Ethanol and Bioelectricity Sugarcane in the Future of the Energy Matrix

Contribution of Ethanol to Climate Change

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The use of low-carbon, renewable energy is an important strategy for mitigating emissions of greenhouse gases (GHG) and combating global warming. Sugarcane ethanol, which has a very favorable energy and emissions balance, is a commercially available alternative with the potential to expand rapidly in many countries and as new applications emerge. From a lifecycle perspective, sugarcane ethanol has the capacity, in Brazil, to reduce around 90% of GHG emissions when compared with gasoline.

In 2006 the reduction of GHG emissions attributable to the use of ethanol (as a gasoline substitute) reached 22% of final emissions for the transportation and electricity generation sectors in Brazil, and could reach 43% in 2020. In relation to Brazil's total energy consumption (electricity, industrial, transportation, residential, and others), large-scale consumption of ethanol avoided the equivalent of 10% of total emissions in 2006 and will reach 18% in 2020 (excluding agricultural and land-use changes). The potential for new uses (substituting other fossil fuels and increased exports) could considerably increase this share.

The emissions reductions to be sought globally through the coming decades make it possible

to study the "value" of GHG mitigations generated by ethanol (determined by the additional global cost of the appropriate set of technologies for a desired level of mitigation). This additional value of Brazilian ethanol is estimated at US$0.20 per liter of ethanol. In other words, each liter of ethanol used is equivalent to US$0.20 that would otherwise have to be spent on measures to mitigate greenhouse gas emissions, so reducing the investments that countries would need to make to control global warming.

An analysis of expectations for the post-Kyoto regime concludes that the debate persists over global reductions goals. Furthermore, the mechanisms for the management of emissions between countries (like the Clean Development Mechanism) are very limited, especially for renewable energies like ethanol.

For Brazil, it is necessary that international goals be adopted in a uniform manner, including China and India, to protect the competiveness of our industry. It is also necessary that a specific advantage – the fact that Brazil has one of the cleanest energy matrices in the world – be considered in international trade.

1. Introduction

The relationship between climate change and increasing concentrations of greenhouse gases in the atmosphere was irrefutably demonstrated in 2007 by the Intergovernmental Panel on Climate Change (IPCC). International negotiations to prevent the inherent problems are currently focused on trying to limit temperature increase in 2100 (to maybe 2° C) with emissions reduction distributed between industrial and developing countries. Negotiations for establishment of these rules are ongoing.

Given the size of the Brazilian program for ethanol use, it is important to verify, in the domestic and international context, its contribution to this global effort through the next decade. Knowledge of this contribution (and its value, in the context of other technologies and emission mitigation policies) is a necessary element in the set of facts to be considered in the development of Brazilian policy for these negotiations.

2. Greenhouse gas emission mitigation via the production and use of sugarcane ethanol

Assessments of GHG emission reduction attributable to the use of sugarcane ethanol have been made since 1992 (Macedo 1992). Gradual improvements have been made to the databases, and changes made due to variations in production and use technologies (Macedo 2007). More recently, work has been developed seeking harmonization between the methodologies used for various raw materials and products (sugarcane, corn, grains, wood, ethanol, biodiesel, etc.). These assessments are generally made for the production and fuel use cycle, and initially did not include effects of land-use change.

Adoption of the European Directive in December 2008 led to the "official" introduction of quantification of the direct effects of land-use change (LUC) in biofuel production. This quantification takes into account changes in carbon stocks (above and below the soil) and seeks to implement a relatively simple calculation.

Table 1 **Scenarios for ethanol demand** *In millions of m^3 per year*

Year	2010		2015		2018		2020	
	Domestic mkt	Export	Domestic mkt	Export	Domestic mkt	Exp	Domestic mkt	Exp
UNICA (2008)	23	6	35	12			50	15
Mapa (2007)	20		28		30			
EPE (2007)	20	4	26	10			34	14
IE-UFRJ, scenario B (2006)							35	
Cepea (2007)		4,4		9,8				18

Given the absence of sufficient and reliable data for soil carbon levels in many regions this calculation is based on IPCC default parameters. In 2009, the Environmental Protection Agency (EPA) and California Air Resources Board (CARB) submitted proposals for discussion that included direct and indirect LUC effects in the United States.

The so-called "indirect effects" of LUC have been under discussion since 2008. These do occur, in certain cases, but the tools available for their evaluation (the models and the cause-and-effect relations for innumerable situations and locations) are clearly inadequate for the desired task. The European Directive has postponed decisions on the use of indirect effect assessments to at least the end of 2010, while in the United States the discussions have advanced considerably in relation to initial proposals.

2.1 Emissions avoided through the use of sugarcane ethanol: estimates for 2009 – 2020

Following are estimates for the reduction of GHG emissions attributable to using sugarcane ethanol as a substitute for gasoline. The process of calculation entails:

- Scenario 2009-2020 for ethanol fuel demand in Brazil and for export;
- Technological scenario for the period (assuming only the introduction of commercial technologies for electrical energy, and continuous progress in usage technologies);
- Specific emissions for these scenarios; composition for the total period.

