Chapter 4
Mitigation of GHG emissions using sugarcane bioethanol

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1. Introduction

The implementation of the Brazilian sugarcane ethanol program always included a continuous assessment of its sustainability. The possibilities for increasing production in the next years must consider the exciting promises of new technologies (that may lead to 50% more commercial energy/ha, from sugarcane) as well as environmental restrictions. The greenhouse gases emissions associated with the expansion are analyzed in the next sections.

2. Ethanol production in 2006 and two Scenarios for 2020

After the initial growth with the Pro-Álcool program (~12 M m^3, from 1975 to 1984) ethanol production in Brazil stabilized at this level until 2002, when the implementation of the Flex Fuel cars led to a new period of strong growth (from 12.5 M m^3 in 2002 to ~24 M m^3 in 2008; internal demand scenarios point to 40 M m^3 in 2020, with exportation in the 10-15 M m^3 range) (Carvalho, 2007; CEPEA, 2007; MAPA, 2007; EPE, 2007). Environmental legislation phasing out sugarcane burning practices, the internal demand for electricity and the opportunity with the large number of new sugarcane mills (Carvalho, 2007) are leading to a fast transition from the 'energy self-sufficient' industrial unit to a much better use of cane biomass (bagasse and trash), turning the sugarcane industry into an important electricity supplier.

The evaluation of the GHG emissions (and mitigation) from the sector in the last years (2002-2008) and the expected changes in the expansion from 2008 to 2020 must consider technology (the continuous evolution and selected more radical changes), both in cane production as in cane processing. Two (alternative) technology paths were selected:

- The *Electricity Scenario* follows the technology trends today, with commercially available technologies: the use of trash (40% recovery) and surplus bagasse (35%) to produce surplus electricity in conventional high pressure co-generation systems (Seabra, 2008).
- The *Ethanol Scenario* considers advanced ethanol production with the hydrolysis of lignocellulosic cane residues; ethanol would be produced from sucrose but also in an annexed plant with the surpluses of bagasse and of the 40% trash recovered (Seabra, 2008). This condition would lead to a smaller area (29% smaller, for the same ethanol production) than the *Electricity Scenario*; technologies may be commercial in the next ten years.

The 2006 results are based on 2005/2006 average conditions, with the best available and comprehensive data for the Brazilian Center-South Region (Macedo *et al.*, 2008). Note that GHG emissions/mitigation are evaluated for each Scenario specific conditions; Scenario implementation schedules are not presented (or needed) for the objective of this study. However, it must be said that the *Electricity Scenario* implementation is occurring now in all Greenfield operations, and already in some retrofit of existing units. The *Ethanol Scenario* as proposed still depends on technological development of the biomass hydrolysis/fermentation processes, and it would take longer to be implemented to a significant level in the context of the Brazilian ethanol production (Seabra, 2008).

The essential parameters for 2006 and the two 2020 Scenarios are presented in Table 1 (Cane production) and Table 2 (Cane processing). The data used for 2006 is for a sample of 44 mills (100 M t cane/season), all in the Brazilian Center South. Data have been collected/processed for the last 15 years, for agriculture and industry, for the CTC 'mutual benchmarking'.

The ethanol transportation (sugar mill to gas station) energy needs are (Seabra, 2008):
2006: 100% road (trucks), 340 km (average), 0.024 l diesel/(m^3.km) (energy consumption).
2020: 80% road, with average transport distance and diesel consumption as in 2006; 20% pipeline, 1000 km (average), 130 kJ/(m^3.km) (pipeline energy consumption).

The hydrolysis/fermentation parameters in the *Ethanol Scenario* correspond to a SSCF process, expected to be commercial before 2020, as seen in Table 3.

3. Energy flows and lifecycle GHG emissions/mitigation

The systems boundaries considered for the energy flows and GHG emissions and mitigation include the sugarcane production, cane transportation to the industrial conversion unit, the industrial unit, ethanol transportation to the gas station, and the vehicle engine (performance). Methodologies use data and experimental coefficients as indicated in the tables, and in some cases IPCC (IPCC, 2006) defaults; details are presented in Macedo *et al.* (2008), Seabra (2008) and Macedo (2008). The CO_2 (and other GHG) related fluxes are:

- CO_2 absorption (photosynthesis) in sugarcane; its release in trash and bagasse burning, residues, sugar fermentation and ethanol end use. These fluxes are not directly measured (not needed for the net GHG emissions).
- CO_2 emissions from fuel use in agriculture and industry (including input materials); in ethanol transportation; and in equipment/buildings production and maintenance.
- Other GHG fluxes (N_2O and methane): trash burning, N_2O soil emissions from N-fertilizer and residues (including stillage, filter cake, trash)
- GHG emissions mitigation: ethanol and surplus bagasse (or surplus electricity) substitution for gasoline, fuel oil or conventional electricity.

