Paulo State, in the last three seasons (2004 to 2007), 19 cases of workers death were reported. Strong publicity has been given to such issues but it seems these can be isolated cases because work conditions in sugarcane crops seem to be better than in other rural sectors.

4.2. Jobs

In São Paulo, non-specialized workers' (sugarcane cutters) wages correspond to 86% of agricultural workers in general, and 46% of industrial workers. The average family income of those workers was higher than the income of 50% of all Brazilian families.

The formal direct jobs in the industry are now increasing in number (18% from 2000 to 2002) and reached 764,000 in 2002, while jobs in agriculture decreased. People having studied for less than 4 years represent 37.6% of workers, with 15.3% being illiterate (4% in the center-south).

This means that the workers in the sugarcane industry are becoming more skilled and are receiving higher wages.

Regarding job creation, for every 300 million tons of sugarcane produced, approximately 700,000 jobs are created. In the early 1990s, there were 800,000 direct jobs in the sugarcane sector; which means that for every 1 Mt of sugarcane produced and processed, there were 2200 direct jobs (73% in agriculture) and 660 indirect jobs (considering only equipment production and maintenance, chemical supplies and others); in the north-northeast, it is three times as much as in the center-south (Macedo, 2005).

In São Paulo State, the same legislation that established the mandatory mechanized harvesting of green cane includes a program of professional re-qualification for those rural workers who used to harvest sugarcane and were replaced by mechanical harvesting. By 2007, around 40% of the sugarcane in Sao Paulo Statewas harvested without burning (Fig. 2) and all workers involved received this re-qualification. In fact, this is an important issue because during the current harvesting season (2007/2008) mills are facing difficulties in hiring qualified workers to operate the machines for mechanical harvesting.

On the other hand, most of the job expansion in São Paulo State in 2005 was due to the ethanol sector. Of the 114 new jobs in the State of São Paulo, 89 were in the ethanol sector, corresponding to 75% (O Estado de São Paulo, 2007).

Regarding the size of sugarcane producers in Brazil, almost 75% of the sugarcane land is owned by large producers. However, there are also around 60,000 small producers in the midwest-southern Regions, organized in cooperatives with an increasing negotiation power. A payment system based on the sucrose content in sugarcane has been used since a long time and has promoted significant growth in agricultural productivity.

Despite the fact that most sugarcane producers are quite big, there are two different situations. In São Paulo State, in most cases the sugarcane planted area belongs to large producers. A different situation is found in Paraná State (southern region, one of the highest sugarcane producers in the country) where most sugarcane producers are small and are members of cooperatives.

Besides the social benefits existing in this sector, there are other socioeconomic issues. The investment needed for job creation in the sugarcane sector is much lower than in the other industrial sectors, as is shown in Figs. 7(left) and (right). The creation of one job in the ethanol agro industry requires on average US$ 11,000, while a job in the chemical and petrochemical industry costs 20 times more. Also, the rate of jobs per unit of energy produced is 152 times higher in the ethanol industry than in the oil industry.

4.3. Wages, income distribution and land ownership

In the center-south, the income of people working in sugarcane crops is higher than in coffee, citrus and corn crops, but lower than in soybean crops (highly mechanized, with more specialized jobs). In the north-northeast, the income in sugarcane crops is higher than in coffee, rice, banana, manioc (cassava) and corn crops, equivalent to the income in citrus crops, and lower than in soybean crops. However, the payment is always based on the amount of sugarcane harvested.

Mills keep more than 600 schools, 200 daycares units and 300 ambulatory care units (Smeets et al., 2006). According to Barbosa (2005) in Smeets et al. (2006), a sample of 47 São Paulo-based units showed that "more than 90% provide health and dental care, transportation and collective life insurance, and over 80% provide meals and pharmaceutical care. More than 84% have profit-sharing programs, accommodations and day care units". Social Balance Sheet Indicators for 73 companies (CENBIO, 2006) show that funds equivalent to 24.5% of the payroll are used for such purposes as profit-sharing programs (6.72%), food (6.54%),

