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Biofuels in Brazil in the Context of South America Energy Policy

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1. Introduction

This article seeks to provide an overview of the current energy policies, focusing on Brazil and regarding biofuels in particular. It does not claim to put forward an exhaustive analysis of the subject. Hence, it focuses on certain particularly relevant aspects, such as climate change and CO₂ emissions abatement, rather than entering into the details of all extant aspects. It is aimed to serve as a policy instrument in order to provide a basis for decision-making and planning actions, contextualizing the discussion within the global framework. In this connection, special attention is paid to the impact of the initial soaring of the oil prices, their subsequent drop with the onset of the economic crisis, which reached Latin America in 2009, as well as the latest hike in the price of oil. This impact has as a counterpoint the discovery of off shore pre-salt oil in Brazilian deep waters, which significantly increases petroleum-producing potential of the country.

Among the different renewable primary energy sources in Brazil, the most relevant are hydroelectricity and biomass, from which biofuels are derived. The former has been the subject of several studies and, therefore, will not be discussed as thoroughly as biofuels in the present text, especially sugar cane ethanol. Both hydro and ethanol have stirred heated debates and controversies internationally. The recent soaring food prices worldwide is attributed by some to the supposed prioritization of biofuels production, which, in addition, is blamed, in the case of Brazil, for contributing further to the deforestation of the Amazon. All of this, in spite of the continuous decrease of the deforestation rates since 2004[1], the increase of ethanol production [2] and the fact that sugarcane for ethanol plantations in Brazil occupy less than 1.5% of the Brazilian crop area [3].

The present situation resembles the not too distant past experience of the crises provoked by the skyrocketing in the price of crude oil on the international market which, until 1973, varied between US\$ 1 and US\$ 2 only to soar, for a spell in 1979, to US\$ 40, then to plummet in the second half of the 1980s, and left to follow an erratic path throughout the 1990s. In 1999, oil prices fell to US\$ 10 but, in 2006, exceeded US\$ 70 and, in 2008, reached US\$ 140. So, in 9 years, the price of oil increased 14-fold, nearly doubling in the span of two years, but then dropped to below US\$ 50, maintaining itself around this value for the rest of 2009, to increase again up to reach about US\$ 100 in 2011.

For its part, natural gas has been the cause of disputes, in recent years, between Russia and Europe, between Argentina and Chile, and, lately, between Bolivia and Brazil. An important new factor is the increasing participation of shale gas in North America. In 2000 only 1% of natural gas produced in the USA was shale gas, with its share growing to 20% in 2010 and projected to reach 46% in 2035, due to its low cost. The share of natural gas in the Brazilian energy matrix is not significant, although it shall become more important with the import of LNG by ships as well as with the pre-salt natural gas production.

Where electricity is concerned, there were serious instances of rationing in 2001, lasting for many months in Brazil and California - in both cases due to lack of adequate power sector regulation. Energy deregulation played an important part in the process of economic liberalization in the course of financial globalization, which is at the root of the global crisis, which first hit the USA in 2008, and worsening in 2009, it spilled over and reached South America, in particular, Brazil.

The energy crisis has been further aggravated by the overlap of an environmental crisis and a financial one, as a result of climate change, due to the intensification of global warming from greenhouse gas (GHG) emissions, such as carbon dioxide from the burning of fossil fuels. Global warming has become a major global political problem, because it bears on society choices which must not be left to business alone to make. The Nobel Peace Prize of 2008 awarded to the Intergovernmental Panel on Climate Change (IPCC) followed the release, in 2007, of its Fourth Assessment Report which caused great concern around the world.

The repercussions of the high international oil prices on the world economy have been significant, although today's share of oil in the world economy is less than at the time of the 70s oil crises. At a global level, this share in the cost of products is generally half of what it was at that time.

Some particular factors contributed to this strong variation in the oil market:

- a. The forecasted decline in world output, despite major discoveries in the Brazilian pre-salt, and increased oil consumption, especially in developing countries, led by China
- b. The global geopolitical instability, especially in the Middle East oil producing regions, and the strong dependence of OECD countries on oil imports. To a lesser extent, this instability is felt in South America as in the case of the political tensions between the USA and Venezuela.
- c. The global economic crisis which first erupted in the USA in 2008.

- d. Environmental pressures, especially due to carbon dioxide emissions from the burning of fossil fuels, which exacerbate the greenhouse effect, thus contributing to global warming.

Finally, with respect to point (d), it is important to point out that the share of renewable primary energy sources is higher in Brazil and in South America as a whole than in other continents, while the use of biofuels in Brazil is widespread and thus, the GHG emissions of the country are mainly from deforestation.

Not considering nuclear energy, released from the fission of uranium and without any chemical combustion, non-renewable fuels, such as coal, oil and natural gas, are responsible for greenhouse gas emissions. Life cycle analysis show that renewable sources such as ethanol from sugar cane and hydroelectricity emit little greenhouse gases. CO₂ emitted from biofuels combustion is reabsorbed from the atmosphere during plant growth. However, roughly half of all firewood and charcoal in Brazil comes from deforestation, charcoal mainly used in steel production [4]. The net emissions in the case of alcohol come primarily from the use of diesel for the tractors and trucks on the sugarcane plantations, as well as the production of the synthetic fertilizers and herbicides employed. In the case of hydropower, COPPE's research group carried out measurements at various reservoirs in the country and recorded the carbon dioxide and methane emissions, confirming that those are much smaller than that of the thermoelectric power plants.

2. Survey of energy policy in South America

According to the latest IPCC report [5], there was a 70% worldwide growth in greenhouse gas emissions between 1970 and 2004. Among these, CO₂ emissions rose by 80% and represented 77% of the anthropogenic emissions in 2004. The energy sector had the highest growth in emissions between 1970 and 2004 (145%) followed by the transport sector (120%), industry (65%), and land use and deforestation (40%). Table 1 provides the rates of primary energy per capita and CO₂ emissions per capita, per energy consumption and per GDP of the South American countries in 2009. It can be seen that countries which have a large share of renewable power, such as Brazil and Paraguay, have better emission indicators than countries such as Argentina and Venezuela, which rely heavily on fossil fuels.

The meeting of the UN Convention on Climate Change in Copenhagen, in 2009, resulted in frustration regarding finding a consensus for more effective commitments to reduce global GHG emissions. However, the commitment to limit to 2° C the rise in global temperature relative to the preindustrial era is encouraging. At the Copenhagen Conference the Brazilian position included this limitation, which entails a major effort to reduce emissions on the part of the rich countries and to keep emissions under control where the developing countries are concerned. One controversial issue refers to the adoption of obligations by developing countries regarding their own emissions. An argument in support of adopting such commitments is the growth of emissions in developing countries, especially China and India. Nevertheless, the per capita CO₂ emissions in rich countries are still well above those in developing countries.

Countries	TJ per capita	ton CO ₂ / capita	ton CO ₂ / TJ	kg CO ₂ / US\$2000 GDP
Argentina	0.077	4.14	53.6	0.42
Bolivia	0.027	1.31	49.3	1.10
Brazil	0.052	1.74	33.6	0.39
Chile	0.071	3.84	53.9	0.63
Colombia	0.029	1.33	46.4	0.43
Ecuador	0.035	2.09	59.9	1.18
Paraguay	0.031	0.64	20.4	0.45
Peru	0.023	1.32	58.2	0.45
Uruguay	0.051	2.31	45.2	0.26
Venezuela	0.099	5.45	55.2	0.97

Source: [6]

Table 1. Energy Per Capita and CO₂ Emissions Indexes from Energy (in Terajoules) Consumption in 2009

It is important to point out that CO₂ emission is not the only indicator to analyze the responsibility among countries. For example, cattle grazing emit a huge amount of CH₄ due to enteric fermentation and N₂O due to manure [7]. Nevertheless, these indicators need to be balanced because they are related to food production, a basic need. In Brazil, an encouraging development has been the creation of the National Climate Change Plan, with its targets for reducing deforestation, responsible for most of Brazil's emissions.

On the other hand, the increased share of fossil fuel use in power generation in Brazil is nothing to cheer about. But the growth of production and consumption of fuel alcohol in cars and the fact that 45% of its primary energy matrix is comprised of renewable sources, including hydroelectric generation and biofuels - as against 13% for the world and 6% for OECD countries - is heartening.

Now, if we consider the different primary energy sources [8], Latin America's share in the world's energy production varies according to the source considered:

- 4.4% of total primary energy
- 9.5% for oil
- 4.9% for natural gas
- 1.4% for coal
- 0.8% for nuclear
- 20.1% for hydroelectricity.