Table 1. Basic data: sugarcane production.

Item	Units	2006 [a]	2020 scenarios [b]
Sucrose content	% cane stalks	14.22	15.25 [c]
Fiber content	% cane stalks	12.73	13.73 [d]
Trash (db) [e]	% cane stalks	14	14
Cane productivity	t cane/ha	87.1	95.0
Fertilizer utilization [f]			
P_2O_5	kg/(ha.year)	25	32
K_2O	kg/(ha.year)	37	32
Nitrogen	kg/(ha.year)	60	50
Lime [g]	t/ha	1.9	2.0
Herbicide [h]	kg/ha	2.2	2.2
Insecticide [h]	kg/ha	0.16	0.16
Filter cake application	t (db)/ha (% area) [i]	5 (70%)	5 (70%)
Stillage application	m^3/ha (% area) [j,k]	140 (77%)	140 (77%) [l]
Mechanical harvesting	% area	50	100 [m]
Unburned cane harvesting	% area	31	100 [m]
Diesel consumption	L/ha	230	314

[a] CTC's database (44 mills in Center-South of Brazil, equivalent to ~100 Mt cane/year) (CTC, 2006a).

[b] Author's projections; Scenarios are Electricity and Ethanol.

[c] 2020: increasing 1 point (%) in 15 years (variety development and better allocation).

[d] Apparent fiber increasing with increase in green cane harvesting (trash).

[e] Hassuani *et al.* (2005).

[f] Total averages, including: fertilizer use in plant and ratoon cane, in areas with and without stillage; full description in Macedo *et al.* (2008). For Scenario 2020 Ethanol averages are slightly lower (~4%) due to larger stillage production/utilization.

[g] Utilized essentially at planting.

[h] Macedo (2005a).

[i] Reforming areas: areas where sugarcane is re-planted, after the 6 year cycle.

[j] Ratoon areas: areas where sugarcane is cut to grow again, without re-planting

[k] It is considered that all stillage is used only in the 'ethanol cane area', but keeping the suitable level of application (~140 m^3/ha). For 2020 Ethanol scenario, see Note l.

[l] In the 2020 Ethanol scenario more stillage would be produced, from the ethanol derived from hydrolysis. Stillage application would reach larger ratoon areas.

[m] Considering the legislation and phase out schedules for cane trash burning in SãoPaulo.

Table 2. Basic data: sugarcane processing.

Item	Units	2006 [a]	2020 electricity [b]	2020 ethanol [b]
Bagasse use		Low pressure cogeneration	Advanced cogeneration	Biochemical conversion
Electricity demand	kWh/t cane	14.0	30	[c]
Mechanical drivers	kWh/t cane	16.0	0	0
Electricity surplus	kWh/t cane	9.2 [d]	135 [e]	44 [f]
Trash recovery	% total	0	40	40
Bagasse surplus	% total	9.6	0 [g]	0 [g]
Ethanol yield	l/t cane	86.3	92.3 [h]	129

[a] CTC information (CTC, 2006b).
[b] Authors' projections.
[c] 30 kWh/t cane + 130 kWh/t hydrolyzed biomass (dry basis).
[d] Cogen's data; only 10% of the mills use higher pressure boilers, and the remaining 90% still use 21 bar/300 °C, with very low electricity surplus.
[e] All mills operating at 65 bar/480 °C, CEST systems; process steam consumption ~340 kg steam/t cane, and using recovered trash (40%).
[f] A hypothetical mill operating at 65 bar/480 °C, 'pure' cogeneration; using ~340 kg steam/t cane.
[g] All biomass (bagasse and 40% trash) is used for power generation or ethanol production.
[h] Only the increase in sucrose % cane was considered.

Table 3. Bioconversion parameters (SSCF process with dilute acid pretreatment)[a].

Hydrolysis	95 % (cellulose); 90% (hemicellulose)
Fermentation	95% (glucose); 85% (other sugars)
Energy demand	
Electricity	130 kWh/t (db)
Steam	
Pre-treatments (kg/kg db)	0.45 (13 bar); 0.25 (4.4 bar)
Distillation (kg/l et)	3.0 (2.5 bar); 0.05 (22 bar)
Concentration (kg/l et.)	0.2 (1.7 bar)

[a] Based on Aden *et al.* (2002); details in Seabra (2008).

