Chapter 4: Impacts on global climate: greenhouse gas emissions

Brazil, as most other countries in the world, is considering its vulnerability to the effects of increased GHG concentration in the atmosphere. Ethanol utilization in Brazil today leads to avoiding 13% of the GHG emissions of the whole energy sector. For every additional 100 Mt of sugar cane, emissions of 12.6 Mt CO_2 equivalent / year could be avoided withethanol, sugar cane bagasse and the added excess electricity.

4.1 Introduction; concepts and the world context

In the 1990's, fossil fuel emissions were responsible for 82 percent of the heating power of greenhouse gas emissions in the United States. Developed countries have contributed 84 percent of total GHG (greenhouse gas) emission worldwide since 1800.[1] Irrespective of the level set as the limit (under discussion) on annual emissions, developed countries shall reduce their current emissions to accommodate the growth of developing ones; the differences in total emissions (and also in *per capita* emissions) are huge. In 1996, the *per capita* carbon emissions in the United States amounted to 5.37 tons; in most of Asia and Latin America, 0.5 to 1.0 ton; and in Japan and Western Europe, 2 to 3 tons.

1 Brown, D.A.: "Climate change", *in*: Dernbach, J. C. (Ed.): *Stumbling toward sustainability*, Washington DC, Environmental Law Institute, 2002

Of all partial solutions being considered, including those involving energy preservation, carbon uptake, and utilization of the set of "renewable" energies, the use of biomass in substitution of fossil fuels appears to be a great opportunity. The efforts to develop and implement technologies in this area are vast. The use of sugar cane ethanol, associated with the bagasse, has become the first experience to bring positive results on a large scale.

The following topics describe the current knowledge of the climate changes arising from the concentration of greenhouse gases in the atmosphere, the impact of the agricultural production system and its vulnerability to changes, the greenhouse gas emissions in Brazil, as well as the emissions avoided by the sugar cane agribusiness in Brazil.

The conditions for sugar cane and ethanol production in Brazil have led to extremely positive results in terms of decreasing emissions, and have put ethanol in the spotlight as a fuel for the world.

4.2 Global climate changes: current knowledge

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The climate change addressed by the United Nations Framework Convention on Climate Change and its Kyoto Protocol focuses on global change caused by the man-induced gradual increase in the amount or concentration of carbon dioxide and other gases.

The concentration of carbon dioxide in the atmosphere 200 years ago has increased from 280 ppmv (parts per million in volume) to 370 ppmv, and continues to grow.

Even though the amount is very small compared to those of nitrogen and oxygen, which jointly correspond to around 99 percent of our atmosphere, carbon dioxide and other gases known as greenhouse gases are responsible for preventing the surface from naturally cooling down due to infrared radiation. Those who live in cold areas know that cloudless winter nights are very cold exactly because of such radiation cooling. By preventing natural cooling, the greenhouse effect causes an increase in the surface temperature, in addition to other climate changes in general.

The greenhouse effect is a natural phenomenon. Without it, the mean temperature on the surface of the planet would be more than 30 degrees Celsius lower than it is today. What happens is that as the concentration of carbon dioxide in the atmosphere increases, the greenhouse of our planet becomes more efficient. Since the pre-industrial period, the mean global surface temperature has increased by around 0.6 ºC. According to the forecasts of the United Nations Intergovernmental Panel on Climate Change (www.ipcc.ch), the temperature will have increased by around 3 degrees Celsius by the year 2010, if we fail to take action in order to mitigate the increase of greenhouse gas concentration in the atmosphere.

In addition to carbon dioxide, methane and nitrous oxide resulting from human activities, as well as other greenhouse gases having a lesser effect, are increasing in the atmosphere and contributing to the climate change.

