Chapter 5
Environmental sustainability of sugarcane ethanol in Brazil

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1. Introduction

Brazil's economy is performing well during the last few year reaching international investment grade levels, while at the same time providing quantifiable reductions of greenhouse gases, specially through its renewable energy matrix and the large scale use of ethanol in transportation. It is well-known that the quality of life in the world increases with economic growth, which increases demand for energy (Figure 1). If one considers the externalities created by burning fossil fuels, then economic growth becomes a major threat to the global well being; reinforcing the need to explore alternatives to improve the efficiency of energy use and diversification of energy sources, and especially from renewable ones.

Brazil's commitment to sustainability in the agribusiness for example can be assessed by concrete examples such as the development and implemental of stringent legal environmental frameworks, agricultural zoning, massive investments in research and development and rural social policies, being the ethanol business a good example from which best practices could be disseminated.

The benefits of the production and use of ethanol in Brazil can also serve as a platform and model for further acceptance and deployment of renewable sources of biomass as feedstock for sustainable production of biofuels in the World. However there are several drivers that currently affect the supply and demand for biofuels and their sustainable production: land use changes, environmental concerns, competition with other sources of energy, food security, agricultural subsidies, innovation and technological development, public policies, oil prices, energy security policies, etc.

The Proalcool program (the Brazilian program for the production of ethanol) started in 1975, 33 years ago, is a good example of a pro-active public policy supporting the development of biofuels with a focus on sugarcane ethanol. It made Brazil the second largest producer of ethanol (expected production of 23 billion liters in 2008), with the lowest production costs in the World (US$ 0.22/l – Table 1).

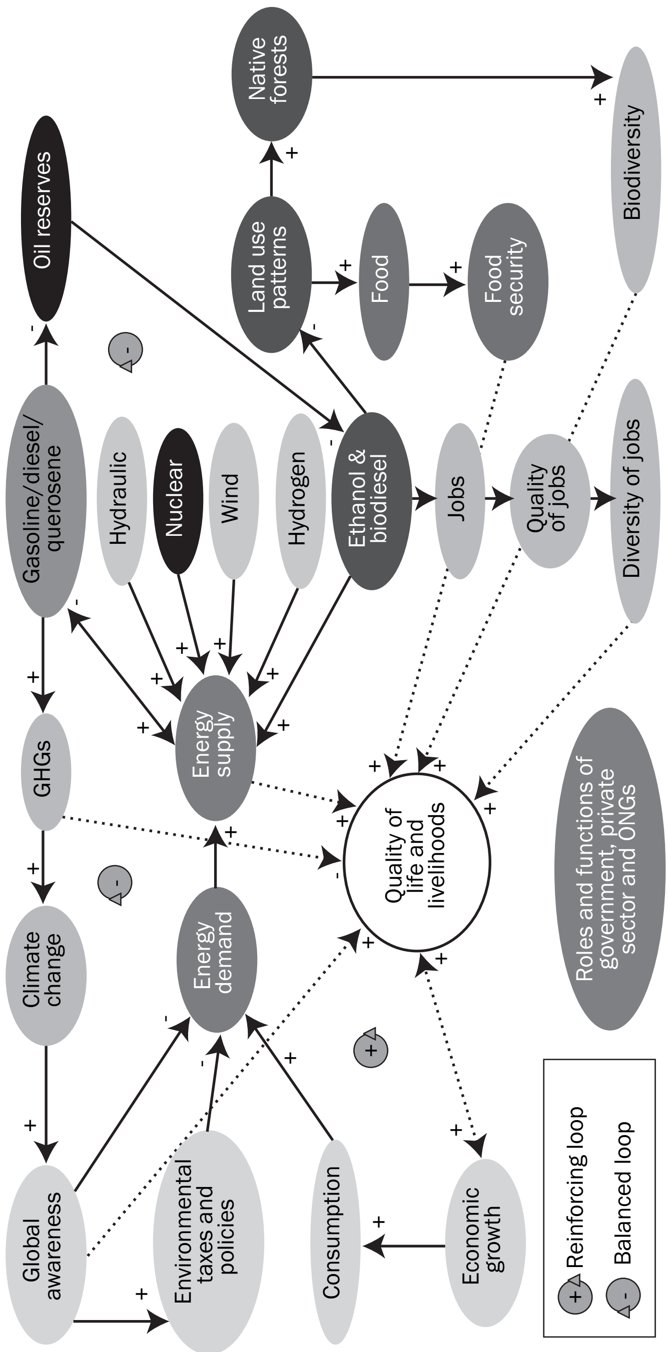


Figure 1. Social-economical-environmental dynamic structure. Source: Venture Partners do Brasil.

Table 1. Production costs of different biofuels (US$/liter)[1].

Costs item	United States							Brazil	EU
	Maize wet milling	Maize dry milling	Sugarcane	Sugar beets	Molasses [3]	Raw sugar [3]	Refined sugar [3]	Sugarcane [4]	Sugarbeets [4]
Feedstock[2]	0.11	0.14	0.40	0.43	0.25	0.84	0.97	0.08	0.26
Processing	0.17	0.14	0.25	0.21	0.10	0.10	0.10	0.14	0.52
Total	0.28	0.28	0.65	0.63	0.34	0.94	1.07	0.22	0.78

Source: USDA (2007).
[1] Excludes capital costs.
[2] Feedstock costs for US maize wet and dry milling are net feedstock costs; feedstock costs for US sugarcane and sugar beets are gross feedstock costs.
[3] Excludes transportation costs.
[4] Average of published estimates.

The long track record of Brazilian sugarcane ethanol proved its economic sustainability over time, while improving its social and environmental indicators, involving technology transfer from Europe, US and other regions and developing several innovations at national level. This program no longer exists, however it has contributed significantly to improve the productivity of sugarcane and ethanol extraction rates (Figure 2).

Due to the increasing internal demands and the possibility of future exports, it is expected that the Brazilian production might increase to 47 billion liters of ethanol by 2015, with an estimated annual growth rate of 10-13% (Table 2).