The GHG emissions associated with direct land use change (LUC) are estimated separately in the next section, where the possible indirect impacts of land use change (ILUC) are also discussed for the specific case of the expansion of ethanol production in Brazil. The energy use/conversion for 2006 and for each 2020 Scenario is presented in Table 4.

The corresponding GHG emissions for are in Table 5. Note that the differences in total emissions are strongly dependent on the co-products credits. The large difference between 2006 and the 2020 Electricity Scenario is due to an actual increase in the system energy efficiency (much larger energy output). An analogous increase in energy output occurred between 2006 and the 2020 Ethanol Scenario, but note that the change is an increase in ethanol output (rather than in electricity) and also the emissions are presented in kg CO_2 eq/m^3 ethanol. In the 2020 Ethanol Scenario the volume of ethanol produced/unit area (or ethanol/ t cane) is 1.4 times larger than in the 2020 Electricity Scenario.

It is important to remember that the 2006 data (and results) correspond to the average values of the parameters; even for a homogeneous set of producers (Brazil Center South region) differences in processes (agricultural and industrial) impact energy flows and GHG emissions. For the sample used, the variation of main production parameters and the

Table 4. Energy balance in anhydrous ethanol production (MJ/t cane).

	2006	**2020 electricity**	**2020 ethanol**
Energy input	235	262	268
Agriculture	211	238	238
Cane production	109	142	143
Fertilizers	65	51	50
Transportation	37	45	45
Industry	24	24	31
Inputs	19	20	25
Equip./buildings	5	4	6
Energy output	2,198	3,171	3,248
Ethanol [a]	1,926	2,060	2,880
Electricity surplus [b]	96	1,111	368
Bagasse surplus [a]	176	0.0	0.0
Energy ratio	9.4	12.1	12.1

[a] Based on LHV (Low Heating Value).

[b] Considering the substitution of biomass-electricity for natural gas-electricity, generated with 40% (2006) and 50% (2020) efficiencies (LHV).

Table 5. Total emission in ethanol life cycle (kg CO_2 eq/m^3 anhydrous) [a].

	2006	2020 electricity	2020 ethanol
Cane production	416.8	326.3	232.4
Farming	107.0	117.2	90.6
Fertilizers	47.3	42.7	23.4
Cane transportation	32.4	37.0	26.4
Trash burning	83.7	0.0	0.0
Soil emissions	146.3	129.4	92.0
Ethanol production	24.9	23.7	21.6
Chemicals	21.2	20.2	18.5
Industrial facilities	3.7	3.5	3.2
Ethanol distribution	51.4	43.3	43.3
Credits			
Electricity surplus [b]	-74.2	-802.7	-190.0
Bagasse surplus [c]	-150.0	0.0	0.0
Total	268.8	-409.3	107.3

[a] Emissions for hydrous ethanol/m^3 are about 5% less than values verified for anhydrous ethanol.
[b] Considering the substitution of biomass-electricity for natural gas-electricity, generated with 40% (2006) and 50% (2020) efficiencies (LHV).
[c] Considering the substitution of biomass fuelled boilers (efficiency = 79%; LHV) for oil fuelled boilers (efficiency = 92%; LHV).

corresponding response to each single parameter variation in GHG emissions are shown in Figure 1.

Note that the electricity surplus and the bagasse surplus show very large variation now, when a few mills have started to export large amounts of electricity. The net GHG avoided emissions, including the ethanol substitution for gasoline and considering the engines performances in Brazil (based on the experience with the fleet of 23 M vehicles, in the last 30 years, with E-24, E-100 and Flex Fuel engines) is shown in Table 6.

The use of the allocation (energy) criterion for the co-products (with the whole GHG emissions associated with cane and ethanol production being distributed among ethanol, electricity and surplus bagasse according to their energy content, and with no co-product credits considered in the net emission) is compared to the use of the substitution criterion (with the mitigation derived from ethanol, electricity and surplus bagasse use being considered as well as all emissions from cane and ethanol production) in Figure 2; the substitution criterion results are detailed in Table 6.