The share of nuclear electricity generation in Latin America represents less than 1% of the world's total, as it is limited to Brazil, Argentina and Mexico. Meanwhile, the share of hydropower exceeds 20%, as Brazil, Venezuela and Peru are among the ten countries with the largest water resources in the world, the first two also being among the top ten producers of hydroelectricity.

Table 2 shows the production, import and export of oil, natural gas, coal and hydroelectric power in the major South American countries. Imports and exports related to oil include oil derivatives in addition to crude oil. With respect to coal, the different types have been computed, as well as coke. The hydroelectricity columns show, in addition to production, the import and export of electrical energy.

Country	Oil (Million toe)			Natural Gas (Million toe)			Coal (million toe)			Hydroelectricity (thousand MWh)		
	Prod	Imp(a)	Exp(a)	Prod	Imp	Exp	Prod	Imp	Exp	Prod	Imp(b)	Exp(b)
Argentina	37.8	1.3	14.9	36.2	1.3	5.4	-	1.0	0.14	34.6	8.0	0.4
Bolivia	2.9	0.2	0.6	9.9	-	8.6	-	-	-	2.5	-	-
Brazil	87.3	28.0	23.4	9.2	7.5	-	2.5	11.3	-	337.4	39.2	0.1
Chile	0.3	14.3	1.7	1.7	5.3	-	0.3	3.9	-	24.8	2.1	-
Colombia	27.4	0.9	16.1	6.1	-	-	38.9	-	34.9	39.8	-	1.7
Ecuador	27.0	2.6	20.6	0.4	-	-	-	-	-	6.8	1.7	-
Paraguay	-	1.1	-	-	-	-	-	-	-	51.2	-	43.8
Peru	5.2	5.9	3.5	1.4	-	-	0.03	0.8	-	19.9	-	-
Uruguay	-	2.3	0.3	-	4.1	-	-	-	-	6.7	1.6	0.8
Venezuela	169.3	-	138.1	23.2	-	-	5.2	-	5.2	75.0	-	-

(*) Includes crude oil and derivatives; (#) Electricity including hydro and thermal generation

Source: International Energy Agency, 2006

Table 2. Oil, Natural Gas, Coal and Hydroelectricity

According to Table 2, the largest oil producers in South America are Venezuela and Brazil, the latter far behind the former. Brazilian exports (mainly of heavy crude oil) match the imports (of light crude for refining). Argentina, Colombia and Ecuador have a similar production and also export oil.

Argentina is the largest producer of natural gas, followed by Venezuela, Bolivia and Brazil, which is also an importer. The exporters are: Argentina (to Chile) and Bolivia (to Brazil and Argentina). Important consumers of natural gas are: Venezuela, Argentina and Brazil. Coal production is particularly significant in Colombia, also an exporter, while Brazil is the largest producer of hydroelectricity on the continent, followed by Venezuela and Paraguay, the latter also being a major exporter.

To understand the changes in South America, the following aspects should be taken into account:

- a. In the years 2000 there has been significant pick-up in economic growth in several countries after a period of stagnation or low growth stretching over quite a few years, under the monetarist policies of economic adjustment under the auspices of the International Monetary Fund and the World Bank with the backing of the rich countries.
- b. Social inequality remains high, even if significant improvements are taking place in the social field in some countries. In Brazil, it has been estimated that some 40 million people have been lifted out from the poorer Class D, to the level of Class C income.

The two main energy integration projects in operation between Brazil and South American countries are the bi-national Itaipu power plant with Paraguay, the world's 2nd largest in electricity generation, whose expansion from about 12 GW to 14 GW was completed in 2008, and the import of 30 million m³ per day of natural gas from Bolivia. Both were subject to crises with Bolivia and Paraguay respectively, already settled.

There is an electricity connection between Brazil and Argentina in the South and another one in the North with Venezuela. Furthermore, there is a small connection with Uruguay.

Given the variation in flow without a regulation reservoir to secure the power of these plants, the reservoirs of the hydroelectric plants of the interconnected grid can be used to store water when the flow is high, in order to offset the energy drop during the months with a low flow. However, to avoid very large environment impacts, in the new hydropower plants the flooding area is small. The Santo Antonio and Jirau hydroelectric projects under construction on the Madeira River, near the border with Bolivia, are run of the river, the same being the case of the new Belo Monte hydroelectric power plant.

Brazil is the foremost user not only of liquid biofuels, particularly ethanol in addition to its biodiesel program, but also of solid biomass - firewood and charcoal, widely used in the steel industry. Brazil and Argentina are currently among the world's top five producers of biodiesel, the latter also being a major exporter, mainly to Europe. However, since biodiesel demand in general is still only a fraction of ethanol, most of this article's focus will be on this alcoholic biofuel.

3. Biofuels in Brazil and automotive ethanol

There is an international debate on biofuels, which are being blamed for the high food prices worldwide and which affect the poor most. The Brazilian government has addressed this concern adequately in connection to the production of alcohol from sugarcane. According to [9], the country's sugarcane crop was cultivated over an area of 8.4 million hectares (8.4 Mha) in 2011. 50.3% of all sugarcane was targeted for ethanol production, the remainder used for sugar. On the other hand, soybean, Brazil's most important crop, occupies 25 Mha [10]. According to [11], Brazil has 152 Mha of arable land, of which 62 Mha are currently in

use. 177 Mha are pastures. So, if one excludes the 440 Mha of virgin forests, there remains 90 Mha left available for expanding agricultural production without deforestation. And these figures do not include the reconversion of degraded pastures. Only a portion of these areas is suitable for sugar cane cultivation and is economically and socially viable for producing biofuels such as ethanol and biodiesel. The latter, to a large extent, comes from soybeans, which, unlike sugarcane, can encourage deforestation in the Amazon, but recently this link cannot be established, because the deforestation rates in Brazil have been decreasing in the last decade [1] in spite of the increase in soy production.

US corn ethanol is subsidized, and, unlike Brazilian sugarcane alcohol, it affects the price of corn, impacting the price of food and feed. Production of corn ethanol also involves the burning of natural gas. The sugarcane crushed stalk, called bagasse, by contrast, has more than enough energy to meet the plant's heat and electricity demand, even providing surplus power to the grid. Therefore, alcohol produced in Brazil is more efficient energy and environmentally-wise. The capture of CO₂ from the air during sugarcane growth roughly balances out the emissions from the production and consumption of alcohol. As a gasoline alternative, it is effective in avoiding the emissions of gases contributing to global warming.

The international biofuels market is poised to increase in the next few years. The US presently consumes twice as much fuel alcohol as Brazil, but its percentage in terms of displacing gasoline is low, around 10%, because of its huge gasoline consumption - 8.74 million barrels per day or roughly 540 billion liters in 2011 [12]. The National Renewable Fuel Standard program (commonly known as RFS) has set an increasing volume of biofuels to be required in the US market [13]. RFS categorizes fuels and caps the so-called "conventional" renewable fuel (corn starch ethanol), so by 2022, 21 billion gallons of the 36 billion gallons (136 billion liters) required must come from cellulosic biofuel or advanced biofuels derived from feedstocks other than corn starch. This categorization of fuels contains specific lifecycle GHG emissions for biofuels relative to lifecycle emissions from fossil fuels and will be further discussed in section 4.

The Energy Independence and Security Act of 2007 (EISA), which established the biofuels mandate, stipulates that indirect, as well as direct, emissions must be accounted for in the lifecycle analysis of any biofuel source, an issue to be explored later on this article. It suffices to say that, currently, the only biofuel currently recognized by the Environmental Protection Agency as being "advanced", from a GHG mitigation standpoint, is Brazilian sugarcane ethanol. If this situation does not change until 2022, at least 19 billion liters will have to be imported from Brazil, for environmental reasons. Considering that Brazilian supply of ethanol in 2011 was 23 billion liters, it will be a major undertaking to supply the projected US demand.

On top of that, in December 2008, the European Parliament approved the Renewable Energy Sources Directive (RED) setting an EU target of 10% for biofuel use in transportation fuels by 2020.

In a nutshell, Brazilian ethanol has generally been regarded the most effective biofuel in terms of mitigating GHG emissions, but, due to the huge markets under consideration, it is

unreasonable to expect that Brazil would be able to meet their demands for environmentally appropriate biofuels. Other countries would have to play their part as well.

The issue of biofuels has raised a controversy concerning the competition with food production. In view of the fact that Brazil has plenty of spare land for crop production, as stated above, it should be clear that cultivating sugarcane for fuel alcohol does not interfere substantially with food production, remembering that sugar cane for biofuel occupies 1.3% of the country's agricultural land[3].

In a recent paper, [14] made a comparison between sugar cane and corn for ethanol production, with focus on the present debate about land use dispute for food and energy production. The indicators used to compare the activities are CO₂ emissions, energy consumption, co-products from the processes and deforestation. From a methodological standpoint, the study conducted a lifecycle inventory evaluation of sustainability issues, both for developed and developing countries. Brazilian government plans to ensure sustainability are commented. A synthesis of that paper together with other considerations follows below.