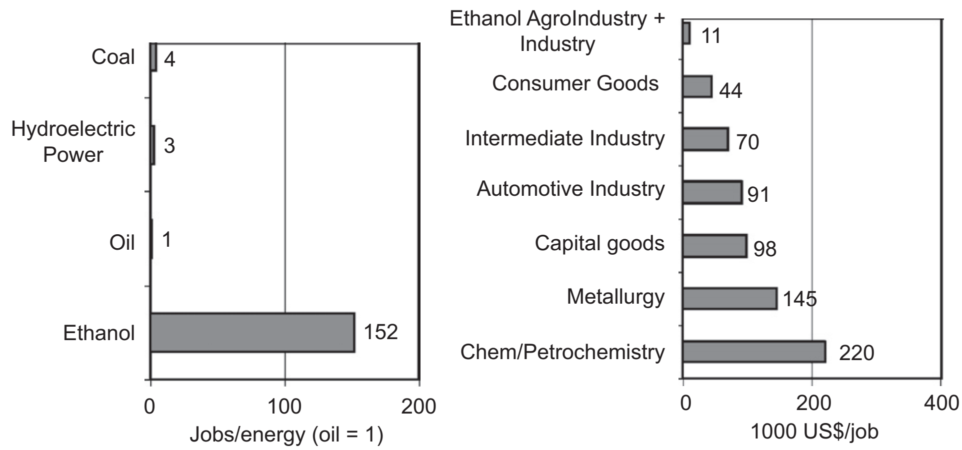


Fig. 7. Employment numbers from Proalcool, the Brazilian Ethanol Program; Jobs per unit of energy produced (left) and investment for job creation (right). *Source*: Goldemberg (2002).

Table 8
Main characteristics of workers in the sugarcane culture and similar industries in Brazil, 2003

Statistic	Sugarcane crops	Sugar	Ethanol	Food and beverages	Fuels	Chemicals
People (× 1000)	789.4	126.0	67.0	1507.0	104.7	641.2
Mean age (years)	35.1	36.6	35.6	34.4	37.1	33.4
Mean education (years)	2.9	6.5	7.3	7.1	8.9	9.6
Mean income (R$/month)	446.6	821.3	849.9	575.0	1281.1	1074.6
Gini coefficient	0.493	0.423	0.393	0.490	0.476	0.531

Source: Macedo (2005).

healthcare (5.9%), occupational health and safety (2.3%), and education, capacity building and professional development (1.9%).

The workers in São Paulo receive, on average, wages that were 80% higher than those of workers holding other agricultural jobs.

Their incomes were also higher than 50% of those in the service sector and 40% of those in industry (Macedo, 2005).

In fact, northeast region wages in general are much lower. However, a recent paper on the sugarcane industry informs that sugarcane workmen's wages rose from R$310 (US$144.2) to R$365 (US$169.8), which represents an increase of 17.74% (CENBIO, 2006). These figures are positive because currently the Brazilian minimum wage was R$350 (US$163.5) per month in 2006 (DIEESE, 2006). This is important because in agriculture, the average education level in the north-northeast is equivalent to half the level (years at school) of the center-south.

Smeets et al. (2006) discuss this issue. Accordingly, Gini's coefficient[3] for the sugarcane and ethanol production sector is low compared to the national average and other sectors.

Table 8 summarizes the main characteristics of the sugarcane sector workers in comparison to other sectors.

4.4. *Working conditions*

The Brazilian government signed ILO's recommendations, which forbid most precarious ways of child labor and define the minimum age of 18 years for hard jobs. Also, Brazil has intensified

Table 9
Overview of workers in agriculture, and specifically in the sugarcane and ethanol production sector, and percentage of workers under 17

	Number of workers	Number of workers <17	%
Total in agriculture	28,860,000	2,400,000	8.3
Of which in sugarcane and ethanol	764,600	22,900	3.0
Percentage	2.65	0.95	

Source: Schwartzman and Schwartzman (2004) and OIT (2006) apud Smeets et al. (2006).

inspection on working conditions in the sugarcane sector (Rodrigues and Ortiz, 2006). Nevertheless, the inspection is still not sufficient and some worker right violations have been reported, and not just in the northeast region.

In 2006, the inspection from Brazilian Public Ministry was stricter, which resulted in over 600 fines in São Paulo State (Primeira Página journal, December 2006). The inspections were focused on work condition and environmental issues.