Several steps will be necessary to achieve these production targets, including sustainable planning of the sugarcane expansion into new areas, improving the logistics, the development of global markets and continuously developing new technological innovations, while at the same time improving the environmental performance of existing brown fields (areas with already established sugarcane fields and industry either/or sugar mills/distilleries) and especially from new green fields (new areas for expansion of sugarcane fields and new industrial plants), which are being implemented using cutting edge technologies in the agriculture and in the industry. With more than 360 mills in operation, there is a gap between the best practices available and the average performance of Brazilian mills, however due to recent developments in the ethanol business, with the consolidation of economic groups, capacity building programs, companies going public, new investments

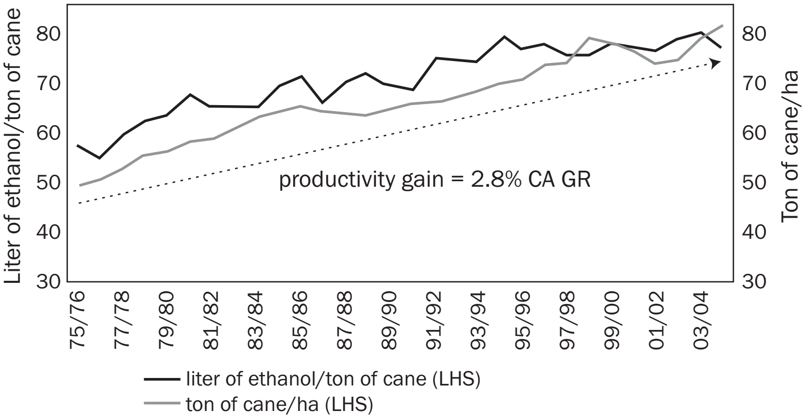


Figure 2. Evolution of productivity of Brazilian ethanol. Source: Itaú Corretora (2007).

Table 2. Future projections of ethanol production in Brazil.

	2007/08	**2015/16**	**2020/21**
Sugarcane Production (M-ton)	493	829	1,038
Area (M-ha)	7.8	11.4	13.9
Sugar (M-ton)	30.8	41.3	45
Internal	12.2	11.4	12.1
Export	18.6	29.9	32.9
Ethanol (B-liters)	22.5	46.9	65.3
Internal	18.9	34.6	49.6
Export	3.6	12.3	15.7
Bioelectricity (GW average)	1.8	11.5	14.4

Source: Unica (2008).

in research and development the speed of this dissemination is increasing significantly from previous decades.

This chapter addresses the following:
- the Brazilian environmental legal frameworks;
- key environmental indicators: carbon, water, soil, agrochemicals, biodiversity, air and by-products;
- different biofuels certifications regimes and compliance;
- the future steps and the role of innovation.

2. The Brazilian environmental legal framework regulating ethanol production

The Brazilian environmental legal framework is complex and one of the most stringent and advanced in the World. As an agribusiness activity, the ethanol/sugar industry has several environmental restrictions that require appropriate legislation or general policies for its operation. Some of them are pioneers in the area which define principles in order to maintain the welfare of living beings and to provide resources for future generations: the first version of the Brazilian forest code dated from 1931, already addressed the need to combine forest cover with quality of life and livelihoods.

Brazil has wide range of federal and state laws regarding environmental protection (Table3), aiming at combining the social economic development with environmental preservation, which the ethanol business need to comply with for its proper operation.

They also involve frameworks such as the Environmental Impact Assessment and Environmental Licensing, among others (Figure 3), especially for the implementation of new project: i.e. new green field projects in Brazil are being stringently assessed (Nassar *et al.*, this book) using these frameworks.

Volunteer adherence to Environmental Protocols represents also a major breakthrough for the sugar business. For example The 'Protocolo Agroambiental do Setor Sucroalcooleiro' (Agriculture and Environmental Protocol for the ethanol/sugar industry) signed by UNICA and the Government of the State of São Paulo in June 2007 deals with issues such as: conservation of soil and water resources, protection of forests, recovery of riparian corridors and watersheds, reduction of greenhouse emissions and improve the use of agrochemicals and fertilizers. But its main focus is anticipating the legal deadlines for ending sugarcane burning by 2014 from previous deadline of 2021. In February 2008, the State Secretariat of Environment reported that 141 industries of sugar and alcohol had already signed the Protocol, receiving the 'Certificado de Conformidade Agroambiental' (Agricultural and Environmental Certificate of Compliance). These adherences correspond for more than 90% of the total sugarcane production in São Paulo. A similar initiative is happening in the State of Minas Gerais with the 'Protocolo de Intenções de Eliminação da Queima da Cana no Setor Sucroalcooleiro de Minas Gerais' from August 2008.

Table 3. Summary of main environmental laws.

Law	Objective	P.S.
No. 4,771, September 15th, 1965	Forest Code	Permanent preservation areas
No. 997, May 31st, 1976	Environment Polution Control	Environmental Permission
Portaria do Ministério do Interior No. 323, November 29th, 1981	It prohibits release of vinhoto in the water	
No. 6,938, August 31st, 1981	Environment National Policy	Mechanisms and instruments (environmental zoning, Environmental Impact Assessment)
CONAMA deliberation No.001/7986	General Guidelines for the Evaluation of Environmental Impact	For 'industrial complex and units and agro-industrial'
No. 6,171, July 04th, 1988	The use, conservation and preservation of agricultural soil	
No. 11,241, September 19th, 2002	Gradual elimination of burning the straw of sugarcane	Elimination of the use of fire as a unstraw method and facilitator of cutting the sugarcane
No. 12183/05	Use of water charge	
No. 50,889, June 16th, 2006	Legal Reserve of landed property in the State of São Paulo	Obligation of reserving an area equivalent to 20% of each rural property
SMA deliberation 42, October 14th, 2006	Environmental prior license to distilleries of alcohol, sugar plants and units of production of spirits	It defines criteria and procedures
Deliberation No. 382, December 26th, 2006	It sets the maximum emission of air pollutants to sources.	Annex III: Emission limits for air pollutants from processes of heat generation from the external combustion of sugarcane's mulch
Agricultural and Environmental Protocol of sugar/ethanol industry	Prominence to anticipate the legal period to the end of the harvest of sugarcane with the previous use of fire in the areas cultivated by plants	Government of the State of São Paulo and UNICA
Elimination intentions of burning sugarcane in the ethanol/sugar sector of Minas Gerais protocol	Removal of burnt by 2014	SIAMIG/SINDAÇÚCAR-MG and Government of the State of Minas Gerais

Source: Brazilian and State laws.