Ethanol demand 2010-2020

Table 1 shows consumption estimates for the domestic and international markets during this decade, remembering that these scenarios are very susceptible to change, depending on the public policies adopted in coming years. This is particularly the case for developed countries, which have traditionally protected their markets with high import tariffs. An "export" scenario was included only to analyze expected mitigation. It is a "moderate" scenario (Cepea, 2007).

As shown in **Table 2**, a scenario was adopted for 2020 specifically to estimate the emissions avoided by the use of ethanol. This takes into account various scenarios and assumptions, together with the demand analysis that includes ethanol blended with Type A gasoline and the increase in the fleet of flex-fuel vehicles with a consequent rise in demand for hydrous ethanol (E-100).

Domestic and export demand for ethanol Table 2

In millions of m^3 per year

	2010	2015	2020
Domestic Demand			
Anhydrous	6	6	5
Hydrous	17	29	45
Subtotal, domestic	23	35	50
Exports, anhydrous	5	10	15
Total	**28**	**35**	**65**

Technological scenario for the period

Technological developments in the period and their impact on GHG emissions are considered from a base point of the current situation for the average for mills, using 2006 parameters as defined from data available for the Center-South region (Macedo 2007). This study considers only technologies that will be commercially available in this horizon (i.e. by 2020), together with clearly identifiable trends, the most important of which is the use of sugarcane straw (up to 40%) and residual bagasse (up to 35%) to produce a surplus of electrical power via conventional high pressure (steam cycle) and co-generation systems (Seabra, 2008). Expected advances in agricultural and industrial productivity, and in conversion efficiency, are also included. In the agricultural area, we expect to see the optimized allocation of new varieties, the more rapid use of genetic modification in plants, and precision agriculture technology. We shall denote this technological stage as "Technology E" (with "E" for electricity). The penetration rates of the technology are estimated and introduced in the study, differentiating new mills from existing mills.

We did not take into account technologies currently under development that are expected to achieve significant penetration only after 2018, for example cellulosic hydrolysis. Estimates in this sense can be found in Macedo (2008) but are not essential for this study.

Basic agricultural and industrial data, along with data for transport, distribution, and final usage of ethanol for the base year 2006 and for "Technology E" in 2020, can be found in Macedo and Seabra (2008). Some of the main parameters are shown below, bearing in mind that for "Technology E," they are not averages for all mills:

Table 3 **Production parameters for the period 2006-2020**

	Tonnes cane/ha	Liters ethanol per tonne cane	Surplus kWH per tonne of cane	Area of sugarcane in millions of ha
2006, average	87	86.3	9.2	2.4
2020, Technology E	95	93.2	135	7.3

Table 4 **Corresponding production of ethanol, electricity and sugarcane**

	2006	2010	2015	2020
Ethanol, domestic market (M^3 millions)	14.2	23	35	50
Ethanol, export market (M^3 millions)	3.7	5	10	15
Sugarcane planted area (ha millions)	2.4	3.6	4,2	7.3
Sugarcane (tonnes millions)	207	318	385	697
Electricity (tWh/year)	1.9	2.9	20.3	52

Rates of penetration for Technology E were estimated taking into account that the technology is already partially in commercial use, being incorporated into almost all new mills (high pressure steam generation). However, it will take some years to reach 40% usage levels for sugarcane straw. The following hypotheses were therefore adopted:

- 2006-2010: as a conservative estimate, the conditions pertaining in 2006 were adopted, without complete new systems;
- 2011-2020: 80% of incremental production will use Technology E (electricity); and
  3% of 2010-level production shifts to Technology E each year.

Thus, 35% of production will use Technology E by 2015, and 53% in 2020.

Reduction of GHG emissions during the period

a. Production cycle (without effects on land-use change)

The analysis of GHG emissions follows the standards currently used for biofuels, including CO_2, methane and N_2O, which are considered to be the most important GHGs in relation to agricultural production, industrial conversion, transportation, distribution, and final use of ethanol. There are still disagreements (albeit smaller today) about some points, notably over the different ways of calculating emissions and mitigation via by-products, and over some processing parameters. When reporting the results, we have always sought the best information available, with the greatest transparent.

Avoided emissions

Table 5

Specific emissions avoided by virtue of using ethanol, compared with gasoline, for average 2006 conditions and for Technology E in 2020; excluding impacts of land use change (tonnes CO_2e/m^3 ethanol)

Year	2006 (average)		Technology E (2020) (1)		
Final use of ethanol	E-100	E-25	E-100	FFV	E-25
Emissions during production	0.44	0.46	0.34	0.34	0.36
Emissions avoided	2.15	2.82	2.36	2.28	3.02
Surplus bagasse (2)	0.14	0.15	0.00	0.00	0.00
Surplus electricity (3)	0.03	0.03	0.38	0.38	0.40
Use of ethanol (4, 5)	1.98	2.64	1.98	1.90	2.64
Avoided emissions (net)	1.71	2.36	2.02	1.94	2.66