In the face of this problem, there are only three possible options:

i. inactivity, which means accepting the climate change and the damage that will be caused as it reaches its peak many years after the emission of gases to the atmosphere (around 20 years of delay, for methane, 40 years, for carbon dioxide, and 50 years, for nitrous oxide).

ii. mitigation of the climate change by reducing greenhouse gas emissions or, in the case of carbon dioxide, removing it from the atmosphere through the process called "carbon uptake". The removal of carbon dioxide from the atmosphere can be temporary, through its fixation to the biosphere by planting trees, for example. It can also be a longer-term action, in the case of what is known as geological sequestration, through carbon dioxide injection into oil wells, etc.

iii. adapting to the climate change through measures designed to mitigate the damage resulting from that change. In a very schematic way, raising the level of ocean restraining dams to diminish the damage resulting from a rise in sea levels, and more generally, actions designed to build-up resistance to climate changes that will tend to increase in extent and frequency as the climate changes, are adaptation measures. In many cases, however, adaptation is simply not possible. The best examples of this are the melting of the Arctic ice cap and, in Brazil, the "savannization" trend on the edges of the Amazon Forest as result of changes in the wet weather flow as part of the climate change.

In 1990, the United Nations General Assembly passed a resolution requiring global action for protecting the climate from changes. They decided to negotiate a convention in order to address this theme. The task was performed in two years, and in 1992, the United Nations Framework Convention on Climate Change was opened in Rio de Janeiro. The Convention was subscribed to and ratified by essentially all of the countries.

According to the Convention, countries must undertake a stabilization of the concentration of greenhouse gases in the atmosphere at such levels as capable of allowing the dangerous human interference with the climate system (atmosphere, oceans and biosphere) to be prevented. No exclusive answer exists to the question as to what greenhouse gas concentration level in the atmosphere should be considered dangerous and should not be exceeded. This is due to the fact that the harmful effects of the climate change are distinct in different regions and in different fields of human activity.

It is also plausible to admit that, initially, a small increase in temperature may even have beneficial effects by improving climatic conditions for agriculture in regions where the weather is very cold. For the most part, however, there is a growing consensus that we should not let the mean global temperature increase by any more than around 2 degrees Celsius by the year 2050. Such is the opinion of European countries, in particular. This theme was the subject of a scientific debate at a recent international science conference held in Great Britain.[2]

2 www.stabilisation.com

As a first step towards fulfilling the goal of the Convention, 1997 saw the adoption of the Convention's Kyoto Protocol. It took effect in February 2005 with the remarkable absence of the United States and Australia, who indicated that they intended to pursue the said goal by other means. The Kyoto Protocol has the noteworthy characteristic of providing for mechanisms to compensate for the reduction of emissions among projects and countries. The reason for this, is to reduce the global cost of decreasing emissions. With this in mind, the compensation mechanisms release market forces that tend to make the decreases take place only in those sectors where the costs are lower.

In the Brazilian case, experience has shown that there are favorable conditions, especially concerning the use of biomass as an energy source. In particular, the substitution of gasoline with ethanol in the transportation sector, and steel works coke with charcoal in the production of pig iron (and steel directly, in some cases).

It is interesting to note that the irreversible world trend towards limiting greenhouse gas emissions, especially those of carbon dioxide, have the immediate effect of valuing the use of renewable fuels. As a result, the consideration of such a factor shall value either those fuels or, in the case of charcoal steel works, the product itself. This, whether due to market requirements or the use of the Clean Development Mechanism to provide an economic margin that is essential to making the activities viable in some cases.

As the Kyoto Protocol takes effect, international attentions turn to the definition of the international system on climate change that shall be adopted following 2012. The participation of the sectors concerned is essential to ensuring that Brazil's competitive edge will be taken into account in future.

4.3 Vulnerability, impacts, and adaptation to the climate change; the present knowledge

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4.3.1. Introduction

In 2004, the CGEE – Center for Management and Strategic Studies conducted a study (Prospective Activity in Climate Change)[3] in order to assess the vulnerability conditions, and the impacts of climate changes arising from increased GHG concentrations in the atmosphere on Brazil and the country's adaptation thereto. The study also focused on the international negotiations concerning the mitigation of such changes. The study had a broad coverage, considering the vulnerability of and impacts on forests, livestock, soils and biodiversity, regional aspects like coastal and subarid areas, social vulnerability aspects, and water resources. As it happens in a large portion of developing countries, there still is little information on these issues. This summary brings some of the results that are interesting to Brazil's agricultural activities.