There are different biofuels feedstocks, such as forest resources; energy crops; agriculture wastes and urban wastes. Table 3 shows biomass raw materials with the corresponding technologies, products and uses in Brazil, as well as the fossil fuels that they replace. Direct combustion of firewood is important in rural areas for cooking. This does not necessarily entail deforestation as families in rural areas, in general, collect twigs and fallen trees branches. The use of charcoal in the steel industry is important for avoiding GHG emissions. For each ton of pig iron produced, 1.7 tons of CO₂ from coke and coal are emitted, while charcoal use in steel production allows, on average, a net capture of 0.9 tons ton of CO₂ from the atmosphere, due to tree growth, assuming a planted forest is employed. Thus, if one third of all pig iron were made with charcoal, the steel industry in Brazil could have zero net emission. However, as mentioned, about half of the firewood for charcoal used in pig iron production comes from deforestation, a problem yet to be solved.

The Brazilian Alcohol Program began in 1975 after the first oil shock and its first phase consisted in using ethanol as a gasoline octane booster. After the second oil shock in 1979, a second phase began, with ethanol replacing gasoline in cars, whose Otto cycle engines were adapted for this purpose. Among the historical factors that contributed for the government to deploy the Alcohol Program was the need to reduce the trade balance deficit, affected by crude oil importation. Besides, the Program boosted job generation in sugar cane agro-industry and reduced atmospheric pollution through the elimination of lead as an additive to gasoline, as ethanol has a high octane index [15, 16].

By 1985 more than 90% of new cars sales consisted of ethanol fuelled engines, but in the 1990 decade there was a shortage of ethanol in the country. An ad hoc temporary solution was to adopt a ternary mix composed of ethanol, methanol and gasoline to supply part of the market. The result was a lack of consumer confidence in ethanol, with the consequent reduction of sales of new ethanol fuelled cars to 11% in 1990, 2% in 1995 and 1% in 2000 [17]. The reasons for the ethanol shortage were the fall of crude oil price and lack of continuity in governmental policy for ethanol.

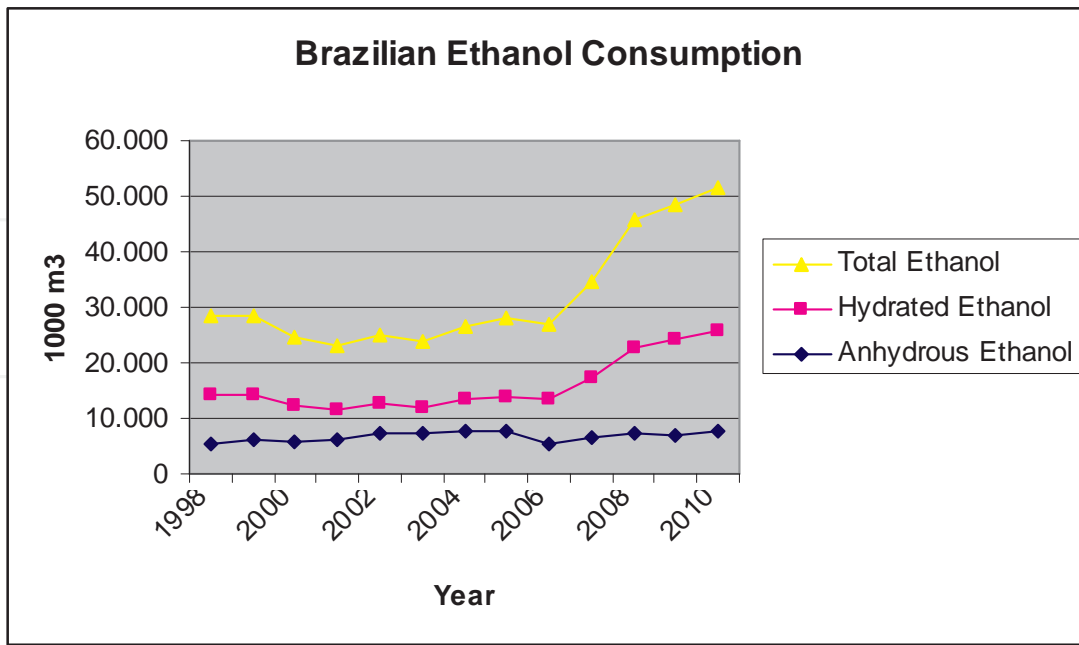
Technology	Biomass Raw Material	Products	Main Use	Fossil Fuels Substitution
Direct Combustion	Firewood Sugar cane bagasse trash and other wastes	Heat	Cooking Industry Electric power	LPG Fuel oil Natural gas
Bioconversion:				
- Fermentation	Sugar cane	Ethanol	Transport	Gasoline*
- Anaerobic digestion	Wastes	Biogas	Potential	Natural gas
Chemical and Thermal:				
- Pyrolysis	Wood	Charcoal	Industry	Coal and fuel oil
-Gasification	Biomass	Synthesis gas	Industry	Natural gas
-Esterification	Vegetable oil and others materials**	Biodiesel	Transport	Diesel
- Cracking	Vegetable oil	Diesel	R&D	Diesel
- Hbio***	Vegetable oil	Diesel	Pilot	Diesel
Hydrolysis	Biomass	Ethanol	R&D	Gasoline*

Obs: (#) Includes urban solid wastes, lixivia from pulp and paper industry, wastes from rice and others; (*) – It can substitute also for diesel oil with some additive; in Brazil gasoline has 25% of ethanol as additive, besides the use of pure ethanol in flex fuel cars; (**) Including animal fat wastes, garbage and micro-algae (R&D); (***) – Petrobras Technology for processing vegetable oil in oil refineries.

Table 3. Uses of Bioenergy in Brazil

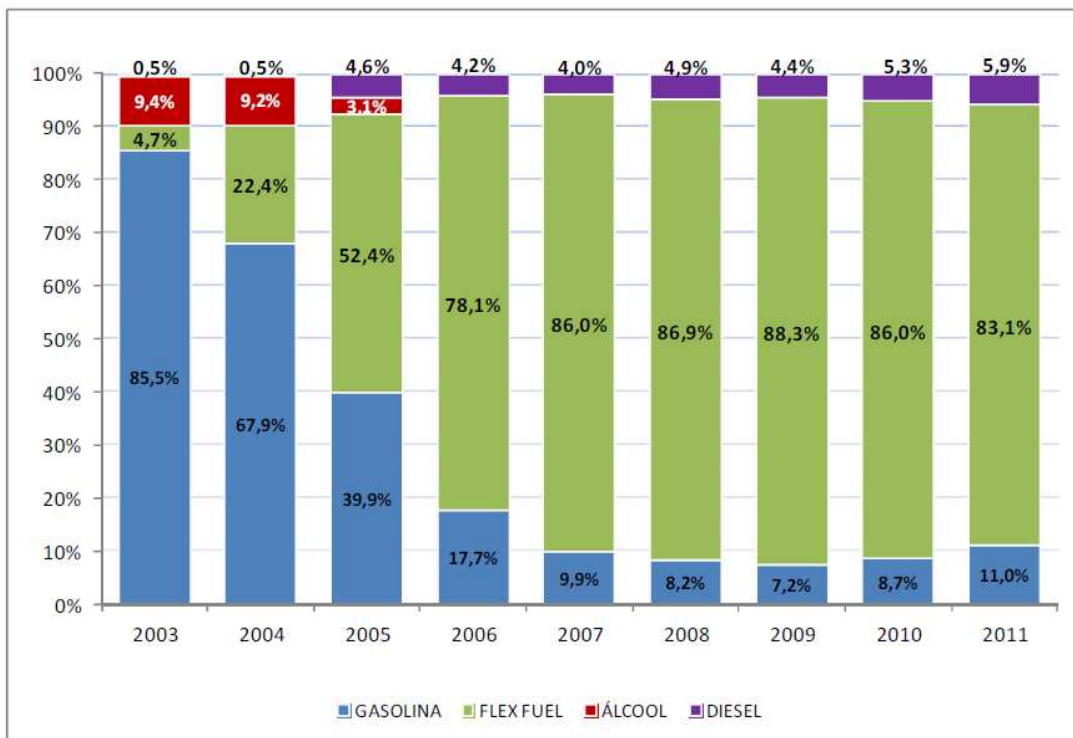
Beginning in 2003 there was an ethanol revival due to local production of flex fuel cars. Their engines can work with two different fuels in any proportion, and were first made in the US in the 1980s, but the technology developed by Brazilian engineers is innovative, as it uses sensors that already exist in the car, which match their fuel readings against information stored in the on-board computer to adjust the engine. Early US flex cars used a special sensor to identify the fuel mix and adjust the engine, but it was expensive and not viable for the Brazilian fleet, dominated by low cost, small and mid-sized compact cars [18].