Existing reports inform that some mills do not respect the labor law in the State of São Paulo and that there is still a long way to go (Fernando Ribeiro, general secretary of UNICA in a report by Barros (2005)). The mechanism of family compensation for the loss of family income from child labor, where parents are compensated for the costs of education. This mechanism is calculated to increase the ethanol costs by 4% (Smeets et al., 2006). Table 9 shows that even with these incentives, 3% of workers in the sugarcane and ethanol production sector are younger than 17 years old.

Despite the improvements on working conditions achieved in the last decade, further progress is still needed.

[3] A measure for the income distribution. It is a number between 0 and 1, where 0 corresponds to perfect equality (e.g. everyone has the same income) and 1 corresponds to perfect inequality (e.g. one person has all the income, and everyone else has zero income).

5. Sustainability criteria

There are indeed concerns regarding biofuel sustainability in most developed countries.

Conclusions from a workshop held in Delhi in 2005 (Shanker and Fallot, 2006) by the GEF of the World Bank showed that biofuels can offer a sustainable and carbon-neutral alternative to petroleum fuels, provided that environmental safeguards are put in place, as well as sustainable land management occurs. This would exclude, for example, the production of biofuels from cleared forest land, and biofuels with negative GHG emission reduction. The potential negative impacts on soil, water and biodiversity in the case of large-scale monoculture plantation must also be considered. It was recognized that the role of biofuels in mitigating climate change is also a question of natural resource management, land degradation, biodiversity and international waters.

The Worldwatch Institute (2007) discussed a number of proposals for standards and certification procedures for biofuels and questions related to trade, which have a strong link to food and forestry commodities, issues associated with WTO regulation.

In 2007, INMETRO (National Institute of Metrology, Standardization and Industrial Quality) informed that they are starting a voluntary certification for sugarcane and ethanol production (Lobo, 2007), to be implemented by the second half of 2008. The main principles will include environmental, social and labor issues, with qualitative and quantitative indicators like carbon emissions and energy balance.

Macedo (2005) also discusses several aspects of sugarcane production and conversion to ethanol, as well as sustainability issues related to it.

According to the Worldwatch Institute (2007), "the issue of trade barriers for biofuels was brought to light in the case of Brazilian ethanol export to Europe, which has tariffs in place for commodities derived from sugar". However, boycotts against oil companies related to human rights and environmental excess is common. Several biofuel-exporting countries have expressed concern about the trade implications of a rigorous biofuels certification scheme, considering that it can create trade barriers for developing countries' exports and can be used by importing countries (industrialized countries) to protect their domestic biofuel industries (Coelho, 2005).

Smeets et al. (2006) have discussed the ethanol production sustainability in Brazil, comparing Brazilian and Dutch legislations and analyzing the perspectives for ethanol production certification in Brazil.

We show the results of our comparison in Table 10.

Biomass and biofuels trade contribute to rural development, allowing additional income and job creation for developing countries, contributing to the sustainability of natural resources, collaborating with GHGes emission reduction in a cost-effective way and diversifying the world's fuel needs.

Table 10
Comparison between São Paulo State and Dutch sustainability criteria, indicators/procedures and suggested levels for 2007 and 2011; Cramer et al. (2006)