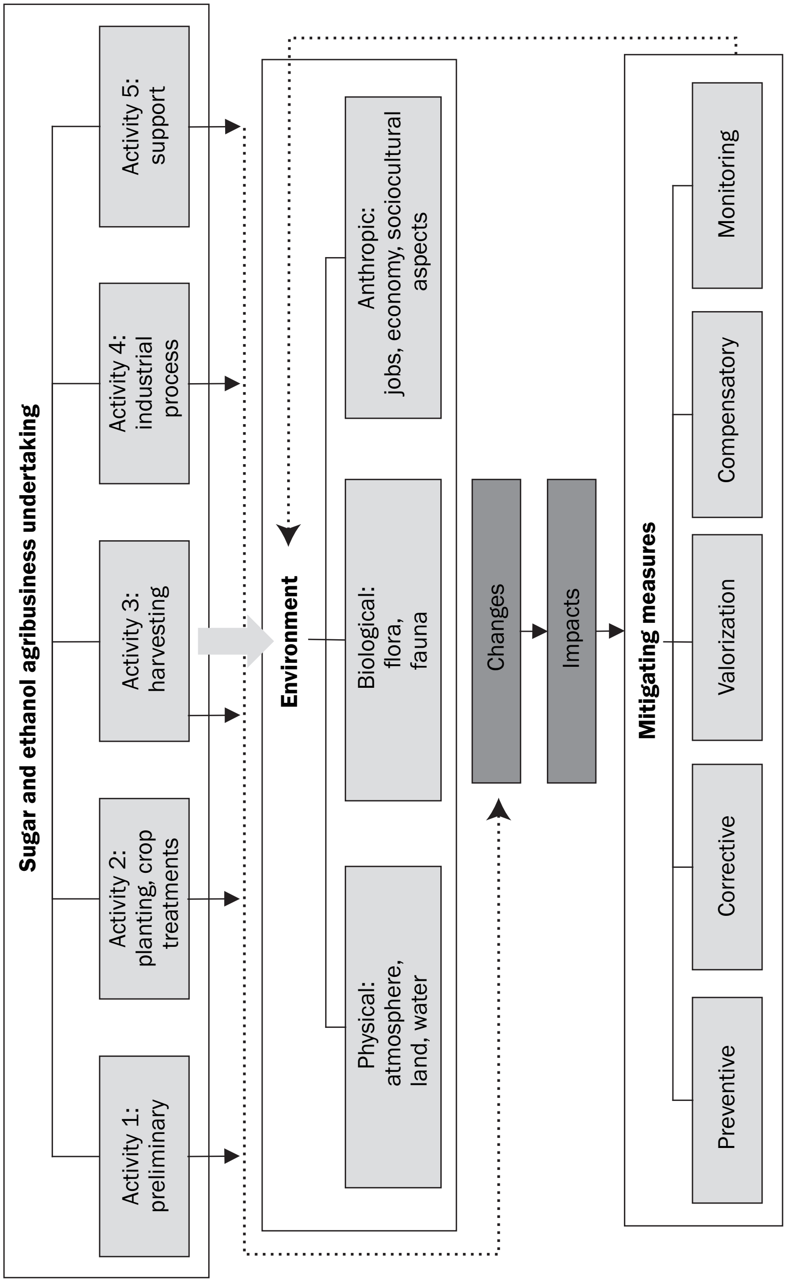


Figure 3. Environmental analysis structure for EIA/RIMA: sugarcane agribusiness. Source: Elia Neto (2008).

3. Environmental indicators

The environmental sustainability is evaluated through indicators such as carbon, water, soil, agrochemicals, biodiversity and by-products.

3.1. Greenhouse gases (GHG) balance

One of the goals of using biofuels is to contribute with net reduction of GHG emissions and thus not affecting carbon stock negatively in different sub-systems of production, below and above ground biomass (roots, branches and leaves) and in the soil (carbon fixed in clay, silt, sand and organic matter). Figure 4 shows that ethanol from sugarcane reduces 86% of the GHG emissions when compared to gasoline. It has also a leading performance when compared to other biofuels from other feedstocks. In addition the energy efficiency difference is even greater: 9.3 against 1.4 to 2.0 of other biomasses (Figure 5).

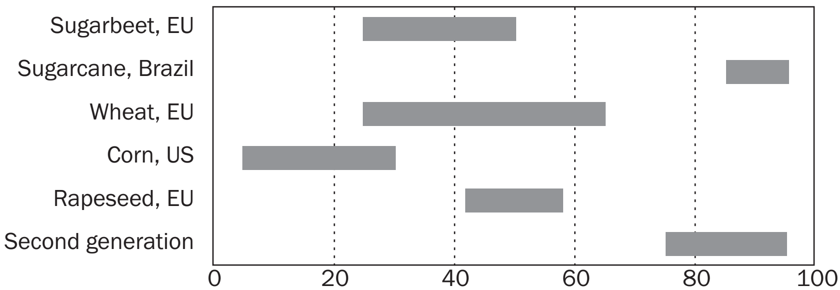


Figure 4. GHG emissions avoided with ethanol or biodiesel replacing gasoline. Source: International Energy Agency (IEA/OECD, 2006).

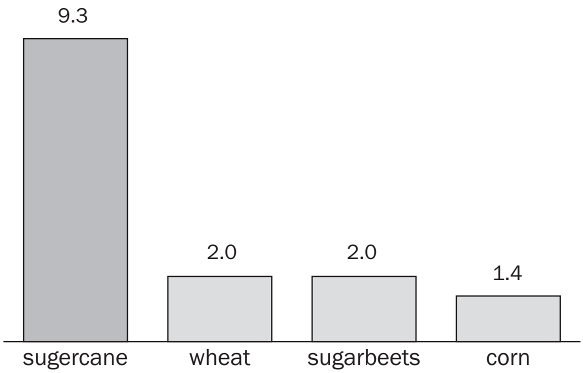


Figure 5. Energy output per unit of fossil fuel consumption in the production process. Source: World Watch Institute (2006) and Macedo *et al.* (2008).

3.1.1. Carbon stocks

One of the main effects caused by land use changes is the variation in the amount of carbon stocks under different subsystem, namely in the soil and in the above ground biomass in the area. When analyzing the environmental effects caused by different land use regimes, the balance of carbon should be taken into account. It is necessary to know how much carbon would be fixed or released into the air under different land use regimes compared with the previous baseline of use.