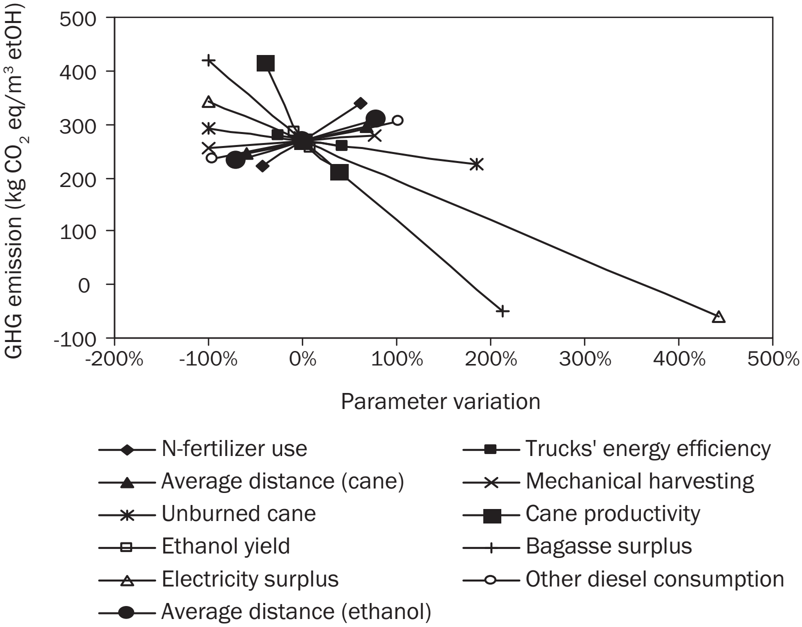

Figure 1. GHG emissions variation in response to single parameter variation; including co-product credits (2006 only).

Table 6. Avoided emissions due to ethanol use (t CO_2 eq/m^3 hydrous or anhydrous; substitution criterion for the co-products).

	Ethanol use [a]	Avoided emission [b]	Net emission [c]
2006	E100	-2.0	-1.7
	E25	-2.1	-1.8
2020 electricity	E100	-2.0	-2.4
	FFV	-1.8	-2.2
	E25	-2.1	-2.5
2020 ethanol	E100	-2.0	-1.9
	FFV	-1.8	-1.7
	E25	-2.1	-2.0

[a] E100, or HDE: hydrous ethanol in dedicated engines; FFV: hydrous ethanol in flex-fuel engines; E25: anhydrous ethanol (25% volume) and gasoline blend.
[b] Avoided emission (negative values) due to the substitution of ethanol for gasoline; fuel equivalencies verified for each application in Brazil (Macedo *et al.*, 2008).
[c] Net emission = (avoided emission due to ethanol use) + (ethanol life cycle emission). Co-products credits are included.

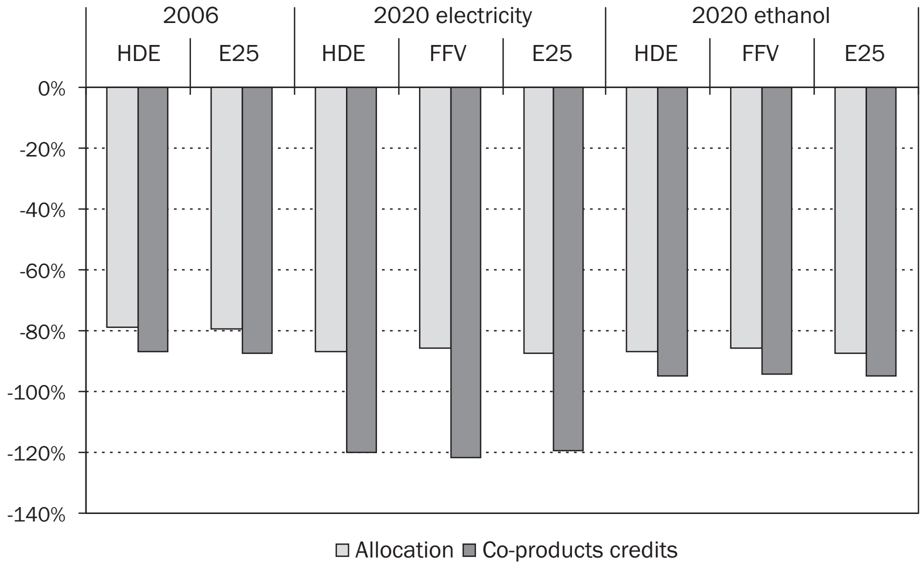

Figure 2. GHG mitigation with respect to gasoline: allocation or co-products credits.