Notes: (1) Technology E: Process improvements + Electricity production (high pressure, bagasse + 40% straw). • (2) Substitution of oil-fired boilers (efficiency 92%; PCI) with boilers fired by bagasse (efficiency = 79%; PCI). • (3) This study used an emissions factor based on the average of factors of the build margin and the operating margin, for Brazil: ~268 t CO_2e/gWh. Emission factors of 579 t and 560 t CO_2e/gWh(e) for 2006 and 2020, respectively (based on IEA estimates, average world emissions, electricity), and emissions of natural gas-fired generating plants, can also be taken into consideration. • (4) Equivalencies: E-25: 1 L ethanol = 0.8 L Type A gasoline; E-100: 1 L ethanol = 0.74 L Type A gasoline; FFV: 1 L gasoline = 0.72 L E-25 = 0.66 L Type A gasoline. • (5) Gasoline, emissions of GHG: 2.64 kg CO_2e/m^3 gasoline.

The detailed analysis of the emissions – parameters, coefficients, default values used, database and its variation, and methodologies – for the current and Technology E cases can be found in the referenced work (Macedo and Seabra 2008, Macedo 2007). We note the inclusion of the average efficiency of motors, which in Brazil can be assessed based on many years of experience. Summarizing, for blends containing up to 10% of ethanol, we have 1 liter of ethanol = 1 liter of Type A gasoline (which becomes an 80% equivalence with E-25); while E-100 engines show an equivalence of 79% (1 liter of ethanol = 0.79 liters of Type C gasoline) – Cetesb (2008). For flex-fuel vehicles, in 2005, we have 1 liter of ethanol = 0.72 liters of E-25 (which is 66% of equivalence compared to Type A gasoline) – Joseph Jr. (2005); Cetesb (2008). The most interesting results are shown in **Tabela 5**.

b. Effect of land-use change

The direct effects of land-use change related to Brazilian sugarcane expansion have been analyzed in recent years. It can be shown that:

- Changes in land use to produce sugarcane for ethanol during the last 25 years in Brazil should be considered only for the period 2002-2009, because the production of ethanol remained constant at around 12 million m3 per year from 1984 through 2002 (Macedo and Seabra, 2008).
- The findings of several independent studies show that in this period the occupation of woodlands (cerrado/savannah, forests) was less than 2% of the total, with land-use changes involving principally existing pastureland and land used for annual crops (Nassar, 2008).

Table 6 **Alterations in carbon stocks by virtue of land use changes (LUC)**

Crop	Change in carbon stock (1)	Emissions (kg of CO_2e/m^3 of ethanol)	
	(tonnes of carbon / ha)	2006	2020 electricity
Pasture – degraded	10	-302	-259
Pasture – natural	-5	157	134
Pasture – cultivated	-1	29	25
Soy	-2	61	52
Maize	11	-317	-272
Cotton	13	-384	-329
Cerrado (savannah)	-21	601	515
Open field	-29	859	737
Cerrado (dense)	-36	1040	891
LUC emissions (2)		-118	-109

Notes: (1) Based on average values for carbon stocks below and above the soil (only perennial). • (2) Distribution of LUC: 2006 – 50% pasture land (70% degraded, 30% natural); 50% annual crops (65% soy, 35% others); 2020 – 60% pasture land (70% degraded, 30% natural); 40% annual crops (65% soy, 35% others); Cerrado less than 1%.

- Information about carbon levels in the soil for the crops being substituted versus those for sugarcane do not differ greatly from the IPCC default levels, indicating that sugarcane cultivation without burning could increase the soil carbon balance for the majority of annual crop and pasture lands (Amaral, 2008).
- An analysis of the average current situation for the change of land-use to sugarcane without burning is summarized in **Table 6** (Macedo and Seabra, 2008), and indicates an increase in the soil carbon level. If the conditions of land-use change are maintained (and this is to be expected, assuming the intensification of livestock grazing) then the direct effect of the land use change will be positive.

Several studies now under way seek to improve the knowledge about soil carbon stocks in Brazil. In this study, however, to maintain our conservative posture, we have not yet included the positive results that have been obtained so far.

c. Results: avoided emissions

Tabela 7 shows total avoided emissions for selected years between 2006 and 2020. Two references are considered in regards to the avoided emissions for the substitution of electrical energy: an average between the build margin and the operating margin in Brazil (260 t CO_2e / gWh) and the value associated with natural gas plants (570 t CO_2e /gWh).

Thus, in the 11 years 2010 – 2020, total avoided emission would be 1,015 million tonnes of CO_2e, with an average of 92 million tonnes of CO_2e per year; or 7% more if the emissions from the substituted electricity are computed based on natural gas generation (a 12% increase in the last year).

2.2 Emissions avoided through ethanol use in the Brazilian context

The values of avoided emissions include the effects of ethanol and electricity. For comparison, we use GHG emissions for the transportation and electricity generation sectors in Brazil, estimated for 2005 and 2020 (EPE 2007). Here, as throughout this study, the computed electricity generation corresponds only to that portion of sugarcane used to produce ethanol; the sector generates almost as much again with the production of sugar.