3 "Atividade prospectiva em mudança do clima", Brasília, CGEE – Centro de Gestão e Estudos Estratégicos, Agosto 2004

The discussions about climate change, vulnerability, impacts and adaptation have particular connotations. Here, *vulnerability* refers to a certain system's level of reaction to a specific climate change. *Impacts* (climatic) refer to the consequences of the climate change to natural and human systems. *Adaptation* describes adjustments in ecological or socioeconomic systems in response to current or projected climate changes resulting from structural practices, processes, measures or changes.

The assessments conducted by the IPCC indicate that developing countries are among the most vulnerable to climate changes. In Brazil, for example, adverse impacts of natural climate changes are droughts, overflows and floods, and hillside landslips.

Adaptation and/or mitigation strategies depend on the existence of credible climate change scenarios on a regional time scale of decades. Present knowledge does not yet allow such scenarios to be established with great confidence. Notwithstanding that all projections point to a temperature increase, it is essential for a tropical country like Brazil to advance in order to get reliable scenarios of likely changes in the water cycle, as many of the impacts are primarily associated with water. Even though some centers in Brazil are building up capacity to set up regional scenarios by downscaling scenarios from global models, the uncertainty inherent in global climate models remains. The main difficulty in analyzing potential sectoral impacts is precisely that which results from the uncertainty about the future behavior of the rainfall intensity and distribution. These impacts still require a wide range of possible scenarios to be considered.

The mean overall temperature on the surface of the planet has increased by 0.6 ºC over the past 100 years, and that increase has been sharper since the 1960-70's. The three hottest years in the past 1,000 years of the recent geological history have all occurred in the past decade. Today, by analyzing the systematic analyses conducted by the IPCC, a reasonable consensus can be reached that the global heating over the past 100 years is probably explained mainly by the man-induced emissions of greenhouse gases (GHG), rather than any natural climate variability.[4] Until the beginning of the Industrial Revolution in the late 18th century, the concentrations of carbon dioxide (CO_2) in the atmosphere had ranged from 180 parts per million in volume (ppmv) to 200 ppmv of the total atmospheric mass (which characterized it as a minority gas) for at least 700,000 years, but possibly for more than 5 million years. Over the past few years the concentration of that gas has exceeded 375 ppmv and keeps on growing, as 8 to 9 million tons of carbon (in the form of CO_2) are released every year by the burning of fossil fuels and man-induced changes in land use, especially deforestation in rain forests. The concentration of other important greenhouse gases (CH_4, N_2O) in the atmosphere has been increasing at rates that are even higher than those of CO_2.

4 HOUGHTON, R.A. *et al.*: *Climate change 2001: The scientific basis*, Cambridge, Cambridge University Press, 2001

4.3.2 Climate change scenarios for South America in the 2090-2100 decade

In order to project probable climate change scenarios for the future, mathematical models of the global climate system are used which take into consideration the behavior of climate components (atmosphere, oceans, cryosphere, soil-vegetation, etc.) and their interactions. These models allow climate evolution scenarios to be simulated for several GHG emission scenarios. Given the uncertainties about future GHG emissions, as well as uncertainties arising from imperfections of the very models, several models and scenarios are used.

Figures 1 and 2 show climate scenarios for South America in the 2091-2100 decade for five different global climate models and two GHG emission scenarios from the Intergovernmental Panel on Climate Change.[5] A2 is a scenario consisting of a high level of GHG emissions, i.e. maintaining the GHG emission standards observed for the past few decades. The level shown here indicates that by 2100 we would have CO_2 concentrations in the atmosphere of 850 ppmv. B2 is a lower emission scenario considering a stabilization of GHG emissions and a concentration of 550 ppmv at the end of this century.