Figure 1 shows the behavior of ethanol consumption in Brazil, which surpassed 15 billion liters in 1998, going down to 10 billion liters in 2001 and grew again in the years 2000, due to the introduction of flex fuel cars, which boosted the demand for hydrated ethanol.



Source: [19,20]

Figure 1. Evolution of ethanol consumption in Brazil (billions liters a year)



Source: [9]

Figure 2. Sales of Gasoline, Alcohol and Flex Cars in Brazil

Figure 2 shows how this phenomenon was correlated to the quick penetration of flex fuel cars, which currently comprise more than half the total fleet of passenger cars in Brazil. The exponential growth of flexible cars after 2003, stimulated by the high gasoline price due to the increase of crude oil price, global warming-related pressure, among others factors. The cost of ethanol in Brazil went down from US\$ 20/GJ in 1980 to US\$ 6/GJ in 2006, corresponding to US\$ 40/barrel of oil [21] following a learning curve. So, while subsidies were necessary to start the program they are not needed nowadays.

4. Avoided CO₂ emission by ethanol substitution for gasoline

4.1. Life cycle avoided emission: Comparison of sugar cane ethanol with corn ethanol

A problem of ethanol in some OECD countries and China is that it is made from corn. From a global warming standpoint, corn ethanol is less effective than sugar cane ethanol as a substitute for gasoline.

The advantage of biofuels is that when biomass grows up it captures from the atmosphere the CO₂ emitted by biofuel combustion in the car engine. However, 1 GJ of fossil fuel is expended to produce 1.3 GJ of ethanol from corn [22]. That is, for each energy unit transformed in heat through corn ethanol combustion, 0.77 energy units is spent producing ethanol from corn, mainly in the natural gas needed for ethanol distillation, as well as the embedded energy in synthetic fertilizers and herbicides.

On other hand, sugar cane has a surplus of biomass enough to generate heat and electricity in the process of ethanol production. For each 1 GJ of fossil fuel consumed in sugar cane and ethanol production there are, on average, 9 GJ of ethanol and this value can reach 11 GJ in the best cases [22].

Therefore, for each unit of energy transformed in heat when sugar cane ethanol is burned in car engines, an average of only 0.11 units of energy from fossil fuel is needed to product it. Besides the bagasse, sugar cane has a significant amount of trash (leaves and top), which is usually burned before harvesting, to allow manual cutting by laborers. However, crop residues are increasingly being recovered, as mechanization, mainly in São Paulo state (responsible for 50% of ethanol produced in Brazil) [23], is becoming more commonplace to harvest cane. To calculate the net avoided emissions, we must subtract, from the gross avoided CO₂ emissions due to fossil fuel substitution, the emissions of CO₂ from fossil fuels used in sugar cane and ethanol production process, as well as other GHG emitted also for producing cane and ethanol. Therefore, there is the need to express the mass of each non CO₂ GHG in terms of equivalent CO₂ emission.

In the literature there is a range of values for emissions in sugar cane production¹ and for the avoided CO₂, depending on the case study and on methodology. For instance, different papers consider alternatively:

¹ It is usual to express the emission in terms of mass of Carbon in the molecule. For instance, the mass of C in CO₂ is $12 / (12 + 2 \times 16) = 12 / 44$ of the CO₂ mass and the mass of C in CH₄ is $12 / (12 + 4 \times 1) = 12 / 16$ of the CH₄ mass.

- a. the best case, a particular one or the average among a set of farms and distilleries in a period of time;
- b. either only the gross avoided emission of the gasoline replaced with ethanol, or the gross avoided emission of gasoline plus the surplus electricity sold to the grid;
- c. either only the direct energy consumption or the life cycle analysis, including emissions in ethanol production and also in gasoline production;
- d. hydrated ethanol, anhydrous ethanol or a mix of them in the market.

Sometimes, the assumptions used in published papers are not clear, causing confusion in quotations.

4.2. Numerical results from field research data on sugar cane ethanol

A detailed life cycle analysis was presented in a report supported by the Environment Secretariat of São Paulo State [21]. The data base was composed of three surveys, the first one covering 26 to 31 distilleries, the second one 17 to 22, and the last one a larger set of 98 distilleries throughout the country. From this reference, it is possible to calculate representative values for emissions from sugar cane and ethanol production in percentages of CO₂ equivalent (Table 4). The percentage of CO₂ that is avoided by the ethanol industry can be found in Table 4.

Emission Source	Emission Type	%
From life cycle (A): equipments, buildings, etc	in cane production	6.6
	in ethanol production	9.5
From fertilizers, herbicides, pesticides etc (B)	in cane production	20.6
From sugar cane burning before harvest (C)	CH ₄	19.1
	N ₂ O	18.2
From soil (C)	N ₂ O	6.9
From fossil fuel consumption (C)	CO ₂	19.1
Total	A	16.1
	B	20.6
	C	63.3

Source: Elaborated by using data from [21]

Table 4. GHG Emissions in Sugar Cane Ethanol Production (% of CO₂ equivalent)

The results in Table 4 deserve some comments. The lower heat value of ethanol is compensated by the higher compression rate and better efficiency of the engine. In the use of anhydrous ethanol as an additive to gasoline, used in a proportion of 25% in Brazil (E25), 1 liter of ethanol corresponds to 1 liter of gasoline. In the case of hydrated ethanol the proportion is 1.3 liters of ethanol

(E100) to 1 liter of E25, which means 1 liter of ethanol for 0.77 liter of E25 or $0.77 \times 0.75 = 0.577$ liter of gasoline. The direct emission factor of gasoline is 0.0693 kg CO₂/MJ [5], but in a life cycle it becomes 0.0817 kg CO₂/MJ [24]. Instead of bagasse substitution for fuel oil to calculate H' in Table 5, the emission by electric power generation in Brazilian interconnected grid established for the Clean Development Mechanism can be applied.

More recent data on the average emissions can be obtained from [25], considering the 2005/2006 harvest. Their case study focused on a set of Brazilian distilleries that process 100 Mt of sugar cane per year.

Results from 2002/2003 Harvest	Average	Best Value Scenario
Energy consumption EC (Mcal/t cane)	48.2	45.8
Sugar cane agriculture	11.8	9.5
Ethanol production	60.0	55.3
Total		
Energy production EP (Mcal/t cane)	499.4	565.7
(ethanol + electric energy from bagasse surplus)		
Energy gain (EP/EC)	8.3	10.2
GHG emissions (kg CO ₂ equiv. / t cane)	19.2	17.7
From fossil fuel consumption	15.3	15.3
Others	34.5	33.0
Total		
Total GHG emission (kg CO ₂ equiv./ m ³ of ethanol) = (A+B+C)	405.8	358.7
Net avoided CO ₂ (kg CO ₂ / m ³ of ethanol) from gasoline (H) and fuel oil (H') used for electric energy: $H+H' - (A+B+C)$	2600	2700
For anhydrous ethanol		
For hydrated ethanol		
Percentage of avoided CO ₂	86%	88%
For anhydrous ethanol	81%	84%
For hydrated ethanol		

Source: Elaborated by using data from [21]

Table 5. Energy gain, GHG emissions and percentage of CO₂ avoided by the Ethanol industry in Brazil

Using data from this article it is possible to calculate the net avoided CO₂ in terms of percentage of fossil fuel CO₂ emission. The results are:

- a. For sugar cane and ethanol production the total GHG emissions, using GWP [26], are 436 kg CO₂ equivalent / m³ of ethanol.
- b. The net CO₂ avoided emissions are 2323 kg CO₂ / m³ of anhydrous ethanol.
- c. In [14] the percentage of avoided fossil fuel CO₂ emission due to anhydrous ethanol is 84.1 %.

The above results, confirmed by Table 5, conclude that a very high percentage of GHG emission is avoided by sugar cane ethanol substitution for gasoline.

In Brazil about 1 toe of bagasse is consumed to produce 2 m³ of ethanol [19], equivalent to 20,900 MJ/m³. Taking this value as the self consumption of energy in the distillery (from bagasse combustion) and assuming that, instead of bagasse, natural gas is burned, whose emission in life cycle is 0.095 kg CO₂/MJ [24], $20,900 \times 0.095 = 1985$ kg CO₂, in a first approximation, the emissions are reduced by 12%.