Table 7 **Emissions avoided through the use of ethanol (in Brazil and exported)**
In millions of tonnes of CO_2e per year

	2006	2010	2015	2020
Mitigation (1)	36	55	91	133
Mitigation (2)	37	56	97	149

(1) Electricity: average of build and operating margins in Brazil (260 t CO_2e / gWh)
(2) Electricity: natural gas generating stations (570 t CO_2e / gWh)

In 2006, emissions mitigation with ethanol (and associated energy) represented 22% of final emissions of the two sectors, and could reach 43% by 2020.

Brazil's total annual emissions (related to energy production and use, across all sectors) were 350 million tonnes of CO_2e in 2006, forecast to reach 720 million tonnes of CO_2e in 2020 (EPE 2007), excluding emissions related to agriculture and changes in the use of land and forests. The ethanol sector avoided the equivalent of 10% of these emissions in 2006, and could avoid 18% in 2020.

3. The global context

Given that the warming caused by increased GHG emissions is a global problem, it is appropriate to put the emissions prevented by ethanol in this context. Anthropogenic emissions of the principal GHGs in 2005[i] were: 36 gigatonnes (Gt) of CO_2 (of which 75% from energy and 11% from land-use change); 6 Gt CO_2e of methane; 2.5 Gt CO_2e of N_2O; and about 0.8 Gt CO_2e of fluorinated gases.

The reference scenario (WEA 2008), maintaining policies in place in October 2008 (average values between various IPCC scenarios), points to GHG emissions growing from 44.2 Gt CO_2e (2005) to 54 Gt in 2020 and 59.6 Gt CO_2e by 2030. Emissions associated with energy correspond to 61%, 67%, and 68%, respectively, of these totals. The Brazilian ethanol sector contributed to a 0.1% reduction of these emissions in 2006, and could reach 0.25% in 2020.

The relationships between GHG emissions and climate are complex. Factors like carbon removal could partially neutralize the greenhouse effect (IPCC 2007-a). Under current conditions, the variation of 1 ppm CO_2 in the atmospheric concentration corresponds to 7.7 Gt CO_2e; but taking into account removal processes (oceans, atmosphere, soils) the corresponding emission would be 13.3 Gt CO_2e.

It is estimated that average global temperatures today are 0.76° C higher than the pre-industrial average, and the rate of growth has increased (0.19° C in the last 20 years).

Table 8 **Emissions by sector and mitigation through the use of ethanol**

In millions of tonnes of CO_2e per year

	Transportation (1)	Electrical energy (1)	Transportation +electricity	Emissions avoided: ethanol + electricity (2)
2006	140	20	160	36
2020	250	60	310	133

Notes: (1) Emissions include a certain quantity of ethanol in the mix (according to EPE estimates); they are therefore final emission values, according to the EPE (2007). • (2) Includes emissions avoided by virtue of exported ethanol.

Two scenarios considered (WEO 2008-a) for 2030 aim for GHG concentrations to stabilize at either 550 ppm of CO_2e, with a global temperature increase of 3° C and emissions reaching 33 Gt CO_2e; or 450 ppm, with a 2° C rise in temperature and an emissions increase of 25 Gt CO_2e. The potentially harmful effects of these levels of temperature rise are well modeled today (IPCC 2007-a).

Several models[ii] (Fischedick 2008) show that in the period 2000-2030 the most relevant mitigation technologies (for stabilization at 450-590 ppm CO_2) would be those of energy conservation and efficiency, followed by technologies related to renewable energy sources. Looking further ahead, to 2100, the same technologies will continue to be important, alongside others such as carbon capture and storage (CCS).

One important point is that in order to obtain adequate emissions reductions, all the technology options under consideration will be necessary. With regard to transportation (the case of ethanol), under the reference scenario global emissions will grow from 6.7 Gt CO_2e to 11.6 Gt CO^2e between 2002 and 2030. Existing options to increase efficiency and the use of biofuels could reduce this by 2.2 to 4.5 Gt CO_2e (IPCC 2007-c), but this potential mitigation would be partially offset by the increased use of non-conventional liquid fuels with higher CO_2 emissions. This means that transportation emissions will continue growing through 2030, even with the use (within their practical possibilities) of all mitigation options currently being analyzed.

Cost of emission mitigation in the world, and the additional value of ethanol

In the current scenario, climate changes will imply significant costs to countries, in terms of implementation and adaptation. The goal is to minimize this impact through the reduction of emissions, so minimizing damage (and the cost of adaptation). Uncertainties regarding adaption costs are clear: annual values were estimated by the IPCC in 2007 to be between US$40 billion and US$170 billion after 2030, but were recently revised to more than US$500 billion.

For just now, it is possible to estimate the average cost of tonnes of avoided carbon emissions, to achieve certain goals. For sugarcane ethanol, this cost is an indicator of its additional value (a non-market externality).