As expected from the energy balances, the use of ethanol from sugarcane substituting for gasoline leads to a very important GHG emissions mitigation; this is due mostly to the use of cane residues as the source of energy for processing sucrose to ethanol. However, the much more efficient use of the cane residues is leading to entirely offset the gasoline emissions, and beyond that, as shown in Figure 2 for the 2020 Electricity scenario. A separate accounting of the gains with electricity and ethanol (with allocation of the emissions) still shows gains in the 2020 Scenarios, due to increase efficiencies/productivity in both cane production and processing.

4. Land use change: direct and indirect effects on GHG emissions

The variation in carbon stocks (both in soils and above ground) due to changes in the land use is included in the national carbon inventories, and evaluation methodologies have been established. The large number of parameters (culture type; soil; cultivation practices; local climate) and the lack of sufficient and adequate information for many cases lead to large error estimates for the default values, both for the basic soil type/climate carbon stocks for native vegetation and for the relative (main parameters) stock change factors (IPCC, 2006). The use of adequate local data is recommended.

Recently the so called indirect land use change (ILUC) impact in emissions is being discussed; the debate shows that we do not have suitable tools (methodologies) or sufficient data to reach acceptable, quantified conclusions about ILUC impacts on GHG emissions, globally.

However, local conditions in Brazil indicate a good possibility of significant increases in ethanol production without increasing ILUC emissions. Both LUC and ILUC impacts on emissions for ethanol are considered below.

4.1. Land use change with the ethanol production in Brazil: past and trends

Brazil has 28.3% (~440 M ha) of all original forests in the world, over a total surface of 850 M ha. From the agricultural land, only 46.6 M ha are used for grain; 199 M ha correspond to 'pasture'; large fraction of this is somewhat degraded land (extensive grazing, not planted pasture).

Sugarcane for ethanol today (2008) uses only 4 M ha, slightly more than 1% of the arable land in Brazil. Ethanol production increased fast with the Pro-Alcool Program until 1985, when it reached 11.8 M m^3; stabilized at this level, and in 2002 the production was 12.5 M m^3. *There was no land use change with cane for ethanol in the period from 1984 to 2002.*

Ethanol production growth re-started only in 2002, to an expected value of 26 M m^3 in 2008 (MAPA, 2007; CONAB, 2008). The expansion area (sugar and ethanol) from 2005 to 2008 was 2.2 M ha in the Center-South (Nassar, 2008); ethanol used 49% of the sugarcane in 2002, and 55% in 2008.

The patterns of land use change, as well as the changes in cane culture procedures determine the associated impacts on GHG emissions. For land use change, a recent analysis (Nassar et al, 2008) uses satellite images (Landsat and CBERS) available since 2003 for State of São Paulo, and 2005 for other States; and secondary data (based on IBGE data, for the whole region, from 2002 to 2006) is also analyzed for each micro-region using a Shift Share model. A comprehensive field survey was reported by CONAB (CONAB, 2008) for the LUC involving sugarcane from 2007 to 2008. Data was also obtained from the Environmental impact reports (EIA – RIMA) needed for licensing new increases in sugarcane area (Nassar et al, 2008); they refer also to the next years expected LUC.

Some of the main conclusions for the changes from 2002 to 2008 are:

1. Sugarcane always substitutes for established crops, or pasture lands; for economic reasons, and with the large availability of low productivity pasture lands associated to some pasture area conversion to higher efficiency systems, very small advances in native vegetation (forests, cerrados) areas are observed. In some cases degraded pasture lands are cultivated for one or two years with soybeans, to improve soil conditions before using for sugarcane. Intercropping (rotation of sugarcane every five or six years, before a new planting, with other crops) is becoming a widespread practice. Satellite data for the last two years (2007/08 and 2008/09) for the cane expansion areas in the six Center South cane producer states (total 2.18 M ha) indicates their origin: 53% from Agriculture; 45% from Pastures; 1.3% from Citrus plantations; and only 0.5% from Arboreal Vegetation

(native or anthropic), including wood plantations (eucalyptus or pinus). The CONAB survey (CONAB, 2008) indicates for 'new areas' (not all related to native vegetation) only 1.5% of the expansion, in 2007/08. All studies indicate that Pasture lands utilization is surpassing Agriculture land utilization (for cane) in the last years, in many areas.
2. The field survey (CONAB, 2008) indicates for 2007/08 LUC the largest Agriculture area substituted was soybean, followed by maize. The use of Pasture lands is also related to the conversion from low productivity pasture (both native and some planted pasture: degradation from inadequate management, and no fertilizers) (Macedo, 2005b), to high productivity pastures, liberating areas. Estimates indicate today 150 M ha of cultivated pasture land, and 70 M ha of 'natural' pastures.
3. Most of the expansion (94%) for sugar from 1992 to 2003 occurred around the existing sugar mills, in the Center South; now sugarcane moves to the West and North of the region, in the States of Goiás, Mato Grosso, Minas Gerais and Mato Grosso do Sul. This is the trend for the next decade.