One limiting factor to perform an in depth analysis of these balances is the lack of long term monitoring plots assessing precisely these dynamics through time. However the stock and flows of carbon for major crops like soybean, maize, cotton and sugarcane have been extensively studied, but in general using different methodologies. There are also other factors that affect the results: crop productivity and management, soil physical and chemical properties, climate and land use history for example.

In large countries such as Brazil, there are many different soils and climatic conditions. The different characteristics of each region will influence the potential for carbon storage. A clay soil, for example, has the ability to store more organic matter and consequently, more carbon than a sandy soil, because of their physical properties. In hot and humid climates, the rate of deposition and decomposition of organic matter is higher than in dry and cold climates, facilitating the deposition of carbon in the soil.

The spatial distribution of crops in Brazil is edaphic-climatic (soil characteristics and climate interactions) dependent for their profitability. These interactions influence carbon content in the soil and in the biomass, which are also affected by soil management practices, such as minimum tillage, which can significantly for example increase soil carbon content. The land use history is also relevant when assessing and explaining current levels of carbon, because when land use changes do occur; soil carbon stocks take several years to achieve a new carbon balance. If carbon is measured in a newly cultivated system, the carbon present in the soil is actually reflecting the carbon content from the formerly existing vegetation/history and not a consequence of current land use. Table 4 presents the carbon stocks in soil for some selected Brazilian crops and in the native vegetation.

For carbon stored in the biomass, crop productivity is of great importance as indicator carbon stored in the above ground biomass per unit of area. The larger the quantity of biomass above ground, the greater the stocks of carbon in biomass (Table 5), which is a measure much easier to obtain and with a larger dataset from multiple management and production systems in Brazil.

According to the National Supply Company (CONAB - Ministry of Agriculture and Livestock, 2008) sugarcane area expanded 653,722 ha in the 2007/2008 period, occupying

Table 4. Carbon stock in soil for selected crops in native vegetation.

Biomass	Carbon stocks in soil (Mg/ha)
Campo Limpo – grassland savannah (a)	72
Sub-tropical forest (b)	72
Tropical forest (c)	71
Natural pasture (d)	56
Soybean (e)	53
Cerradão – woody savannah (a)	53
Managed pasture (f)	52
Cerrado – typical savannah (a)	46
Sugarcane without burn (g)	44
Degraded pasture (h)	41
Maize (h)	40
Cotton (i)	38
Sugarcane burned (g)	35

Sources: (a) Lardy *et al.* (2001); (b) Cerri *et al.* (1986); (c) Trumbore *et al.* (1993); (d) Jantalia *et al.* (2005); (e) Campos (2006); (f) Rangel and Silva *et al.* (2007); (g) Estimated from Galdos (2007); (h) d'Andréa *et al.* (2004); (i) Neves *et al.* (2005).

Table 5. Carbon stocks in the above biomass of selected crops and native vegetation.

Biomass	Carbon stocks in biomass (Mg/ha)
Tropical rain forest (a)	200.0
Cerradão – woody savannah (b)	33.5
Cerrado – typical savannah (b)	25.5
Sugarcane without burn (c)	17.5
Sugarcane burned (c)	17.0
Campo Limpo – grasland savannah (b)	8.4
Managed pasture (d)	6.5
Maize (e)	3.9
Cotton (f)	2.2
Soybean (g)	1.8
Degraded pasture (d)	1.3

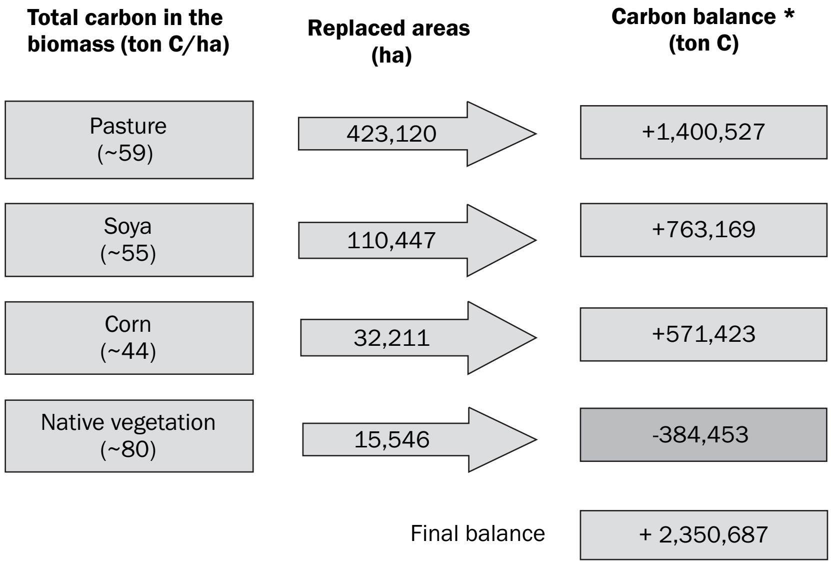
Sources: (a) INPE; (b) Ottmar *et al.* (2001); (c) VPB Estimative; (d) Estimated from Szakács *et al.* (2003); (e) Estimated from Titon *et al.* (2003); (f) Adapted from Fornasieri and Domingos *et al.* (1978); (g) Adapted from Campos (2006).

areas previously covered with pasture (67%), soybean (16.9%), maize (4.9%) and 2.4% of these new areas expanded into native vegetation of cerrado (savannah-like vegetation). From these numbers, it is possible to estimate the overall carbon balance resulting from land use changes due to sugarcane expansion for this period (Table 6). Figure 6 shows the positive carbon balance resulting from 91.2% in the area of expansion of sugarcane, corresponding to the areas of pasture, maize, soybeans and native vegetation as replaced by not burned sugarcane as 100% of these new green field are using mechanized harvesting practices. It was considered for this assessment that the totality of pastures replaced was of planted pastures and the native vegetation replaced as areas of Grassland Savannah (Campo Limpo). However it is important to mention that there are other statistics of sugarcane expansion (See Nassar *et al.* in this volume for details), which could affect this carbon balance.

Table 6. Carbon balance under different land uses replaced by sugarcane.