The above calculation roughly shows the avoided percentage of CO₂ when fossil fuel is not necessary to produce ethanol as in corn ethanol. Other factors that make the latter more energy intensive than sugarcane ethanol: better photosynthetic efficiency of sugarcane, producing more biomass; corn produces starch, which must be hydrolyzed (broken down into sugars), before fermentation; corn demands significantly more nitrogen fertilizers than Brazilian sugarcane, which employs biological nitrogen fixation techniques. Besides, Brazilian sugarcane industry is increasingly employing high efficiency steam boilers. All these factors explain why the avoided CO₂ from sugar cane ethanol is much higher than that from corn ethanol.

4.3. Potential of GHG emission mitigation through energy efficiency and harvest mechanization

4.3.1. Potential energy improvement from ethanol, bagasse and residues

It is possible to improve the energy balance of sugar cane ethanol by:

- a. Increasing sugar cane productivity in tons of cane per hectare;
- b. Increasing the amount of ethanol produced from each ton of sugar cane;
- c. Obtaining more agricultural residues through harvest mechanization;
- d. Improving conversion efficiency of bagasse and trash (sugarcane top and leaves) into heat, mechanical and electric energy.

Ethanol productivity grew up from 2024 liters per hectare in 1975 to 5931 liters per hectare in 2005 [27]. The production of sugarcane in the period 1975-2006 rose from 89 million metric tonnes to 426 million metric tonnes [28]. However, for several reasons – old plantations, poor weather prior and during harvest, sugarcane production and ethanol yield has decreased in 2011, as shown in Table 6.

On average, 55% of sugar cane has been used for producing ethanol in the last five years, but this percentage has decreased to 50.3% in 2011, one of the reasons for the steep decline from 2010 [9]. The best average ethanol yield ever obtained, was 92 liters/t of cane [29], but this performance will take some years to return, due to lack of investments in sugarcane plantation renovation, linked to the Federal Government current gasoline price freeze policy, which has also led to an increase of sugar production instead of ethanol.

The energy available in bagasse and trash is quite significant. Each ton of cane has 280 kg of bagasse with 50% of humidity and 2,130 kcal /kg [19], yielding 596 Mcal / ton of cane. The average value for trash is slightly lower, but the combined energy of bagasse and trash is more than the double of ethanol energy (Table 7) calculated with 92 liter with 0.8 kg/liter and heat value 6,500 kcal/kg [19].

Processed Cane	Ethano	Productivity	
Year	Mt	Mm3	liter/t
2003	359.3	14.5	74.8
2006	426.0	17.7	75.7
2009	622,6	26,2	84.1
2010	627,3	28,0	90,0
2011	565,8	23,0	80,0

Source: [9]

Table 6. Sugar cane and Ethanol Production and Productivity

Mcal/t of cane	
92 liters of ethanol (best value)	478
280 kg of bagasse with 50% of humidity	596
280 kg of trash with 50% of humidity	596

Source: [22]

Table 7. Energy from 1 Metric Ton of Sugar Cane Considering Heat Values

In 2006 bagasse production was 121.0 Mt, from which 71.5 Mt (59.1%) was converted into heat for sugar production, 42.0 Mt (34.7%) for ethanol production and 7.5 Mt (6.2%) for electric power, part of it exported to the grid [19]. Sugar cane trash was not computed. So, 94% of bagasse is converted into heat and mechanical work for sugar and ethanol production. If there were a reduction of 20% in this percentage, through efficiency improvement, the energy from bagasse available for electric power would increase by a factor of 4 ($24.2+7.5/7.5$).

Besides, if 50% of the trash is used, thermal energy for electric generation will increase by a factor ($61.5+24.2+7.5 / 7.5$) = 12.4. As nowadays only a small part of electric energy from bagasse is sold to the grid, the avoided GHG emission due to electric energy sale to the grid could be multiplied even further.

In this scenario, it would be possible to avoid more CO₂ emissions than that from gasoline replaced by ethanol, as can be shown below. The percentage of net avoided CO₂ in terms of percentage of fossil fuel CO₂ emission is given by the following formula:

$$P' = 1 - (A + B + C - H') / H \quad (1)$$

A = emission from fossil fuels to make the equipments and to construct the buildings for cane and ethanol production in an entire life cycle analysis;

B = emission from fossil fuel to produce fertilizers and other materials;

C = emission from fossil fuel in sugar cane production² and from soil (N₂O), as well as CH₄ and N₂O emission from cane (trash) burning before harvesting;

H = gross avoided emission of gasoline that is substituted with ethanol, in a life cycle analysis;

H' = gross avoided emission of fossil fuel used for electric generation in the grid, replaced by electric energy sold by the distilleries, using the bagasse (and trash) surplus after their self consumption in ethanol production.

The electric installed capacity using bagasse in 2006 was 2.6 GW [19], 85% of which, 2.2 GW, for self consumption and 15%, only 0.4 GW, sold to the grid. In the same year 8,357 GWh was produced, 1,256 GWh relayed to the grid [BEN, 2007]. In the hypothesis of increasing by a factor 4 the electric power generation from bagasse, as pointed above, the installed capacity could become 10.4 GW and 10.4 – 2.2 = 8.2 GW could be sold to the grid, a twenty-fold increase, expanding generation to 25,120 GWh.

Assuming that it will replace natural gas plants (which has a life cycle emission 0.095 kg CO₂/MJ [16]) with 40% conversion efficiency, the avoided CO₂ yields 2.13 billion kg of CO₂. As in 2006 ethanol production was 17.7 Mm³, the avoided emission would be 1,200 kg CO₂/m³ of ethanol. The bagasse computed for electric generation in the above estimate came from ethanol and sugar production as this industry is integrated. Considering that 55% of sugar cane is for ethanol production, H' = 660 kg CO₂/m³ of ethanol. Using in formula (1) this figure and the average values from Table 4, the result is P' = 1.10, or 110%.

Therefore, besides compensating the full emission of sugar cane and ethanol production, for each ton of CO₂ avoided through ethanol substitution for gasoline, a further 100 kg of CO₂ could be avoided due to bagasse surplus conversion into electric power.

4.3.2. Energy and emissions scenario with mechanization

Focusing only ethanol production and consulting again Table 6 and reference [19], it is easy to calculate that bagasse consumption for heat and mechanical work in ethanol production amounts to $42 \times 2,130 / (426 \times 0.55) = 382$ Mcal/ t of cane. Subtracting this value from 596 Mcal (Table 6) there is a 214 Mcal bagasse surplus per ton of cane in ethanol production that

² It includes emissions from diesel oil in tractors, mechanized harvesting and trucks for transportation

can be used for electric energy. By the same token, it can be deduced that 68.2 Mcal of bagasse per ton of cane was used for electric power in 2006.

Considering a substitution of 1 liter of ethanol (average of hydrated and anhydrous) for 0.79 liter of gasoline, with heat value 10,400 kcal / kg and density 0.74 kg / liter, the corresponding energy is $0.79 \times 0.74 \times 10,400 = 6,080$ kcal per liter of ethanol or $75.7 \times 6,080 = 460,000$ kcal/t of cane. In the case of 92 liters/t of cane the equivalent energy will be 559 Mcal / t of cane.

There are limits for the sugar cane residues recovery because a portion is needed to recycle nutrients as well as protect the soil from erosion and because mechanization cannot be used in more than 50% of the area with present technology, due to declivity. On the other hand, the burning of bagasse and residues could be done with improved thermodynamic efficiency. Table 8 shows a hypothetical scenario regarding the 2006 harvest, based in the above considerations:

	Brazil 2006	Future Scenario	Increase
Ethanol (energy of displaced gasoline)	460*	559**	21%
Bagasse for electric energy (part to grid)	68	214***	314%
Trash for electric energy (all to grid)	-	298 ****	infinite

* Considering 75.7 liters of ethanol per ton of cane (Brazil's average in 2006)

** With the best value of 92 liters of ethanol per ton of cane

*** It is subtracted self consumption of 377 Mcal / t of cane

**** 50% of total mass

Table 8. Energy (Mcal) from 1 Metric Ton of Sugar Cane

The scenario of Table 7 does not take into account the possible improvement of efficiency in energy transformation that can increase the bagasse surplus, for instance by changing low efficiency steam systems for electric power. In many plants low pressure steam boilers are used. One can obtain more mechanical and electric energy per ton of cane with higher efficiency systems, decreasing bagasse self consumption. In general the sugarcane sector in Brazil employ boilers and turbines with 22 bars of steam pressure, which can be increased to 60 bars or 80 bars, improving efficiency by at least a factor of 2. Bagasse self consumption in ethanol production is usually divided in the following way: 90% for heat in ethanol distillation, 5% for mechanical work and 5% for electric power. If efficiency is improved in the conversion of heat into mechanical and electric energy, not only the bagasse surplus will be higher, but there will also be more electric power available to the grid per ton of bagasse. Therefore, H' could be even higher.