The analysis (Nassar *et al.*, 2008) included the projected patterns of land use change for the sugarcane expansion to 2020, considering land availability, biomes and reserved areas; the response to prices/costs, demand and competition in Brazil and outside.

4.2. Soil and above ground carbon stocks

A recent study (Amaral *et al.*, 2008) on ethanol production sustainability included data on below and above ground carbon stocks for sugarcane (both burned and green cane harvesting conditions) in Brazil, as well as for the most important replaced crops and vegetation. The data was obtained from more than 80 reports in the last 8 years; a selection was made to yield comparable results (for soil types, soil depths, methodology, cultural practices).

Table 7 shows some results for soil carbon from the survey, as well as the default values calculated with the IPCC recommendations (IPCC, 2006). The IPCC based values correspond to the specific soil types (High or Low activity clay, HAC or LAC), climate, crop type and cultivation practices for each crop. The experimental data indicates the soil types (HAC, LAC or Sandy) and some cultural practices, always for 20 cm depth. Selected values were used to evaluate the soil carbon stock change with land use change, for each specific case (last column).

Table 8 (Amaral *et al.*, 2008) shows the experimental values for the sugarcane and the main replaced crops/pasture above ground carbon.

Table 7. Soil carbon content for different crops (t C/ha).

Crop	IPCC defaults [a]		Experimental [b]		Selected values
	LAC	HAC	HAC	Other	
Degraded pasturelands	33	46	41	16 [c]	41
Natural pasturelands	46	63	56		56
Cultivated pasturelands	55	76	52	24 [c]	52
Soybean cropland	31	42	53		53
Maize cropland	31	42	40		40
Cotton cropland	23	31	38		38
Cerrado	47	65	46		46
Campo Limpo	47	65	72		72
Cerradão	47	65	53		53
Burned cane	23	31	35-37	35 [d]	36
Unburned cane	60	83	44-59		51

[a] Based on IPCC parameters indicated, IPCC, 2006
[b] Amaral *et al.*, 2008 (all 0-20 cm).
[c] Sandy soils.
[d] LAC soils.

Table 8. Above ground carbon stocks (t C/ha)[a].

Degraded pasturelands	1.3
Cultivated pasturelands	6.5[b]
Soybean croplands	1.8[c]
Maize croplands	3.9
Cotton croplands	2.2[d]
Cerrado *sensu strictu*	25.5[e]
Campo Limpo	8.4[f]
Cerradão	33.5[g]
Unburned cane	17.8

[a] Amaral *et al.* (2008).
[b] LAC soils.
[c] HAC soils.
[d] General value.
[e] Areas with more than 20 years without burning.
[d] Areas with 3 years without burning.
[e] Areas with 21 years without burning.

4.3. Estimated emissions from LUC

For the changes from 2002 to 2006 (areas closer to the existing mills) soil types were frequently HAC, and some of the cane was burned; for the expansion now and in next decade, soils will be closer to LAC (and for 2020, 100% green cane harvesting is assumed). The trends for land use change until 2020 are discussed in the next sections.

It is assumed that at least 70% of the pasture land used for cane is not planted pasture, with varying degrees of degradation. Using the values in Tables 7 and 8, and the areas for each type of vegetation replaced with sugarcane, the total carbon stock change was evaluated and divided by a 20 year period. For the above ground carbon stock, only the values corresponding to perennial vegetation were considered. Results are in Table 9.

Note that in all Scenarios there is a net reduction in emissions (close to 100 kg CO_2 eq/m^3 ethanol); this was expected, since the expansion areas for sugarcane include a very small fraction of native lands with high carbon stocks, and some degraded land. The specific situation for land availability, the environmental restrictions and local economic conditions (relative crop values and implementation costs), discussed in the section *Ethanol in the*

Table 9. Emissions associated with LUC to unburned cane.