Biomass	**Total carbon stocks (Mg/ha)**	**Carbon balance due to sugarcane replacement (Mg/ha)**
Cotton (d)	40.1	21.8
Degraded pasture (b)	42.0	19.8
Maize (h)	44.1	17.7
Sugarcane burned (g)	52.1	9.7
Soybean (e)	54.9	6.9
Managed pasture (f)	58.5	3.3
Cerrado – typical savannah (a)	71.5	-9.7
Campo Limpo – grassland savannah (a)	80.4	-18.6
Cerrado – woody savannah (a)	86.5	-24.7
Tropical forest (c)	271.0	-209.2
Total carbon stocks in sugarcane net burned = 61.8 Mg/ha		

Sources: (a) Lardy *et al.* (2001)/Ottmar *et al.* (2001); (b) d`Andréa *et al.* (2004)/Estimated from Szakács *et al.* (2003); (c) Trumbore *et al.* (1993)/INPE; (d) Neves *et al.* (2005)/Adapted from Fornasieri and Domingos *et al.* (1978); (e) Campos (2006)/Adapted from Campos (2006); (f) Rangel and Silva *et al.* (2007)/Estimated from Szakács *et al.* (2003); (g) Estimated from Galdos (2007)/ VPB Estimative; (h) d`Andréa *et al.* (2004)/Estimated from Titon *et al.* (2003).



* Carbon balance = total C in biomass - total C in sugar cane × replaced area (ha)

Figure 6. Carbon balance of sugarcane expansion in São Paulo State, 2007. Source: VPB analysis.

3.2. Water

Despite having the greatest water availability in the world, with 14 percent of the surface waters and the equivalent of annual flow in underground aquifers, the use of crop irrigation in Brazil is minimum (~3.3 Mha, compared to 227 Mha in the world). Practically all of the sugarcane produced in São Paulo State is grown without irrigation (Donzelli, 2005).

The levels of water withdraw and release for industrial use have substantially decreased over the past few years, from around 5 m^3/ton sugarcane collected in 1990 and 1997 to 1.83 m^3/ton sugarcane in 2004 (sampling in São Paulo). If we take 1.83 m^3 of water/ton of sugarcane, and exclude the mills having the highest specific consumption, the mean rate for the mills that account for 92% of the total milling is 1.23 m^3 of water/ton of sugarcane. In addition the recycling rate has been increasing since 1990 (Figure 7). Mills with better water management practice replace only 500 liters in the industrial system, with a recycling rate of 96,67%.

Recent developments might lead to convert sugarcane mills from water consumers to water exporters industry. Dedini the largest Brazilian manufacturer of sugar mills and equipment suppliers has developed a new technology that allows the process of transforming sugarcane in ethanol to be much more efficient, and in the end of this process, industrial mills will be able to sell about 300 liters of water per ton of sugarcane (Figure 8). This would be

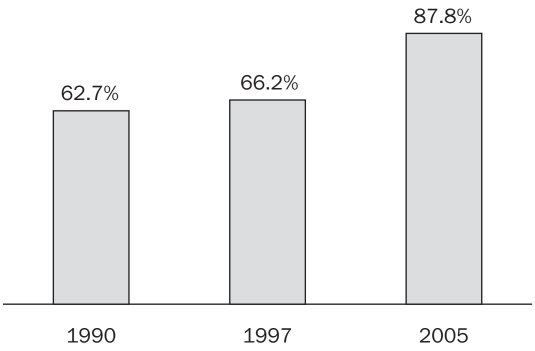


Figure 7. Evolution of water recycling. Source: Elia Neto (2008).

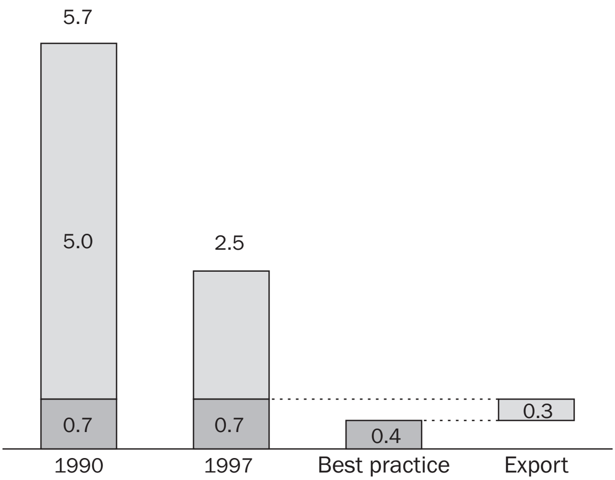


Figure 8. Evolution of water consumption in industrial ethanol production from sugarcane (m^3/ton of sugarcane). Source: Dedini (2008).

possible because water represents approximately 70% of sugarcane's composition. This new technology will be available next year (2009). Current estimates from maize ethanol mills on water consumption are of 4 liters of water per liter of ethanol produced (Commission on Water Implications of Biofuels Productions in United States, 2008).

3.3. Soil and fertilizers[8]

The sustainability of the culture improves with the protection against soil 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 yields and soil carbon content. Soil erosion in sugarcane fields is lower than in soybean and maize (Macedo *et al.*, 2005) and other crops (Table 7). It is expected also that the growing harvesting of cane without burning will further improve this condition, with the use of the remaining trash in the soil. Recent sugarcane expansion in Brazil has happened mostly in low fertility soils (pasture lands), and thus improving their organic matter and nutrient levels from previous land use patterns. Sugarcane uses lower inputs of fertilizers: ten, six and four times lower than maize respectively for nitrogen, phosphorous and potassium (Table 8). An important characteristic of the Brazilian sugarcane ethanol is the full recycling of industrial waste to the field.

Vinasse, a by-product of the distillation process, rich in nutrients (mainly potassium) and organic matters is a good example, which is being used extensively as a source of ferti-irrigation (nutrients associated with water). For each liter of alcohol, 10 to 15 liters of vinasse

[8] This text was adapted from Donzeli (2005) and Souza (2005).

Table 7. Losses of soil and water for selected crops.

Annual crop	Losses	
	Soil (t/ha-year)	Water (% rain)
Castor	41.5	12.0
Beans	38.1	11.2
Manioc	33.9	11.4
Peanut	26.7	9.2
Rice	25.1	11.2
Cotton	24.8	9.7
Soybean	20.1	6.9
English potato	18.4	6.6
Sugarcane	12.4	4.2
Maize	12.0	5.2
Maize + beans	10.1	4.6
Sweet potato	6.6	4.2

Source: Bertoni *et al.* (1998).