Criterion and level	Indicator/procedure 2007 Dutch criteria	São Paulo State (2007)
1. GHG balance, net emission reduction by ⩾30% in 2007 and ⩾50% in 2011	Use of developed methodology Use of reference values for specific steps in logistic chain	Energy ratio (renewable energy production/fossil fuel consumption) in the ethanol production is 8:1[a]
2. Competition with food supply, local energy supply, medicines and building materials Supply is not allowed to decrease	[b]	Presently, no competition
3. Biodiversity, no decline of protected areas or valuable ecosystems in 2007 also active protection of local ecosystems in 2011	No plantations near gazetted protected areas or high conservation value areas; max. 5% conversion of forest to plantations within 5 years[b]	Decree for legal reserve
4. Wealth, no negative effects on regional and national economy in 2007, and active contribution to increase of local wealth in 2011	Based on Economic Performance indicators of the global reporting initiative[b]	Occurring in all sugarcane regions
5. Welfare, including	Compliance with social	
5a. Labor conditions	Accountability 8000 and other treaties	Best conditions in rural areas for sugarcane workers
5b. Human rights	Compliance with universal declaration of HR, as 2007. Three criteria from existing systems (RSPO 2.3, FSC 2, FSC 3)	Compliance with universal declaration of HR
5c. Property and use rights		Well-enforced local legislation
5d. Social conditions of local population	[b]	
5e. Integrity	Compliance with business principles of countering bribery	
6. Environment, including		
6a. Waste management	Compliance with local and national laws; good agricultural practice	Compliance with local/national legislation
6b. Use of agro-chemicals (incl. fertilizers)	Compliance with local and national laws	Compliance with local/national legislation
6c. Prevention of soil erosion and nutrient depletion	Erosion management plan avoid plantations on marginal or vulnerable soils, or with high declivity monitoring soil quality nutrient balance	No information available
6d. Preservation of quality and quantity of surface water and ground water	Special attention for water use and treatment[b]	Controlled by São Paulo State Environmental Agency
6e. Airborne emissions	Comply with national laws	State decree to phase-out sugarcane burning
6f. Use of genetically modified organisms (GMOs)	Compliance with USA (safety) rules	Presently not authorized

[a] In Brazil, the current reduction on GHG emissions due to the use of ethanol replacing gasoline in the transportation sector is 53%.
[b] For this criterion a reporting obligation applies. A protocol for reporting will be developed.

References

Abrantes, R., 2003. A Emissão de Aldeídos e Hidrocarbonetos Policíclicos Aromáticos de Veículos Comerciais a Diesel (Aldehydes and Polycycicle Aromatic Hydrocarbon Emissions in Commercial Diesel Vehicles), SIMEA 2003. CETESB, São Paulo, Brazil.

Apace Research Ltd., Intensive Field trial of ethanol/petrol blend in vehicles. EDRC Project No. 2511, Australia, December 1998. Available at 〈http://journeytoforever.org/biofuel_library/EthanolApace.PDF〉.

Barros, C.J., 2005. Novo ciclo da cana expõe superexploração do trabalho (New sugarcane cicle of working explore). Carta Maior, São Paulo.

Bates, D.V., Koenig, M.B., 2003. Health and air quality 2002—Phase 1: methods for estimating and applying relationships between air pollution and health effects. Final Report, British Columbia Lung Association [RWDI Project: W02-304], May 2003.

Brito, A., 2007. Em cinco anos, preço da terra em São Paulo subiu mais de 100% (In five years, price of land in São Paulo raised more than 100%). O Estado de São Paulo, Caderno Economia, May 20, p. B5.

Cançado, J.E.D., Saldiva, P.H.N., Pereira, L.A.A., Lara, L.B.L.S., Artaxo, P., Martinelli, L.A., Arbex, M.A., Zanobetti, A., Braga, A.L.F., 2006. The impact of sugarcane-burning emissions on the respiratory system of children and the elderly. Environmental Health Perspectives 114 (5), 725–729.

CENBIO, 2006. Analysis of status and opportunities. Study prepared by the Brazilian Reference Center on Biomass (CENBIO) to the BP.

Cerri, C.C., 2007. Seqüestro de Carbono (Carbon Sequestration). Presentation at II Encontro de Tendências em Biocombustíveis, na Área Internacional, Petrobrás, Rio de Janeiro.

CETESB, 2005. Decisão de Diretoria No. 35, DE 9.03.2005, Dispõe sobre a homologação da Norma Técnica P4.231, Vinhaça-Critérios e Procedimentos para Aplicação no Solo Agrícola (Criteria and Procedures to Vinasse Application), São Paulo.

Coelho, S.T., 2005. Biofuels—advantages and trade barriers. Presentation at the United Nations Conference on Trade and Development, Geneva.

Coelho, S.T., Goldemberg, J., 2004. Alternative transportation fuels: contemporary case studies. Encyclopedia of Energy 01, 67–80.

Coelho, S.T., Goldemberg, J., Lucon, O.S., Guardabassi, P.M., 2006. Brazilian sugarcane ethanol: lessons learned. Energy for Sustainable Development X (2), 26–39.

CONAMA Resolution, 382/2006 Estabelece os limites máximos de emissão de poluentes atmosféricos para fontes fixas (Establishes limits to atmospheric emissions from stationary sources). Diário Oficial da União. Available at 〈http://www.mma.gov.br/port/conama/res/res06/res38206.pdf〉.