5 NAKICENOVIC, N.; SWART, R. (Eds.): *Emissions scenarios 2000: Special report of the Intergovernmental Panel on Climate Change*, Cambrigde, Cambridge University, 2000

Figure 1: Projected surface temperature changes for 2091-2100, computed according to five global climate models,[6] IPCC Data Distribution Center

6 Ruosteenoja, K. *et al.*, IPCC Data Distribution Center, 2003

A2: High gas emission scenario B2: Low gas emission scenario

Temperature anomalies (°C, compared to the average for 1961-1990)

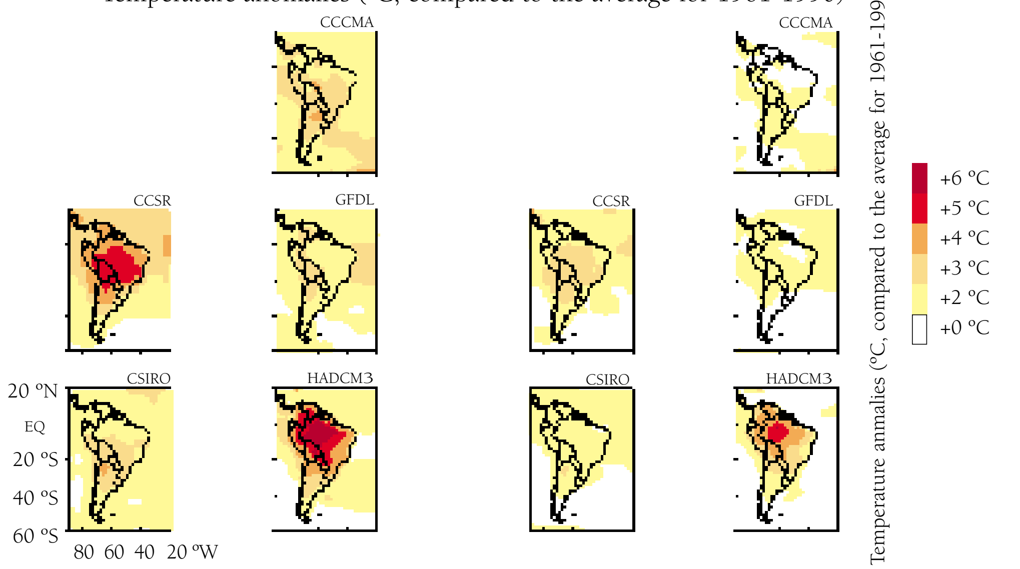
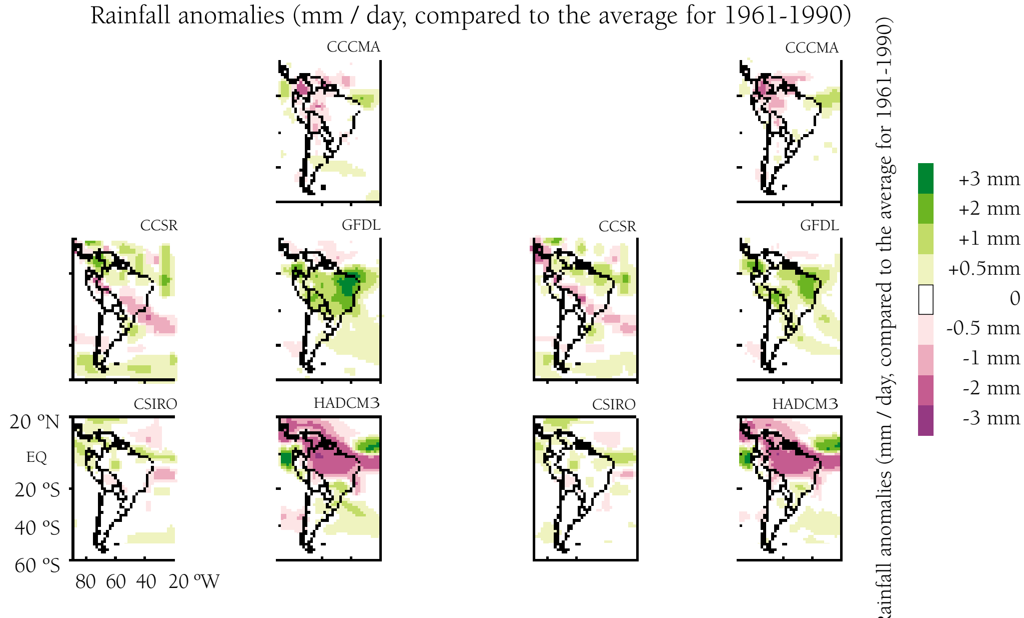