Table 8. Agrochemical inputs consumption (per ha) and per ethanol production (m^3).

	Sugarcane		Maize	
	Cons./ha	**Cons./m^3**	**Cons./ha**	**Cons./m^3**
Ethanol production (m^3)	8.1	-	4.2	-
Quantity of N (kg)	25.0	3.1	140.0	33.7
Quantity of P (kg)	37.0	4.6	100.0	24.1
Quantity of K (kg)	60.0	7.4	110.0	26.5
Liming materials (kg)	600.0	74.5	500.0	120.5
Herbicide (liters)	2.6	0.3	13.0	3.1
Drying hormone (liters)	0.4	0.0	-	-
Insecticides (liters)	0.1	0.0	2.2	0.5
Formicide (kg)	-	-	0.5	0.1
Nematicide (liters)[a]	1.2	0.1	-	-
Total	726.2	90.2	865.7	208.5

Sources: Agrianual (2008); Fancelli and Dourado Neto (2006).

[a] Product used to control microscopic multicellular worms called nematodes.

are produced. Generally the vinasse has a high organic matter and potassium content, and relatively poor nitrogen, calcium, phosphorus and magnesium contents (Ferreira and Monteiro 1987). Advantages of using vinasse include increased pH and cation exchange capacity, improved soil structure, increased water retention, and development of the soil's micro flora and micro fauna. Many studies have been conducted involving specific aspects pertaining to leaching and underground water contamination possibilities at variable vinasse doses over periods of up to 15 years. The results obtained from tests so far indicate that there are no damaging impacts on the soil at doses lower than 300 m^3/ha, while higher doses may damage the sugarcane or, in specific cases (sandy or shallow soil), contaminate underground water (Souza, 2005).

Investments in infrastructure have enabled the use water from the industrial process and the ashes from boilers. Filter cake (a by product of the yeast fermentation process) recycling processes were also developed, thereby increasing the supply of nutrients to the field.

3.4. Management of diseases, insects and weeds[9]

Strategies for disease control involve the development of disease resistant varieties within large genetic improvement programs. This approach kept the major disease outbreak managed, i.e. the SCMV (sugarcane mosaic virus, 1920), the sugarcane smut, *Ustilago scitaminea*, and rust *Puccinia melanocephala* (1980's), and the SCYLV (sugarcane yellow leaf virus, 1990's) by replacing susceptible varieties.

The soil pest monitoring method in reform areas enabled a 70% reduction of chemical control (data provided by CTC), thereby reducing costs and risks to operators and the environment.

Sugarcane, as semi-permanent culture of annual cycle and vegetative propagation, forms a crop planted with a certain variety that is reformed only after 4 to 5 years of commercial use. These characteristics determine that the only economically feasible disease control option is to use varieties genetically resistant to the main crop diseases.

Insecticide consumption in sugarcane crops is lower than in citrus, maize, coffee and soybean crops; the use of insecticides is also low, and of fungicides is virtually null (Agrianual, 2008). Among the main sugarcane pests, the sugarcane beetle, *Migdolus fryanus* (the most important pest) and the cigarrinha, *Mahanarva fimbriolata*, are biologically controlled. The sugarcane beetle is the subject of the country's largest biological control program. Ants, beetles and termites are chemically controlled. It has been possible to substantially reduce the use of pesticides through selective application.

The control or management of weeds encompasses specific methods or combinations of mechanical, cultural, chemical and biological methods, making up an extremely dynamic process that is often reviewed. In Brazil, sugarcane uses more herbicides than coffee and maize crops, less herbicides than citrus and the same amount as soybean (Agrianual, 2008).

On these issues mentioned above related to use of agrochemicals, soil management and water uses, UNICA's (Brazilian Sugarcane Growers Association) associated mills are developing a set of goals, aiming at improving agricultural sustainability in the next few years (Table 9).

[9] This text was adapted from Arrigoni and Almeida (2005) and Ricci Junior (2005).

Table 9. Sugarcane agricultural sustainability.

Sugarcane		
Less agrochemicals	**Low soil loss**	**Minimal water use**
Low use of pesticides. No use of fungicides Biological control to mitigate pests. Advanced genetic enhancement programs that help idntify the most resistant varieties of sugarcane. Use of vinasse and filter cake as organic fertilizers.	Brazilian sugarcane fields have relatively low levels of soil loss, thanks to the semi-perennial nature of the sugarcane that is only replanted every 6 years. The trend will be for current losses, to decrease significantly in coming years through the use of sugarcane straw, some of which is left on the fields as organic matters after mechanical harvesting	Brazilian sugarcane fields require practically no irrigation because rainfall is abundant and reliable, particularly in the main South Central production region. Ferti-irrigation: applying vinasse (a water-based residue from sugar and ethanol production). Water use during industrial processing has decreased significantly over the years: from 5 m^3/t to 1 m^3/t.

Source: Unica (2008).

3.5. Conservation of biodiversity

Brazil is a biodiversity hotspot and contains more than 40% of all tropical rain forest of the World. Brazilian biodiversity conservation priorities were set mainly between 1995 and 2000, with the contribution of hundreds of experts; protected areas were established for the six major biomes in the National Conservation Unit System.

Steps for the implementation of the Convention on Biological Diversity includes the preparation of the biodiversity inventory and monitoring of important biodiversity resources, the creation of reserves, the creation of seed, germoplasm and zoological banks, and the conduct of Environmental Impact Assessments covering activities that could affect the biodiversity.

The percentage of forest cover represents a good indicator of conservation of biodiversity in agricultural landscapes. In São Paulo State for example the remaining forest covered is 11%, of which 8% being part of the original Atlantic Forest. Table 10 demonstrates that while the sugarcane area increased from 7 to 19% of the State territory, native forests also increased from 5 to 11%, showing that it is possible to recover biodiversity in intense agricultural systems.

Table 10. Sugarcane and vegetation area in São Paulo State.