Harvest mechanization, utilized in such a way to avoid cane burning, can allow not only a higher value of H' due to the use of trash in electric power generation, but also a lower value of C emission in formula 1. 100% of mechanization is not feasible because of the slope in part of the lands where sugar cane is planted. If mechanization is increased in 50% in relation to the case study depicted in Table 3, there could be a reduction of $0.5 \times 37.3 = 18.6\%$ in CO₂ equivalent emission of CH₄ and N₂O from cane burning.

However, 50% more machine-based harvesting will increase emissions from diesel oil in the same proportion. Assuming that half of fossil fuel consumption in Table 3 is diesel oil, the corresponding emissions ($0.5 \times 19.1\% = 9.5\%$) will increase by 4.75%. The net result should be an emission reduction of $18.6 - 4.75 = 13.85\%$. Diesel oil can be eliminated by fuelling diesel engines with either biodiesel or ethanol with additive. In this scenario, the higher indirect energy in life cycle of harvesting machines (A in Table 3) is considered negligible.

The problem of increasing harvesting mechanization is the drastic reduction of workers in sugar cane crop. The number of workers in the year 2005 in sugar cane agriculture was 414 thousand, in sugar production 439 thousands and in ethanol industry 128 thousand [30]. However, manual harvesting of sugar cane is a very hazardous activity, often causing stress-related diseases in workers. Also, sugar cane burning is a major source of air pollution, causing respiratory illnesses to local populations.

5. Discussion on land uses, ethanol competition with food and deforestation

5.1. Land uses and deforestation

The issue of food crop displacement due to biofuel competition has been raised recently by several authors, which have concluded that land use change is the main cause of GHG emissions of biofuels in general. Land use change (LUC) is a complex process caused by the interaction of natural and social systems at different temporal and spatial scales. LUC can induce GHG emissions due to oxidation of soil organic carbon and due to burning or decomposition of above-ground biomass.

However, it's important to notice that biofuels account for a very small proportion of global agricultural production; approximately 2%, or around 36 Mha [31] from a total cropland area of around 1,527 Mha [32]. Therefore, the magnitude of GHG emissions due to LUC from global biofuel production is small compared to the total emissions from all LUC: agricultural land expansion for food, feed, fibre, cattle ranching, fuel wood and timber (loggings), and expansion of infrastructure generates the greater part of LUC emissions. With respect to biomass cultivation, LUC can be divided into:

- Direct land Use Change (DLUC) – it occurs when bioenergy feedstock production modifies an existing land use, resulting in a change in above- and below-ground carbon stocks

- Indirect land Use change (ILUC) - occurs when land that was formerly used for the cultivation of food, feed or fiber is now used for biomass production shifting the original land use to an alternative area that might have a high carbon stock, like forests and wetlands. This carbon stock could be reduced if utilized for agricultural purposes. The resulting (indirect) GHG emissions are (at least partly) caused by increasing biomass/biofuel production.

[33] were the first to address the issue of ILUC: they estimated that allocation of 12.8 Mha of corn to produce ethanol in the USA would result in 10.8 Mha of new cropland around the world. The conversion of native ecosystems to cropland would result in indirect emissions potentially twice as large as direct lifecycle emissions, yielding emissions that surpass the gasoline it would replace. As there are no direct measurements that can be made, the authors used a partial economic equilibrium model of the global agricultural sector to assess the indirect emissions. ILUC will be discussed in more detail in the next section.

The problem of ILUC is not new in Brazil. It was exhaustively discussed since the displacement of food crops in São Paulo State by sugar cane was pointed out a long time ago by [34;35]. There was indeed displacement of food crops; however, its dimension is very different in the case of sugar cane in Brazil as opposed to that of corn in US. The US participation in World corn production is higher than the participation of Brazil in global sugar cane production, while the area used for corn production in US is almost 5 times the area for sugar cane production in Brazil (Table 9).

	US corn	Brazil sugar cane
Percentage of World production	38%	21.7%
Crop area	37 Mha	8.4 Mha

Source: [9;36]

Table 9. Corn in US X Sugar Cane in Brazil

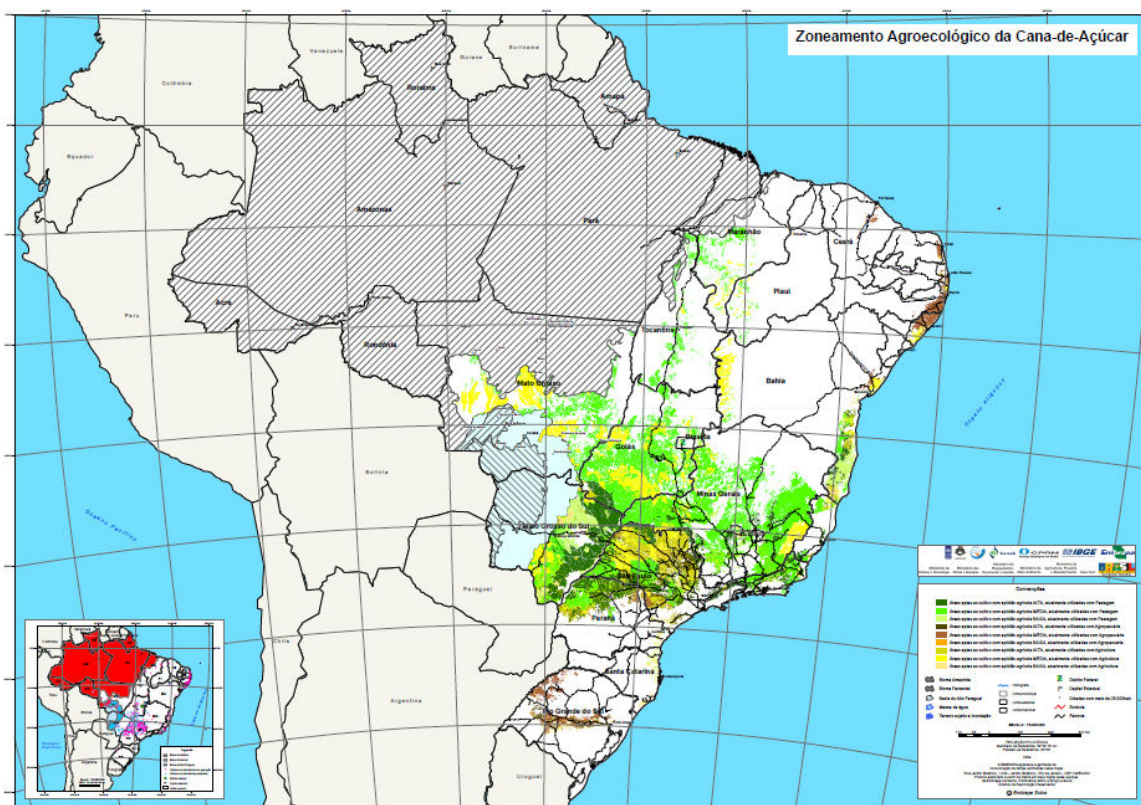
In 2011, the area used for sugar cane production in Brazil was 8.4 million ha, 4.2 million ha each to produce ethanol and sugar. As previously mentioned, Brazil has 152 Mha useful for agriculture, but only 62 Mha are currently cultivated for food, feed and biofuels. Thus, sugar cane for ethanol utilizes only 2.7% of the area useful for agriculture, not taking into account the recovery of degraded pasture lands. Native vegetation area of Brazil comprises 440 Mha, most of it in Amazon rain forest, in the North. The production of sugar cane is concentrated in the Southeast, followed by Center West, South and Northeast regions, but only 0.4% from the North Region (Table 10).

Southeast - 63.7%	Northeast – 11.8%	Center West-16.7%	North - 0.4%	South - 7.3%
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Source: [23]

Table 10. Sugarcane Production in Brazil per Region

In September 2009, to emphasize the Brazilian Federal Government disposition to preserve its main natural resources from sugarcane expansion, EMBRAPA, its agricultural research agency, published the *Agro Ecological Zoning of Sugarcane*. In it, EMBRAPA surveys the entire territory, pointing out the appropriate sites to cultivate sugarcane, from a soil and climate standpoint. The survey explicitly excluded any areas within the Amazon Rainforest, the Pantanal Biome (Wetlands), as well as Indian territories and protected areas according to the National System of Conservation Units. The study identified a total of 64.7 Mha of appropriate land for sugarcane expansion, 37.2 Mha from pasture land. It concludes that those numbers demonstrate the country's capacity to expand sugarcane production without causing deforestation or displacing lands with other crops used for food and feed. Figure 3 shows the resulting map.



Source: [37]

Figure 3. Brazilian Sugar cane Agroecological Zoning

No correlation between expansion of sugar cane and soy beans crops and deforestation has been established, since Brazil's production of both crops has continuously increased, whereas deforestation rates have been decreasing since 2005 [1].