Cap and trade systems are seen as the most likely. In these systems, the cost of stabilizing emissions depends on the target (i.e. the concentration of CO_2), the baseline and the set of available technologies (Fischedick 2008). Ideally, the technological options to be used would start with the lowest-cost options. This was summarized in (IPCC 2007-a): "Studies indicate the necessity for a diversified portfolio; carbon prices in the range US$20-50/t CO_2e would be sufficient to drive large-scale fuel-switching and make both CCS and low-carbon power sources economically viable as technologies mature." Several studies have looked at specific aspects of the estimated costs. In general, there is a consensus that cost estimates are still very imprecise. There is insufficient knowledge about some specific costs (CCS, for example) for different scales and timeframes. It is difficult to analyze interdependent systems and there is large variation depending on location. Some recent results are:

- Considering the available technologies for electricity (including CCS with coal and natural gas), and compared to the base of 15.77 Gt CO_2e in 2030, emissions reduction could reach 4 Gt CO_2e with a carbon price of up to US$20/t CO_2e; 6.4 Gt CO_2e with a price of up to US$50/t CO_2e; and 7.2 Gt CO_2e with a price of US$100/t CO_2e. (IPCC 2007-b)
- Stabilization at 550 ppm CO_2 would correspond to a price of US$20-50/t CO_2e, between 2020 and 2030; but US$100/t would be necessary for 450 ppm CO_2. (IPCC 2007-a)
- It is possible to reduce emission by 55% by 2030 (leading to 550 ppm) with a price below 60 Euros/t CO_2e; and by 70% (for 450 ppm) with a price between 60 and 100 Euros/t CO_2e. (McKinsey 2009)
- There are two scenarios for 2050: maintain emissions at the same level as 2005 (with marginal costs of CO_2 mitigation up to US$50/t CO_2e), or reduce 2005 emissions by half by 2050 – in this more optimistic scenario some technologies would go to US$200/t CO_2e, but the average would stay between US$38 and US$117/t CO_2e). (IEA 2008)
- In the scenario of stabilization at 550 ppm CO_2, cap and trade would bring the price of CO_2 to US$90/t CO_2e in 2030 (OECD+), and US$40/t CO_2e in 2020. For stabilization at 450 ppm, the price would be up to US$180/t CO_2e in 2030. (WEO-2008-a)

From these indications, and considering the need to reduce the atmospheric concentration of CO_2 to 450 ppm, we have assumed a reference cost for mitigation of US$100/t CO_2e for the next 20 years. This cost is determined by the total emissions to be reduced, and from the cost and potential (varying by location and time) of the various technologies under consideration.

Considering the use of ethanol in substitution for gasoline and its excess electricity, the avoided mitigation cost of US$100/t CO_2e and the average value of mitigation (~2 t CO_2e/m^3 ethanol, see **Table 5**) create an additional value for ethanol of US$0.20 per liter. This additional value (that is to say, in addition to the equivalent value of the gasoline which it substitutes) is one of the externalities of ethanol use. While this externality is unremunerated, it should be taken into account when developing appropriate policies to promote the production and use of ethanol.

Possibilities for expansion of ethanol use in other sectors in Brazil

Ethanol could be used in other sectors in Brazil, so increasing its potential for emissions mitigation. While this possibility is not included in this assessment, we suggest some possibilities:

- The use of natural gas (NG) needs to be redirected to areas like industry and thermoelectric generation, where it is more appropriate than being used as vehicular natural gas (Compressed Natural Gas-CNG). In 2008, CNG use corresponded with about 4.5 million m^3 of ethanol (approximately 30% of the fuel ethanol used in the country).
- The consumption of diesel in isolated stand-alone generating systems was equivalent to 1.4 million m^3 of ethanol.

- The consumption of diesel just in the sugarcane agricultural sector was equivalent to about 2.2 million m^3 of ethanol.
- The use of ethanol substituting just 5% (by energy content) of diesel would require about 4 million m^3 of ethanol (this could occur as a priority in sectors like urban mass transportation).

Evolution of knowledge on climate change; trends and expectations for the post-Kyoto regime; ethanol in Brazil

Global climate change, caused by the increased concentration of CO_2 and other greenhouse gases in the atmosphere as a result of human activity, is "one of the greatest challenges of our times," according to the leaders of countries represented at the G-8 Major Economies Forum, held in L'Aquila, Italy, in July 2009.

Climate change and greenhouse gases

Global warming is caused by human activity that increase the atmospheric concentration of greenhouse gases: carbon dioxide (from the burning of fossil fuels, cement production, and deforestation); methane (anaerobic decomposition of organic material); nitrous oxide (nitrogenated fertilizers and the chemical industry); and certain industrial gases with halogen bases. The higher concentration of these gases produces a gradual warming of the Earth's surface, changing the dynamic of the oceans and the atmosphere. It is predicted that such changes will have various harmful effects. Ecosystems and human activity are adapted to the current climate, and the predicted climate change will be much quicker than the capacity of nature or humanity to adapt.