Year	Sugarcane					Vegetation			% SP State	
	New lands (Kha)	Land in use (Kha)	Total area (Kha)	Production (Kton)	Productivity (ton/ha)	Woody-Cerradao (Kha)	Shrubby-Cerrado/ savana (Kha)	Native forests (Kha)	Sugarcane area	Native forests area
1983	345	1,421	1,765	107,987	76.0	196	489	1,139	7%	5%
1984	317	1,526	1,842	116,666	76.5	167	427	1,453	7%	6%
1985	326	1,626	1,952	121,335	74.6	221	438	1,545	8%	6%
1986	350	1,704	2,054	122,986	72.2	205	378	1,795	8%	7%
1987	311	1,753	2,064	132,322	75.5	211	348	1,870	8%	8%
1988	325	1,771	2,097	134,108	75.7	192	316	1,624	8%	7%
1989	322	1,757	2,078	130,795	74.5	198	325	1,487	8%	6%
1990	276	1,836	2,112	139,400	75.9	175	290	1,097	9%	4%
1991	301	1,864	2,165	144,581	77.6	198	301	1,601	9%	6%
1992	372	1,940	2,311	150,878	77.8	204	284	2,109	9%	8%
1993	371	1,989	2,360	156,623	78.7	238	259	2,120	10%	9%
1994	421	2,180	2,601	168,362	77.2	201	238	2,453	10%	10%
1995	449	2,260	2,709	175,073	77.5	189	220	2,434	11%	10%
1996	428	2,388	2,816	187,040	78.3	217	232	2,462	11%	10%
1997	422	2,451	2,872	194,801	79.5	215	244	2,478	12%	10%
1998	342	2,544	2,887	199,764	78.5	217	241	2,482	12%	10%
1999	281	2,475	2,756	193,374	78.1	218	244	2,468	11%	10%
2000	338	2,491	2,829	189,391	76.0	221	257	2,629	11%	11%
2001	440	2,569	3,009	201,683	78.5	223	262	2,622	12%	11%
2002	457	2,661	3,118	212,707	79.9	224	263	2,725	13%	11%
2003	495	2,818	3,313	227,981	80.9	225	264	2,720	13%	11%
2004	463	2,951	3,414	241,659	81.9	211	262	2,732	14%	11%
2005	553	3,121	3,673	254,810	81,7	217	254	2,648	15%	11%
2006	822	3,437	4,258	284,917	82,9	228	271	2,695	17%	11%
2007	935	3,897	4,832	327,684	84,1	233	277	2,716	19%	11%

Source: IEA/CATI-SAAESP (Annual statistics from 1983-2007).

3.6. Air quality

Burning sugarcane for harvesting is one of the most criticized issue of sugarcane production system, causing local air pollution and affecting air quality, despite of the benefits of using 100% ethanol running engines instead of gasoline (Figure 9), which decreases air pollution from 14 to 49%.

In order to eliminate gradually sugarcane burning, several attempts are being made. The São Paulo Green Protocol is being considered the most important one, setting an example for other regions and states in Brazil. Signed between the São Paulo state government (State Environment Secretariat) and the Sugarcane Growers Association (UNICA) in June 04, 2007, the Green Protocol aimed at:

- The anticipation of the legal deadline for the elimination of the practice of sugarcane straw burning to 2014.
- The protection of river side woods and recovering of those near water streams (permanent protected areas - APPs).
- The implementation of technical plans for conservation of soil and water resources.
- The adoption of measures to reduce air pollution.
- The use of machines instead of fire to harvest new sugarcane fields.

Voluntarily 141 of the total of 170 sugar mills from the state of São Paulo signed this Protocol, and recently 13 thousand sugarcane independent suppliers, members of the Organization of Sugarcane Farmers of the Center-South Region (Orplana), signed also this protocol. Therefore the entire production chain of sugar and ethanol of São Paulo participates

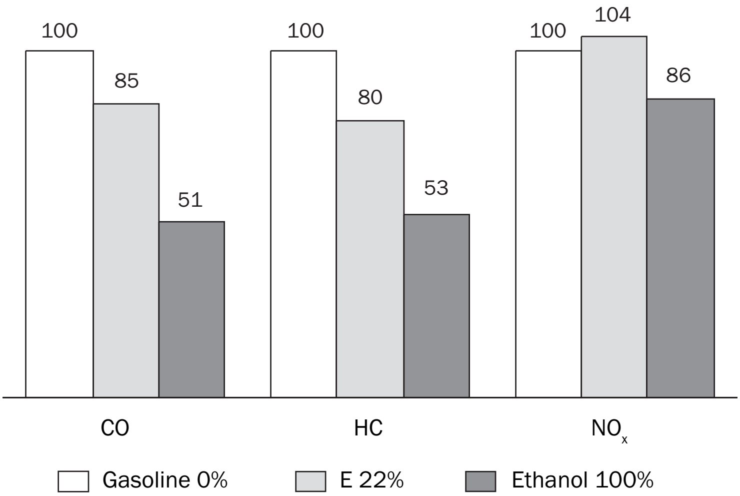


Figure 9. Air pollution by different blends of ethanol. Source: ANFAVEA (2006).

in the implementation of the Protocol. Maintaining the 2007 levels of mechanization, when 550 new harvest machines have begun to operate, it will be possible to complete the mechanization even prior to the deadline (2014) set by the Protocol.

4. Initiatives towards ethanol certification and compliance

The discussion on sustainable production of biofuels has fulfilled the scientific literature lately (see for example Hill *et al.*, 2006; Van Dam *et al.*, 2006; Goldemberg *et al.*, 2006; Smeets *et al.*, 2008; Macedo *et al.*, 2008). At the same time several initiatives are being developed in Europe and in the United States related to certification, traceability and definition of criteria and indicators for sustainable production of biofuels, mainly due to different supporting policies. For example in May 2003, the European Commission launched its Biofuels Directive 2003/30/EC, establishing legal basis for blending biofuels and fossil fuels. The EU member countries are urged to replace 2% of fossil fuels with biofuels by 2005 and 5.75% by 2010. From 2003 to 2005 the group of 25 countries members enhanced biofuel's market share of 0.6% to 1.4%. However, they have not yet achieved the first target yet. The EU Directive 2003/96/EC had also established tax incentives to encourage renewable energy use.