Cramer, J., Wissema, E., Lammers, E., Faaij, A., Hamelinck, C., Bergsma, G., van den Heuvel, E., Junginger, M., Smeets, E., 2006. Criteria for sustainable biomass production, Netherlands.

CTC, 2007. Tópicos de Sustentabilidade Ambiental na Agroindústria Sucroalcooleira (Topics of Environmental Sustainability in Sugarcane Industry).

DIEESE, 2006. Salário mínimo nominal e necessário (Minimum nominal and necessary wage). Available at 〈www.dieese.org.br/rel/rac/salminmar06.xml〉.

Energy Information Administration (EIA—Official Energy Statistics from the US Government), 2008. Oxygenate production. Accessed on January 2008. Available at 〈http://tonto.eia.doe.gov/dnav/pet/hist/m_epooxe_yop_-nus_1m.htm〉.

ESMAP, 2005. Potential for Biofuels for Transport in Developing Countries. ESMAP, Energy and Water Department, World Bank, Washington, DC, USA, p. 182.

Goldemberg, J., 2002. Brazilian Energy Initiative. World Summit on Sustainable Development, Johannesburg, South Africa.

Goldemberg, J., Coelho, S.T., Lucon, O.S., Nastari, P.M., 2003. Ethanol learning curve—the Brazilian experience. Biomass and Bioenergy 26/3, 301–304.

IEA (International Energy Agency), 2004. Biofuels for Transport: An International Perspective, Paris, ISBN:92-64-01.

IEA (Instituto de Economia Agricola), 2007. Banco de Dados (Database). Available at 〈http://www.iea.sp.gov.br/out/banco/menu.php〉. Accessed on May 2007.

Jacobson, M.Z., 2007. Effects of ethanol (E85) versus gasoline vehicles on cancer and mortality in the United States. Environmental Science and Technology Available at 〈http://www.stanford.edu/group/efmh/jacobson/E85PaperEST0207.pdf〉.

Larson, E.D., 2006. A review of life-cycle analysis studies on liquid biofuels systems for the transport sector. Energy for Sustainable Development 10 (2), 109–126.

Leal, R.L.V., 2007. Potencial da Produção de Álcool para Exportação (Potential of ethanol production to be exported). Presentation at II Encontro de Tendências em Biocombustíveis, na Área Internacional, Petrobrás, Rio de Janeiro, November 26–27, 2007.

Lobo, A., 2007. Certifying Biofuels. In: Conference on Biofuels: An Option for a Less Carbon-Intensive Economy, Rio de Janeiro, December 2007. Available at 〈http://www.unctad.org/Templates/Page.asp?intItemID=4412&lang=1〉.

Lora, B.A., Monteiro, M.B., Assunção, V., Frigerio R., 2006. Levantamento Georreferenciado da Expansão da Cultura de Cana-de-Açúcar no Estado de São Paulo (Georeferenced Assessment of Sugarcane Culture Expansion in São Paulo state), São Paulo, December 2006.

Macedo, I.C., 2005. Sugarcane's Energy: Twelve Studies on Brazilian Sugarcane Agribusiness and its Sustainability. União da Agroindústria Canavieira de São Paulo, São Paulo, p. 195.

Macedo, I.C., Leal, M.R.L.V., da Silva, J.E.A.R., 2004. Assessment of Greenhouse Gas Emissions in the Production and Use of Fuel Ethanol in Brazil. Secretariat of the Environment of the State of São Paulo, Brazil Available at 〈http://www.unica.com.br/i_pages/files/pdf_ingles.pdf〉.

Matioli, C.S., 1998. Irrigação suplementar de cana-de-açúcar: modelo de análise de decisão para o Estado de São Paulo (Sugarcane suplementar irrigation: a decision analysis model to São Paulo state). Piracicaba, SP, Tese (Doutorado)—Escola Superior de Agricultura "Luiz de Queiroz," Universidade de São Paulo.

MCT (Ministry for Science and Technology), 2004. Comunicação Nacional Inicial do Brasil à Convenção—Quadro das Nações Unidas sobre Mudança do Clima (Brazil's Initial National Communication to the UNFCCC), Brasília. Available at 〈http://www.mct.gov.br/index.php/content/view/4004.html〉.