There are two points to be observed about biofuels and deforestation:

- a. The presence of sugar cane in Center-West region (17%) has an impact on the Brazilian Cerrado, although its savanna type vegetation is less dense than rain forest.

- b.** Soybean, mainly used for feed, but also for biodiesel, is different, because its presence in the North region is high, although Brazilian biodiesel production is only one-tenth of ethanol's. A multi-stakeholder initiative was established in 2006 with a commitment from major buyers not to acquire soybeans from areas in the Amazon that have been deforested after July 2006. The Soy Moratorium was signed by corporate unions which represent more than 90% of Brazil's soybean industry.

Among the goals of the Brazilian Biodiesel Program there is the cultivation of castor, palm, sun flower and other crops by small farmers to supply the raw materials. But, since its inception, soybean oil from large soybean plantations has been the dominant feedstock for biodiesel.

The commonly accepted drivers of deforestation are four, mainly in the rain forest:

- a.** wood extraction;
- b.** pastures for cattle grazing;
- c.** crop plantations;
- d.** mineral resource exploration.

But in the case of Brazil all these drivers increased in the last decade while the deforestation rates decreased, showing that this mainstream deforestation model does not hold true in Brazil.

Different concepts of deforestation yield different values of deforested areas due to the accounting (or not) of deforested areas where vegetation is growing again. In some studies the deforested areas are only the ones that really changed their land use definitively, but others consider the burning of biomass as deforestation. Nevertheless these differences are mostly qualitative for the Brazilian Legal Amazon. Another issue is the vegetation classification which leads to varying results in terms of carbon emissions for the same area. It depends on the adopted vegetation classification because carbon content can differ a lot. For example, according to HYDE/IVIG database, the Brazilian Legal Amazon land use changes representing agriculture and pasture lands added up to 422,070 km², in 1990. The natural areas were originally tropical forest, wooded tropical forest and savanna. According to INPE database, the cumulative Brazilian Legal Amazon deforestation until 1990 was 415,000 km². These numbers show the compatibility of the 2 databases in terms of magnitude but the quality of the information present huge differences. These differences indicate that it is important to adopt a more detailed focus of analysis with new indicators [38].

Deforestation was responsible for about 78% of CO₂ emissions of Brazil in 2000/2005 [39]. In 2006, Brazil proposed to the UN Climate Change Convention the creation of an International Fund for Reducing Deforestation. In 2007, the Brazilian Forum on Climate Change³ presented the Government a formal suggestion for a National Plan of Action, with contributions from universities and research institutions, NGO's and private companies. In December 2008 the National Plan on Climate Change was published.

³ The President is the chairman of the Brazilian Forum on Climate Change. Members include the Minister of Science and Technology, of the Environment, of Foreign Affairs of Energy, members from academia, NGOs and industry.

To achieve its GHG emission targets, NPCC set as one of its main actions a sustained reduction of deforestation rates in all Brazilian biomes, in particular the Amazon Forest. Specifically, it calls for a reduction of 40% in the average deforestation rate by the 2006-2009 period in relation to the average rate of the ten years preceding years (1996-2005). For each of the next two periods of four years, it aims to reach a further 30% reduction, in relation to the previous period.

Since Brazil does not belong to Annex I of the UN Climate Change Convention, it does not have to set a binding emission commitment. But its decision is compatible with the so called road map decided in Bali (in 2007), which called for *“Nationally Appropriate Mitigation Actions by developing country Parties in the context of sustainable development, supported and enabled by technology, financing and capacity building, in a measurable, reportable and verifiable manner”*. NAMAs are to act as a bridge between developed and developing country parties, following the principle of *‘common but differentiated responsibilities’*.

5.2. Indirect land use change and GHG emissions

Before [33], biofuel “well-to-wheel” LCAs were mostly attributional, consisting of a linear chain-like series of analytical steps, carrying out no assessments of nonlinear feedback-like effects. As already mentioned, the above authors suggested that when including ILUC, the previously thought GHG-saving corn ethanol turned into a net producer of GHG emissions. This raised serious concerns and new efforts were launched, particularly in the U.S. and Europe, to study biofuels LUC.

The logic that supports ILUC is that biofuel production competes for agricultural resources, which results in an increase in the price of agricultural products, and these price increases cause additional conversions of the world’s grasslands and forests to cropland. This additional land conversion results in loss of carbon previously sequestered in grassland and forest ecosystems. These emissions are an indirect result of producing biofuels and should be considered in calculating the GHG implication of adopting biofuels.

The quantification of the net GHG effects of DLUC occurring on a site used for bioenergy feedstock production requires the definition of a reference land use as well as carbon stock data. This data can be uncertain but still allows quantification of emissions with sufficient confidence for guiding policy. ILUC emissions estimation, on the other hand, is highly problematic given the complexities of the economic and social systems that connect biofuel production with land conversion throughout the world.

To make matters worse, ILUC due to the recent expansion of the biofuel industry is hard to assess because this expansion constitutes a very small driver as ILUC effects are not specific to biofuels or bioenergy, but to all incremental land use, so the biofuel impact is likely to be dwarfed by other causes. Besides, as the name implies, ILUC cannot be measured, only modeled, although case studies could offer some useful evidence. The fact is, up to now, there is still no sound and commonly accepted methodology either to calculate or to assign iLUC effects properly. Hence, bioenergy policies worldwide face a dilemma: neglect iLUC effects that in fact exist or take them into account although no sound methodology is available?

Despite these difficulties, the US Environmental Protection Agency, as part of the updated Renewable Fuels Standard (RFS-2), specified that life-cycle GHG are to include “direct emissions and significant indirect emissions such as significant emissions from land use change” to determine if a specific biofuel is eligible to be counted towards the RFS-2 mandate. Biofuels in the RFS were divided into four categories:

- Renewable biofuel – any qualifying renewable fuel, including corn ethanol. Must meet 20% lifecycle GHG threshold
- Advanced biofuel – anything but corn ethanol, can include cellulosic ethanol and biomass-based diesel. Must meet 50% lifecycle GHG threshold
- Cellulosic biofuel – renewable fuel produced from cellulose, hemicellulose, or lignin. BTL, green gasoline also apply. Must meet 50% lifecycle GHG threshold
- Biomass-based diesel – biodiesel, renewable diesel. Must meet 50% lifecycle GHG threshold

Using the FAPRI/CARD model, EPA published in 2009 an analysis of GHG emissions of a set of biofuels: US corn ethanol, Brazilian sugarcane ethanol, soybean biodiesel, among others. Brazilian sugarcane ethanol, after taking ILUC into account, was found to reduce emissions by 26%, which would disqualify it as an advanced biofuel. Corn ethanol did not qualify as a renewable fuel, except when cogeneration was used, nor did soybean biodiesel. There was an immediate backlash from the industry.

ICONE, a Brazilian consultancy, sent a letter to EPA listing shortcomings of the agency’s adopted model. It presented BLUM - Brazilian Land Use Model, more sophisticated, with better spatial resolution, and whose calculations resulted in total emission reduction (DLUC + ILUC) of 60%.

On February 2010, EPA concluded that, in fact Brazilian sugarcane ethanol reduced emissions by 61%, qualifying it as an advanced biofuel. The impacts of this decision will be discussed in the following section. EPA also revised the GHG emission reductions of other biofuels: corn ethanol was found to reduce emissions by 21%, qualifying it as a renewable fuel; soybean biodiesel was found to mitigate 57% of emissions, qualifying it as biomass-based diesel.

In the European Union (EU), ILUC calculations were more carefully considered. On April 2009, the EU adopted the Renewable Energy Directive which included a 10% target for the use of renewable energy in road transport by 2020. It set a minimum rate of direct GHG emissions savings – 35% in 2009, rising over time to 50% in 2017. Moreover, the European Commission (EC) was asked to examine the matter of ILUC, including measures to avoid it and report back this issue by the end of 2010. In that context the EC undertook a review of the scientific literature modelling the land use change impacts of biofuels, reviewing over 150 contributions on the topic and reviewing 22 different modelling exercises [40]. Large discrepancies were found in their results, reinforcing the arguments that good estimates of land use indirect impacts are hard to achieve. Comments sent to the EC [41] in regard to the need to improve sugarcane ethanol model assumptions from those studies include:

- Projections on sugarcane and ethanol yield: models project smaller yields as compared to historical trends
- Poor analysis or lack of analysis on pasture intensification, leading to an overestimation of LUC resulting from the expansion of biofuels, as pasture is the largest land user in Brazil and there has been high cropland expansion in this land category in the current decade
- Lack of evidence supporting the criteria used to allocate marginal land demand over native vegetation. The main criterion was historical data, either inaccurate or based on the assumption that additional cropland due to biofuels expansion will determine a frontier advancement similar to what has been observed historically.