The government of Germany (GE), Netherlands (NL) and United Kingdom (UK) are supporting different assessment studies, while another one initiative is taking place from Switzerland, the Roundtable on Sustainable Biofuels (RTB), a multiple stakeholder initiative, hosted by the Ecole Polytechnique Federale de Lausanne. The main environmental issues addressed by these different initiatives are related to greenhouse gas reduction compared with fossil fuels; competition with other land uses, especially food competition; impacts on the biodiversity and on the environment (Table 11). Considering carbon and greenhouse gases balance current agricultural and industrial practices sugarcane ethanol from Brazil does comply with the targets of greenhouse reduction higher than 79% from existing brown fields, and from new green fields, when not replacing large areas of native vegetation. On food competition, there is no direct evidence that sugarcane is replacing the basic Brazilian staple foods (Nassar *et al.*, this book). On biodiversity conservation, data from São Paulo State show that sugarcane expansion did not reduce forest cover, but on the contrary (IEA/CATI – SAAESP). On the use of water, fertilizers and agrochemicals, sugarcane ethanol does perform well above any other current biofuel in the market (in this chapter).

In the USA, the Environmental Protection Agency (EPA) under the Energy Independence and Security Act of 2007 is responsible for revising and implementing regulations on the use of biofuels blended with gasoline. The Renewable Fuel Standard program will increase the volume of renewable fuel required to be blended into gasoline from 9 billion gallons in 2008 to 36 billion gallons by 2022. At the same time, EPA is conducting several studies on the direct and indirect impacts of the expansion of biofuels production and their carbon footprint and potential reduction of greenhouse gases.

Table 11. Main issues related to sustainable production of biofuels being considered under different certification regimes.

Criterion	NL	UK	GE	RTB	EU
1. Greenhouse gas balance	✓	✓	✓	✓	✓
a1) Net emission reduction compared with a fossil fuel reference is at least 50%. Variation in policy instruments could benefit the best performances.	✓				
a2) Life cycle GHG balance reduction of 67% compared with fossil fuels			✓		
a3) Processing of energy crops GHG reduction of 67% compared with fossil fuels			✓		
a4) GHG emissions savings from the use of biofuels at least 35% compared with fossil fuels		✓			✓
a5) GHG emissions will be reduced when compared to fossil fuels				✓	
b) Soil carbon and carbon sinks		✓		✓	✓
c) Emissions of N_2O from biofuels		✓			
2. Competition with other applications/ land use	✓	✓	✓	✓	✓
a) Availability of biomass for food, local energy supply, building materials or medicines should not decline	✓	✓	✓	✓	✓
b) Use of less productive land for biofuels		✓			
c) Increasing maximum use of crops for both food and fuel		✓			
d) Avoiding negative impacts from bioenergy-driven changes in land use			✓	✓	
3. Biodiversity	✓	✓	✓	✓	✓
a) No deterioration of protected area's or high quality eco-systems.	✓	✓	✓	✓	✓
b) Insight in the active protection of the local ecosystem.	✓				
c) Alteration of local habitats		✓			
d) Effect on local species		✓		✓	
e) Pest and disease resistance		✓			
f) Intellectual property and usage rights	✓		✓		
g) Social circumstances of the local residents	✓		✓		
h) Integrity	✓				
i) Standard on income distribution and poverty-reduction			✓		
j) Avoiding human health impacts			✓		
4. Environment	✓	✓	✓	✓	
a) No negative effects on the local environment					
b) Waste management	✓	✓			
c) Use of agro-chemicals, including artificial manure	✓	✓	✓		

Table 11. Continued.

Criterion	NL	UK	GE	RTB	EU
4. Environment (continued)	✓	✓	✓	✓	
d) Preventing erosion and deterioration of the soil to occur and maintaining the fertility of the soil	✓	✓	✓	✓	
e) Active improvement of quality and quantity of surface and groundwater	✓		✓	✓	
f) Water use efficiency of crop and production chain		✓	✓		
g) Emissions to the air	✓			✓	
h) Use of genetically modified organisms			✓	✓	

Source: adapted from Van Dam *et al.* (2006).
NL = the Netherlands; UK = United Kingdom; GE = Germany; RTB = Round table on sustainable biofuels; EU = European Union.

While the above concerns are well-justified, some criticism of biofuels and their impacts are motivated by protectionism and interest in agricultural subsidies and agribusiness production chains in several developing countries, especially from EU countries. Certification schemes suggested may become non-tariff barriers, rather than environmentally and socially sound schemes.

Scientific and technological assessments comparing different kinds of biofuels are needed to reduce the play of such interests and to establish the strengths of best potential of biofuels along with their dangers and limitations.

The OECD's latest report on biofuels illustrates how fears can be perpetuated without proper scientific basis. Suggestively titled: ('Biofuels: is the cure worse than the disease?'), the report stated: 'Even without taking into account carbon emissions through land-use change, among current technologies only sugarcane-to-ethanol in Brazil, ethanol produced as a by-product of cellulose production (as in Sweden and Switzerland), and manufacture of biodiesel from animal fats and used cooking oil, can substantially reduce [greenhouse gases] compared with gasoline and mineral diesel. The other conventional biofuel technologies typically deliver [greenhouse gas] reductions of less than 40% compared with their fossil-fuel alternatives'.

This report also recognized that while still trade barriers would persist to the international market, it will be difficult for the world to take advantage of the environmental qualities of the use of some biofuels, mainly the ethanol form sugarcane and so forth as international markets are not yet fully created for biofuels.

5. Future steps towards sustainable production of ethanol and the role of innovation

A huge challenge facing policy makers, businesses, scientists and societies as a whole is how to responsibly establish sustainable production systems and biofuel supplies in sufficient volume that meet current and future demands globally.

The examples and best practices found in Brazilian sugarcane ethanol provides a good framework and baseline of sustainability compared with other current biofuels available in large scale in the World, having the smallest impact on food inflation, high levels of productivity (on average 7,000 liters of ethanol/ha and 6.1 MWhr of energy/ha), with lower inputs of fertilizers and agrochemicals, while reducing significantly the emissions of greenhouse gases. The ending of sugarcane burning in 2014 is a good example of improving existing practices. The proper planning of sugarcane expansion into new areas will for another important step towards sustainable production of ethanol

In addition new technologies and innovation are taking place in Brazil and elsewhere in the world, aiming at optimizing the use of feedstocks: using lignocellulosic materials (the second generation of biofuels); reducing waste; adding value to ethanol co-products and moving towards ethanol chemistry and biorefinaries full deployment.

Different initiatives in Brazil from the State of São Paulo Research Foundation (FAPESP), Ministry of Science and Education (MC&T – FINEP) and investments from the private sector are contributing to the deployment of new opportunities provided by the sugarcane biomass, at the same time improving the environmental performances at the agriculture and at the industry.

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