In 1988, the Intergovernmental Panel on Climate Change (IPCC) was created by the United Nations to assess the state of human knowledge about climate change, including scientific questions, impact estimates and possible response strategies. After the 1990 report, the rapid advance of knowledge about the topic made continuous reevaluation necessary. New reports were published in 1995, 2001 and 2007, and another is planned for 2013. The first report (1990) recorded an increase in the concentration of carbon dioxide in the atmosphere and predicted that the average global surface temperature would increase by about 3° C in 2100. The report also predicted that another decade would pass before climate change could be detected. The latest IPCC report in 2007 stated that man-made climate change had been unequivocally detected. Given that climate change includes natural effects (volcanic eruptions, solar variation, and El Niño), it is necessary to separate these out by using mathematical models. Current models and the increasing intensity of climate change allowed climate simulations for the past century. Comparing these with actual observation makes it possible to separate natural causes from human-induced climate change.

The cause-and-effect chain in the climate system starts with human decisions and actions, which lead to the emission of greenhouse gases. Increasing concentrations of these gases in the atmosphere leads to warming, higher temperatures, local and regional impacts from climate change and the associated harmful effects. The relationship between emissions and the increase in concentrations is dictated by the average lifetime of each gas in the atmosphere. The relationship between the increase in concentrations and the radiative strength is a function of the properties of each gas. The relationship between the radiative strength and the temperature increase is determined by the climatic sensitivity, which is the average increase in surface temperature each time the carbon dioxide concentration is doubled, and by the timescale of the vertical transfer of heat in the oceans. There is a complex relationship between temperature increase and the local and regional impacts of climate change, and as a consequence the harmful effects, but we can say that it is a monotonically increasing function of the rise in temperature.

We therefore know that stabilizing the temperature requires stabilization of the atmospheric concentration of greenhouse gases, which in turn requires stabilizing net anthropogenic emissions. "Net emissions" is a concept that takes into account the removal of carbon dioxide from the atmosphere, which is considered as negative emissions. The only greenhouse gas that lends itself to anthropogenic removal is carbon dioxide, which can be removed from the atmosphere by planting trees, or through capture and geological storage (in oil and gas wells or in saline aquifers), or by seeding the oceans with iron salts. These last two technologies are still under development. Given a temporal profile of future emissions, this corresponds to a single profile of increasing concentration and a single profile of rising temperature. The inverse is not true, however – there is more than one possible emissions profile that can achieve the same temperature increase. In this case, the tendency is to look for the emissions profile that corresponds to the lowest possible cost for the same result.

Reactions to climate change

Our knowledge about climate change has evolved slowly and gradually since 1990. In parallel, society has become more aware and there have been more positive actions from governments, businesses and individuals. The possible reactions – in addition of course to inaction – are mitigation and adaptation. Mitigation comprises actions to reduce net anthropogenic emissions of greenhouse gases. Adaptation relates to measures that reduce the harmful impacts of climate change. The preferred combination of inaction, mitigation, and adaptation can be summarized as the choice of a tolerable limit for climate change.

Reacting to the first IPCC report, the UN General Assembly in 1990 established a negotiating process that culminated in 1992 with the adoption of the text of a convention. In force since 1994, this convention sets as a goal the stabilization of atmospheric greenhouse gas concentrations at a safe level, although it did not specify this value. The convention also embodied the principle that all countries share a responsibility that is common, but differentiated in function by their respective capacities for action. At the first Conference of the Parties to the Convention (COP-1), in 1995, the assessment was that the commitments made by industrialized countries were inadequate to reach their goal of stabilizing the concentration of greenhouse gases in the atmosphere. This led to a mandate to negotiate what became the Kyoto Protocol, adopted in 1997 and in force since 2005.

In essence, the Kyoto Protocol established limits for national aggregate emissions for industrialized countries, national emission mitigation programs for all countries, and carbon market mechanisms to minimize the overall cost of emissions reductions. The first period for verification of compliance to Kyoto targets is 2008-2012. Limits for the second period are now under discussion.

At the same time, the 13th Conference of the Parties to the Convention (COP-13) in Bali, Indonesia, adopted a two-year plan of action generating decisions relating to an agreement that would be adopted at the COP-15 in Copenhagen at the end of 2009. This would be broader than the Kyoto Protocol and would seek to achieve the goal of the Convention, stabilizing atmospheric concentrations of greenhouse gases[iii].

The international negotiation process, taking place under the aegis of the Kyoto Protocol, is moving to define new emissions limits for industrialized countries through 2020. It is reasonable to assume that these values will be defined only at the end of the other front the negotiations. The limits under the Kyoto Protocol are also important because they will have a direct impact on the market value of carbon credits under Clean Development Mechanism (CDM).

On the other front of the negotiations, under the aegis of the Convention but outside the scope of the Kyoto Protocol, the goal is to establish a longer-term regime that could lead to meeting the goal of the Convention. Although the goal of the Convention mentions the stabilization of greenhouse gas concentrations in the atmosphere, the tendency today is to look for a limit to temperature increase – a variable that is more directly related to the magnitude of the harmful impacts of climate change. Also, as we have seen, there is more than one temporal profile for concentrations and emissions that generates the same result. This introduces an additional degree of flexibility and therefore tends to minimize the costs of mitigation.

Although the official negotiations take place in the Conferences of the Parties to the Convention, several high level meetings tend to include the question of climate change on their agendas, seeking to build the consensus that is necessary for the success of the official conferences. The most recent such meeting was the Major Economies Forum (MEF). This saw consensus between the 14 participating countries that climate change should be limited to a temperature increase of 2° C at the end of the century.