The EC published a report in December 2010 setting out four policy options it was considering:

- Take no action for the time being while continuing to monitor.
- Increasing the minimum greenhouse gas threshold for biofuels.
- Introducing additional sustainability requirements for certain biofuels.
- Attributing GHG emissions to biofuels reflecting the estimated ILUC impact

Recognizing the difficulties in establishing a consistent methodology for calculating biofuels ILUC emissions, as of this writing, no decision has yet been made by the EC.

5.3. Potential sugar cane expansion and external markets

The next question concerning possible impacts arising from the expansion of sugar cane production is related to the potential exportation of ethanol to OECD countries.

The European car fleet uses a growing proportion of diesel engines, although there is a non negligible consumption of gasoline either with or without ethanol as additive. For instance, part of Sweden's car fleet uses 80% of ethanol and 20% of gasoline (E80).

The most important ethanol producers, as well as the countries to which Brazil exports can be seen in table 11. Only the USA and Brazil, which together supply 87% of the world's production, use ethanol substitution for gasoline in a large scale. The current percentage of ethanol mixed to gasoline in the US is 10%, due to an EPA blend "wall", which has recently expanded to a 15% threshold.

Until recently, the North-American market, almost all supplied by domestic production, was not open to Brazilian ethanol. However, at the end of 2011, a US\$ 0.54/gallon levy on Brazilian ethanol, as well as a US\$ 0.45/gallon credit for American producers of corn ethanol was waived, paving the way for a better relationship between these two major players. Also, due to EPA's classification of Brazilian ethanol as an advanced biofuel, the US market, where Otto cycle engines are predominant in the car fleet, has become more attractive than ever. There are other potential importers, as Japan, where Petrobras created a joint venture with Mitsubishi to export ethanol. China, which uses corn to produce ethanol, has also become a major market. Many foreign investors are being attracted to ethanol agro-business in Brazil, including oil majors (BP, Shell) as well as companies re-

searching 2nd generation biofuels, due to the widely held perception of sugarcane comparative advantages over corn, as seen on table 12:

- a. Inefficacy of corn ethanol to mitigate global warming (as previously discussed).
- b. higher competition of corn ethanol with food agriculture (as previously discussed);
- c. lower productivity per hectare and higher cost of corn ethanol (Table 11);

Production in 2011		Brazilian Export Destination in 2010	
USA	54.2	South Korea	334
Brazil	21.0	USA	233
China	2.1	Japan	230
Canada	1.8	Netherlands	221
France	1.1	United Kingdom	156
Germany	0.8	Jamaica	107
Spain	0.5	Nigeria	80
TOTAL	86.1 billion liters	TOTAL	1.650 million liters

Source: [42],[43]

Table 11. Ethanol Supply and Brazilian Exports

	Productivity	Costs
Sugar cane ethanol	4000 to 7000 liters / ha	0.19 US\$ / liter (S.Paulo)
		0.23 US\$ / liter (Northeast Region)
Corn ethanol	3500 to 4700 liters / ha	0.33 US\$ / liter

Source: [44;17]

Table 12. Comparison of Sugar Cane Ethanol with Corn Ethanol

Based on Brazilian ethanol’s competitive advantages, it is reasonable to imagine a virtual extreme scenario for future ethanol demand to be supplied through international trade. According to the RFS2 mandate, US biofuels consumption will total 136.5 billion liters/year by 2022, 19 billion from advanced biofuels, for which only Brazilian sugarcane ethanol currently qualifies. The entire American market alone will be equal to 7 times Brazil’s current production.

If we consider a technology and productivity freeze, land requirement should increase seven-fold, resulting in 28 Mha for sugar cane ethanol, approximately 25% of the land still available to expand agriculture in Brazil. This percentage is not small taking into ac-

count the need of cropland for food and feed to supply the internal market (including biofuels), as well as exports to other countries. If the EU ethanol market expands, due to a more favorable ILUC-wise view of this biofuel over biodiesel, the area needed for sugar cane exports could become too large, especially if we consider the inherent problems of very large monocultures. Second generation technology for ethanol production can change the present prospects.

6. Conclusion

At this point there is no major obstacle from a land use point of view to expand ethanol supply for Brazil's internal market, but it should not attempt to supply all the global ethanol market, if it is decided that biofuels is a valid global warming mitigation scheme. Conversely to aforementioned studies, emissions due to indirect land use change in Brazil cannot be attributed to the increase of biofuel production, because deforestation and ethanol production have presented opposite trends for almost ten years.

Government's scenarios predict a domestic demand of 63 billion liters of ethanol in 2020 [45]. However, due to the recent downfall of ethanol exports from a peak of 5.1 billion liters in 2008, the amount exported in 2020 has been revised to only 6.8 billion liters. Brazil can comfortably supply such quantities as the area needed – 10 Mha - is compatible with the available land for agriculture.

As was pointed out in the present paper, CO₂ is dominant among GHG emissions and automotive fleet contributes with 20% of World CO₂ emission. It amounted to 890 million light vehicles in 2005 and it consumes half of petroleum products in the World [46]. Besides, the fleet increases 20% per year in China and 3.5% in Brazil, where more than half the cars are flex fuel vehicles running with either gasoline or ethanol. As in Brazil cars use from 25% to 100% of ethanol, CO₂ avoided emissions are substantial.

Ethanol per se is not enough to mitigate CO₂ emissions at the World level. A deeper change in energy technology, transport, and consumption pattern is needed, including in public transportation, which use more efficient diesel engines. But ethanol can become an important fuel for different technologies, besides Otto cycle engines in cars. With additives, ethanol could feed Diesel engines used in buses, trucks and railway trains. It serves as fuel in hybrid vehicles of electrical propulsion - in which an Otto or Diesel engine is coupled to an electric generator that supplies current to an electrical motor and to accumulate energy in batteries – or in fuel cell vehicles to replace combustion engine based ones.

Sugar cane is the better way to produce bio-ethanol, from both an economic and environmental view point, including GHG mitigation through gasoline replacement. However, ethanol industry in Brazil has to improve, undergo technological changes, some of them concerning efficiency in energy transformation and natural resource use, by applying the best available technologies. The main changes must be, at a first level:

- a. Efficiency improvement in the transformation of sugar cane bagasse chemical energy into heat, mechanical and electric energy for self consumption and export to the grid; current participation of bagasse in the Brazilian electric generation matrix is too small and must increase.
- b. Utilization of the sugar cane trash, which is burned before harvesting to allow access to manual laborers; the amount of energy that could be converted into electric generation is significant.
- c. Item (b) implies the increase of harvesting mechanization in sugar cane agriculture, decreasing the number of workers; however, manual harvesting is known to be hazardous.
- d. Job conditions of workers in sugar cane plantation have to improve in some cases, including a social dimension besides the environmental one in clean energy production.
- e. Technological improvement in agriculture.

On a second level there are:

- a. Gasification of sugar cane bagasse and sugar cane residues;
- b. Second generation ethanol production through hydrolysis;
- c. Bio-refineries with multiple byproducts or integrated oil & bio-refineries, in an advanced concept.

Gasification could allow either high efficiency conversion in electric energy through combined cycle or could be used to produce liquid fuel from gas. Second generation ethanol consists in an acidic or enzymatic hydrolysis followed by fermentation that converts cellulose from biomass into ethanol.

The commercial use of hydrolysis can reduce sugar cane comparative advantage in relation to other kinds of vegetable to produce ethanol. On the other hand, the entire sugar cane biomass could be used to obtain ethanol, including the hydrolysis of bagasse and residues, as well as allowing fermentation of pentoses from hemicellulose to produce ethanol. [28] predicts a time horizon between 2010 and 2020 for second generation ethanol to become commercial, while gasification will take a little bit longer, 2015 to 2025, in spite of already existing technological uses of wood gasification. In the case of hydrolysis there are prototypes and some recent small scale industrial plants are in construction in the World, but no 2nd generation ethanol production has, to this date, become commercial.

Bio-refineries can produce ethanol together with other chemical byproducts. For instance, biodiesel production needs ethanol or methanol and has glycerol as a byproduct that can be used to produce biogasoline. Since the beginning ethanol production in Brazil was integrated with sugar production in the so-called annex distilleries. A more advanced concept is the integration of bio-refinery with oil refinery.

Finally, biofuels for private cars must not prevent the search for technical and social efficiency in transport, with an emphasis on public transport. Climate Change Policy must be devoted to find realistic solutions for sustainable development with social justice. Elimination

of poverty needs more energy per capita in developing countries, but, at same time, it is necessary to change the intensive energy use and consumption pattern of high income and middle classes. It is not possible to radically mitigate global warming without any change in business as usual energy consumption.

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