Reference crop	Carbon stock change[a] (t C/ha)	Emissions (kg CO_2 eq./m^3)		
		2006	2020 electricity	2020 ethanol
Degraded pasturelands	10	-302	-259	-185
Natural pasturelands	-5	157	134	96
Cultivated pasturelands	-1	29	25	18
Soybean cropland	-2	61	52	37
Maize cropland	11	-317	-272	-195
Cotton cropland	13	-384	-329	-236
Cerrado	-21	601	515	369
Campo Limpo	-29	859	737	527
Cerradão	-36	1,040	891	638
LUC emissions[b]		-118	-109	-78

[a] Based on measured values for below and above ground (only for perennials) carbon stocks.
[b] Considering the following LUC distribution – 2006: 50% pasturelands (70% degraded pasturelands; 30% natural pasturelands), 50% croplands (65% soybean croplands; 35% other croplands); 2020: 60% pasturelands (70% degraded pasturelands; 30% natural pasturelands); 40% croplands (65% soybean croplands; 35% other croplands). Cerrados were always less than 1%.

specific Brazilian context, indicate that LUC motivated GHG emissions will not impact ethanol production growth in Brazil in the time frame considered (2020).

It must be noted that the above ground carbon in the sugarcane plant is relatively high, and even with its annual harvesting the change from any of the other crop, or even a *campo limpo*, to sugarcane will produce an additional carbon capture (corresponding to differences in the 'average' above ground carbon in the plants). This was not included here, since it has not been considered in the IPCC methodology.

4.4. Indirect land use change effects on GHG emissions of biofuels worldwide

For most land use changes anywhere some impacts (including in GHG emissions) may happen; and in our increasingly globalized economy indirect LUC impacts may occur. However some of the hypotheses and tools leading to the initial quantification of the impacts of biofuels production (Gnansounou *et al.*, 2008), as presented today, are clearly not suitable:

- A key issue for the models is the correct description of the drivers to LUC, everywhere; but many agricultural products are interchangeable, and (increasingly) traded globally; and the drivers of LUC vary in time and regionally. 'Equilibrium' conditions are not reached. Drivers are established by *local* culture, economics, environmental conditions, land policies and development programs. The development of a range of methodologies and the acquisition/selection of suitable data are needed to reach acceptable, quantified conclusions on ILUC effects. The growing consensus over this problem is summarized in the recent letter from 28 scientists to the CARB (M.D. Nichols, personal communication): '…a severe lack of hard empirical data'… (the need to) 'further study highly controversial and speculative indirect land use changes… (for the) necessary time over the next five years… before incorporating any of these indirect impacts in (the LCFS) standard'.
  Simplifying methodologies (looking to 'regions' in the world, therefore losing the global implications; or relying on indexes for too large areas, to by-pass the lack of data; or distributing the total 'estimated' ILUC emissions equally among all biofuels) would lead to still less accurate results.
- The land used for agriculture today is ~1300 M ha, *excluding pasture lands*; biofuels use less than 1.5% of that; and possibly less than 4% in 2030 (IEA, 2006). Today's distribution of production among regions/countries has never considered GHG emissions; it was determined by the local/time dependent drivers (including subsidies and food security considerations). The better knowledge of those drivers and their effects, and its use to re-direct land use as possible over all the agricultural and pasture lands worldwide, would be much more effective than just to work on the 'marginal' biofuels growth areas. We should not simply take as 'unchangeable' the huge context of today's agriculture.
- Increases in agricultural productivity, energy end-use efficiencies and the use of other energy renewable resources in the next decades may be expected, changing energy

demand and required areas for energy production, and they can entirely change the 'future' ILUC impacts of biofuels.

4.5. ILUC effects from ethanol in the specific Brazilian context

In general, exceptions (biofuel sources with no LUC indirect GHG emissions) have been considered: waste or residues; use of marginal or degraded land; unused or fallow arable land; or improving yields in currently used land. Looking at the scenarios for ethanol production in Brazil, and the land use in Brazil today (in the context of the available land) we note that:

- Most scenarios (based on Internal Demand plus some hypotheses for Exports) indicate a total of ~ 60 M m^3 ethanol in 2020 (CEPEA, 2007; Carvalho, 2007; EPE, 2007), corresponding to 36 M m^3 more than in 2008. For the 2020 conditions, *the additional area needed will be only 4.9 M ha (Scenario Electricity) or 3.5 M ha (Scenario Ethanol).* Since the Scenario Ethanol would not be implemented (even if technically successful, and competitive) in time, we may expect ~5.1 M ha of new cane area, until 2020.
- Agricultural production (crops) uses a small fraction of the total area, and only 18.5 % of the arable land (Table 10). Pasture land (200 M ha) is nearly 60% of the arable land. Sugarcane for ethanol uses only 1% of the arable land, and the Land Available (not including the conversion of pasture lands) is twenty times larger. The new area needed for sugarcane until 2020 (5.1 M ha) is only 8% of the total crop area today, or *2.5% of the pasture area today.*
- The conversion of low quality pasture land to higher efficiency productive pasture is liberating areas for other crops. The average heads/ha in Brazil was 0.86 (1996); and 0.99 (2006), with nearly 50% planted pasture (IBGE, 2006). In the State of São Paulo the average was 1.2-1.4 in the last years. The conversion of low grade pasture could release ~30 M ha for other uses.
- Sugarcane expansion is smaller than the expansion of pasture and crops; and in the places where sugarcane expands the eventual competition products (crops and cattle) also expand. *The expansion for other agricultural crops and pasture is taking place independently of sugarcane expansion.* In the period from 2002 to 2008 the sugarcane expansion displaced Pasture and Crops (CONAB, 2008; Nassar, 2008) as follows: crop area displaced, 0.5% (but crop area increased 10%, and cereal + oilseeds production increased 40%); pasture area displaced, 0.7%; total pasture area decreased 1.7% (but beef production grew 15%).

Within its soil and climate limitations, the strict application of the environmental legislation for the new units, and the relatively small areas needed, the expansion of sugarcane until 2020 is not expected to contribute to ILUC GHG emissions.

Table 10. Land use in Brazil: selected uses (2006) (UNICA, 2008; Scolari, 2006; FAO, 2005; IBGE, 2005).

Land use	Area, M ha	% of arable land	% cultivated land
Total land	850		
Forests	410		
Arable land	340 (40%)	100.0	
Pasture land	200	58.8	
Cultivated land (all crops)	63	18.5	100.0
Soybean	22	6.5	34.9
Maize	13	3.8	20.6
Sugarcane (total)	7	2.1	11.1
Sugarcane for ethanol	3.5	1.0	5.6
Available land	77	22.6	122.2

5. Conclusions

The analyses of the GHG emissions (and mitigation) with ethanol from sugarcane in Brazil in the last years (2002-2008) and the expected changes in the expansion from 2008 to 2020 show that:

- The large energy ratios (output renewable/input fossil) may still grow from the 9.4 value (2006) to 12.1 (2020) in two Scenarios: the better use of canebiomass to generate surplus electricity (2020 Electricity Scenario: already under implementation) or to produce more ethanol (2020 Ethanol Scenario: depending on technology development). The Ethanol Scenario, if fully implemented, would reduce the area needed by 29%.
- The corresponding GHG mitigation (with respect to gasoline), for ethanol use in Brazil, would increase from the 79% (2006) to 86% (2020) if only the ethanol is considered (with emissions allocation to co-products), or from 86% (2006) to 95% or 120% (2020: Ethanol or Electricity Scenarios) if all co-products credits and emissions are considered for ethanol (substitution criterion).
- LUC due to ethanol expansion started in 2002 (ethanol production was constant at the 12 M m^3 level, since 1984). In the expansion, land availability, the environmental restrictions, the relatively small area used for expansion and the local economic conditions (relative crop values and implementation costs) led to very small use of native vegetation lands (<1%), and large use of low productivity pasture lands and some crop areas: soy and maize. LUC derived GHG emissions were actually negative in the period 2002-2008. The growth scenarios for 2020 (~reaching 60 M m^3 ethanol) indicate the need for relatively small areas (~5 M ha) as compared to the availability (non used arable lands, or even degraded pasture lands); the trend is the use of more pasture lands and less crop areas, in the expansion. Again, very little impact (if any) on LUC GHG emissions are expected.

- Suitable evaluations (even estimates) of ILUC impact in emissions are far from possible today, due to the lack of adequate methodologies and corresponding (global) data. However local conditions in Brazil indicate a good possibility of significant increases in ethanol production without increasing ILUC GHG emissions:
  - The area needed for expansion (~5 M ha, until 2020) is very small when compared with the areas liberated with increased cattle raising efficiency (30 M ha) and other non used arable lands.
  - Sugarcane expansion has been independent of (and much smaller than) the growth of other agricultural crops, in the same areas. In all sugarcane expansion areas the eventual competition products (crops and beef production) also expanded.

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