A limit for the increase in temperature (for example, 2° C) would imply the need to reduce net global anthropogenic emissions of greenhouse gas by approximately 60% in comparison to 1990 levels. As a first suggestion, the main industrialized countries in the G8 (including the European Union) at the same event outlined an effort to reduce their emissions by 80%, so allowing developing nations to act more slowly. Although these projections made four decades in advance are subject to many uncertainties, and still have not been adopted, they point to an important change in the global energy matrix with impacts for all countries.

Biofuels; Ethanol in Brazil and Climate Change

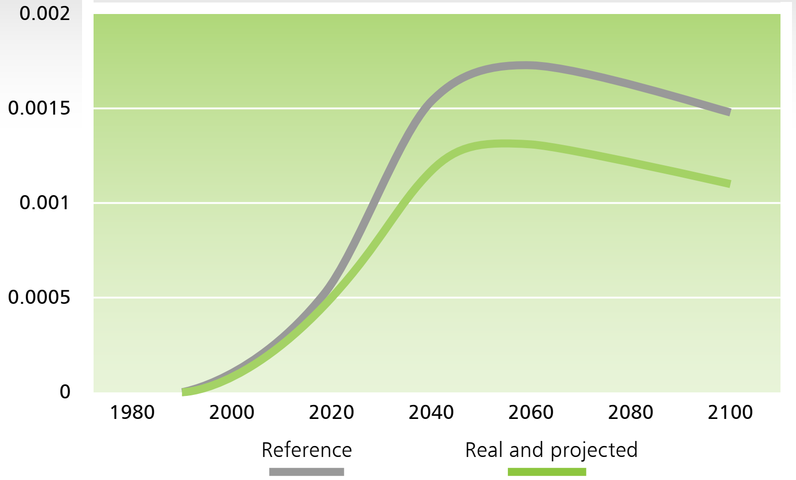
Global studies (Pacala 2004) show that renewable biofuels are a necessary part of this transformation. It will not be possible to reach the desired goal for limiting the increase in temperature without a significant increase in the participation of renewable biofuels in the new energy matrix.

It is interesting to consider the impact on global temperature increase caused by the introduction in Brazil of fuel ethanol to replace gasoline. To do this we must first establish a baseline. It has been common to use as a baseline a "business as usual" scenario that corresponds to what would occur if no action were taken to reduce emissions. This emissions scenario is adopted by the IPCC and is based on demographic projections, the intensity of energy use and the technology used for its generation. This is done for the whole world, although it may sometimes be compiled regionally. In the case of individual projects, such as those in the CDM, the baseline is constructed using an approved methodology that seeks to establish the most plausible scenario. The "business as usual" (BAU) baseline scenarios are hypothetical, or counterfactual – future scenarios that could happen, but have not happened – and therefore are not subject to objective demonstration or verification. Furthermore, these scenarios lend themselves to manipulation.

The only way to avoid these problems is to adopt a fixed and measurable reference. The trend in the Convention and especially in the Kyoto Protocol is to adopt 1990 emissions as the fixed reference. The above-mentioned need to reduce global emissions by 60% refers to 1990 levels.

Figure 1

Increase in the average global surface temperature resulting from the use of ethanol and gasoline in Brazil: 1990 to 2030 *In °C*



Reference: volume of ethanol held constant at 1990 level, from 1990 to 2030. • **Real and project**: real consumption (1990-2008) and projected (2008-2030).

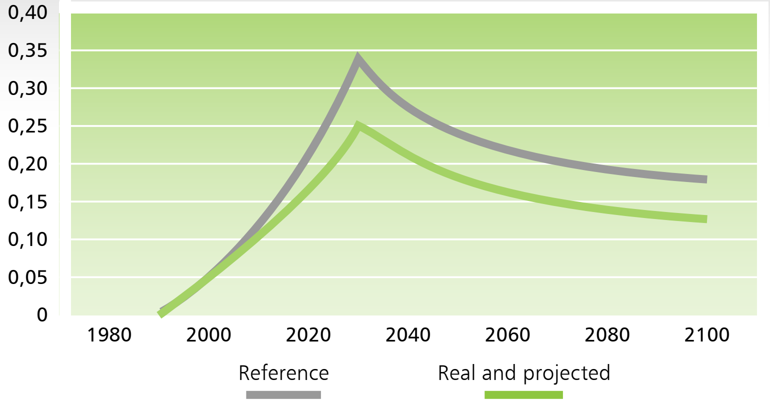
Using 1990 as a base year – it has been adopted as a benchmark in international negotiations – we can calculate the contribution to climate change resulting from the use of Type A gasoline and ethanol for a certain period, for example, between 1990 and 2030. This benchmark implies holding constant during the period the volume of ethanol produced in 1990 (11.8 million cubic meters), with the fuel consumption of Otto Cycle engines being complemented by gasoline up to the levels of real demand for 1990-2008 and projected demand for 2008-2030 (EPE 2007). Based on this benchmark we can calculate the effect of ethanol, measured by consumption of ethanol and gasoline (real, from 1990 to 2008, and projected from 2008 to 2030).