Miranda, E.E., Dorado, A.J., Assunção, J.V., 1994. Doenças respiratórias crônicas em quatro municípios paulistas (Chronic respiratory disease in four São Paulo municipalities). USP/UNICAMP/Ecoforça, São Paulo.

MME (Ministry of Mines and Energy), 2007. Brazilian Energy Balance 2007—Base Year 2006, Rio de Janeiro, 2007. Available at 〈www.mme.gov.br〉.

Moreira, J.R., Goldemberg, J., 1999. The alcohol program. Energy Policy 27, 229–245.

NIPE/Unicamp, 2005. Estudo sobre as possibilidades e impactos da produção de grandes quantidades de etanol visando à substituição parcial de gasolina no mundo (Study on possibilities and impacts of the production of large amounts of ethanol to partially replace gasoline in the world). Final Report, Campinas, Dezembro 2005.

O Estado de São Paulo, Caderno Economia, May 11, 2007.

OIT (Organização Internacional do Trabalho-International Labor Organization), 2006. Available at 〈http://www.oitbrasil.org.br/〉.

Primeira Página Journal, December 2006.

Rodrigues, D., Ortiz, L., 2006. Em direção à sustentabilidade da produção de etanol de cana-de-açúcar no Brasil Amigos da Terra and Vitae Civilis, October 2006.

Rosseto, R., 2004. A cultura da cana, da degradação à conservação (Sugarcane culture, from degradation to conservation). Visão Agrícola, ESALQ—USP, Year 01, January 2004.

Saldiva, P., 2007. Personal communication, April.

Schwartzman, S., Schwartzman, F., 2004. O trabalho infantil no Brasil (Child Labor in Brazil). Journal do Brasil 27/12/1996.

Sepúlveda, D.G., 2007. Personal communication. Contact: dulio@semad.mg.gov.br.

Shanker, A., Fallot, A., 2006. Global environmental facility—scientific and technical advisory panel workshop on liquid biofuels: main findings. Energy for Sustainable Development X (2), 19–25.

Smeets, E., Junginger, M., Faaij, A., Walter, A.C., Dolzan, P., 2006. Sustainability of Brazilian bio-ethanol. Report NWS-E-2006-110. Universiteit Utrecht Copernicus Institute, Department of Science, Technology and Society and University of Campinas, Brazil.

Souza, N., 2007. São Paulo centraliza a polêmica (São Paulo centers the controversy). O Estado de São Paulo. Suplemento Agrícola, May 23, 2007, p. 7.

Tomita, R.Y., 2005. Legislação de Agrotóxicos e sua Contribuição para a Proteção de qualidade do meio ambiente (Legislation on agrotoxics and its contribution to environment quality protection). Biológico, São Paulo 67(1/2), Jan/Dez 2005, pp. 1–10.

UK DTI, 2003. Technology status review and carbon abatement potential of renewable transport fuels in the UK. Report B/U2/00785/REP, 2003. Available at 〈www.dti.gov.uk/renewables/publications/pdfs/b200785.pdf〉.

UNICA, 2007. Produção e uso do Etanol combustível no Brasil. Respostas às questões mais freqüentes (Fuel ethanol production and use in Brazil: answers to most frequent questions). São Paulo, May 2007. Available at 〈http://www.portalunica.com.br/portalunica/files/referencia_publicacoes_livros-3-Arquivo.pdf〉.

UNICA, 2008. Statistics of sugarcane sector—season 2006/ 2007. Accessed on January 2008. Available at 〈http://www.portalunica.com.br/portalunica/files/referencia_estatisticas_producaobrasil-9-Tabela.xls〉.

USDA, 1995. Estimating the net energy balance of corn ethanol. Report by Shapouri, H., Duffield, J.A., Graboski, M.S., US Department of Agriculture, Economic Research Service, Office of Energy, Agricultural Economic Report No. 721, July 1995. Available at 〈http://www.ers.usda.gov/publications/aer721/AER721.PDF〉.

Worldwatch Institute, 2007. Biofuels for Transport—Global Potential and Implications for Energy and Agriculture. London, Earthscan.