Figure 1 shows the increase in the average global surface temperature, indicating the magnitude of climate change from that date. **Figure 2** shows the increase in the atmospheric concentration of carbon dioxide. The calculation takes into account the emissions relating to ethanol and gasoline (as shown in **Table 5**), the dynamics of the process of CO_2 absorption by the Earth, and the result of global warming itself in the increase of temperature.

The forecast horizon is 2100, which is the year normally adopted by the IPCC and in political negotiations about the future regime of climate change. Note that we have used only official data to the horizon for which they are available (2030), to avoid any pre-judgment of what will happen after that date (zero emissions from 2030 to 2100). Interestingly, while Brazil's National Climate Change Plan (PNMC) provides for mitigation measures, and thus for limiting greenhouse gas emissions, the government's detailed energy plan foresees the resumption of exponential growth in Type C gasoline consumption as of 2020, maintaining a constant ratio between consumption of ethanol and Type C gasoline. It does not include the proportional increase in ethanol consumption that would seem to be compatible with the goals of the PNMC.

Figure 2

Impact on the concentration of CO_2 in the atmosphere resulting from the use of ethanol and gasoline in Brazil 1990 to 2030 *Concentration of CO_2 in PPM*



Reference: volume of ethanol held constant at 1990 level, from 1990 to 2030. • **Real and project**: real consumption (1990-2008) and projected (2008-2030).

Prospects for international negotiations

The trends in international negotiations are:

- Limiting temperature increase in 2100 to 2° C;
- Industrialized countries reduce emissions by 80%, compared to 1990 levels;
- Emerging countries reduce emissions in comparison to current trend;
- Special consideration for least developed countries.

Physical considerations allow us to state that, to achieve temperature stabilization, we must first stabilize the concentration of carbon dioxide (and other GHG) in the atmosphere. To stabilize the concentration of carbon dioxide in the atmosphere, it will be necessary to reduce net anthropogenic emissions to a level 60% below that recorded in 1990. This reasoning allows us to estimate the level of emissions possible in developing countries that, taken together with the 80% reduction in emissions of industrialized countries, will result in a 60% reduction in global emissions. Given that emissions from industrialized countries represented three-quarters of global emissions in 1990; the proposals under consideration today lead us to conclude that emerging countries must limit their emissions to 1990 levels.

There are no indications of how to divide this limit amongst emerging countries. Assuming, however, for purposes of illustration, that each country acts individually, we can conclude that Brazil should adopt measures in its national planning to stabilize emissions at 1990 levels. Energy planning in its current form does not indicate measures in this manner, and it is therefore reasonable to assume that this planning needs to be revised to match the declared objectives of national policy and the PNMC.

The options for limiting greenhouse gas emissions can, in general, be classified in three main groups:

I Regulatory policies and measures that require the adoption of certain practices, for example energy efficiency standards, the outright prohibition of certain practices, and so on. In general, measures like these tend to be the least efficient because they increase the cost to society of measures to contain emissions;

II Fiscal measures, ranging from a tax on greenhouse gas emissions – a “carbon tax” – to tax incentives (effectively negative taxes) and the provision of credit on favorable terms for enterprises that result in reduced emissions;

III Mechanisms to limit and trade emissions (cap-and-trade), under which the imposition of emission limits is accompanied by the preparation of certificates that allow for emissions at levels compatible with the desired limits, coupled with permission to trade such certificates. This system is currently used in the European Union, where it is known as the European Union Emissions Trading System. Under certain conditions to control emissions from stationary sources, with available technology, this scheme can result in minimizing costs for society as a whole, because the market is responsible for ensuring that reductions will occur where their marginal costs are lowest.

There is also an innovative tendency to combine the second and third approaches, as for example in the Waxmann-Markey Bill, approved by the U.S. House of Representatives, where permits are auctioned rather than handed out free. Brazil's Secretary for Economic Policy at the Ministry of Finance has expressed interest in this model.

In addition to the debates about global targets for temperature increase (and thus for overall emissions), the allocation of these targets amongst countries or groups of countries, and the list of possible domestic policies to be adopted by countries in general and Brazil in particular, two other questions remain. One relates to international mechanisms by which emissions limitations can be re-allocated among countries – the international carbon trade; the other is the relative competitiveness of Brazil.

The international debate about the international carbon market is still extremely limited. The existing mechanism within the ambit of the Kyoto Protocol, the Clean Development Mechanism, has its limitations, in particular with respect to renewable energy and ethanol.

As for international targets, these need to be adopted uniformly, including China and India, in order to protect the competitiveness of Brazilian industry.

Brazil's advantages, such as its relatively clean energy matrix, should also be incorporated. It is necessary to quantify and transfer this in order for it to be translated into advantages in international trade.

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Explanatory Notes

[i] Sources: WEO 2008, EPA data for the IEA, IEA databases and IPCC 2007.

[ii] Image, Ipac, AIM and Message.

[iii] This study was concluded before the COP-15 meeting in Copenhagen.