Figure 2: Projected rainfall changes for 2091-2100, computed according to five global climate models[6]

A2: High gas emission scenario B2: Low gas emission scenario

Rainfall anomalies (mm / day, compared to the average for 1961-1990)



An analysis of these scenarios shows a greater fluctuation of temperature and rainfall anomalies between different climate models than between the high emission scenario (A2) and the low emission scenario (B2). For temperature, a fluctuation range is projected at 1-4 ºC for the B2 scenario, and as much as 2-6 ºC for the A2 scenario: a substantially hotter weather for any of the scenarios and climate models considered. For the projected rainfall changes (where all projections point to heating), different climate models show significant differences in rainfall patterns, sometimes with radically opposing projections. For example, the GFDL model (US) points to an increase in rainfall in the tropical South America, whereas other climate models point to a decrease (such as the HADCM3, of Great Britain) or little change. Therefore, current methods do not allow the setting of reliable scenarios of changes in the rainfall distribution and intensity, on a regional scale, so as to subsidize active governmental policies to mitigate vulnerabilities and/or seek a potential adaptation to climate changes. Advances in the scientific knowledge may diminish the uncertainties inherent in such projections, perhaps within fewer than 10 years. Nevertheless, there is an indication of a more frequent occurrence of climate extremes and intense events (droughts, short summers, windstorms, severe storms) on a hotter planet.

The possible increase in climate extremes turns our attention to the problem relating to the vulnerability of populations and ecosystems to those changes. With hotter weather, there will be more water vapor in the atmosphere and an acceleration of the water cycle. This is one of the projected climate changes considered to be of high reliability. Such acceleration would result in an increased frequency of severe, intense storms, with consequences we can evaluate.

4.3.3 Impacts of climate changes on ecosystems and agroecosystems

The possible changes in Brazil's major natural biomes as a response to the climate change scenarios illustrated in **Figures 1** and **2** were evaluated by the CPTEC-INPE.[7] We remind that natural ecosystems are unable to migrate or adapt to the projected climate changes on the time scale in which they are taking place, i.e. decades. Therefore, we should expect significant rearrangements of the ecosystems and biomes.

Most of the differences in projections of the future distribution of biomes again lie in the comparison between the GFDL and the HADCM3 models, and are attributable to differences in rainfall patterns. Since rainfall increases in the tropical South America in the first model, there would be no sensible change in distribution in the Amazon Rain Forest, but there the savannah would expand to the northeast, thereby replacing the *caatinga* biome in the northeastern subarid area. For the other scenarios, there is a trend towards "savannization" of parts of the

7 Nobre, C.A.; Oyama, M.D.; Oliveira, G.S.; Marengo, J.A.; Salati, E.: "Impact of climate change scenarios for 2100 on the biomes of South America", First International CLIVAR Conference, Baltimore, USA, 21-25 June 2004. http://www.clivar2004.org

8 Cox, P.M.; Betts, R.A.; Jones, C.D.; Spall, S.A.; Totterdell, I.J.: "Acceleration of global warming due to carbon-cycle feedbacks in a coupled climate model", London, Nature, vol .408, 2000, pp. 184-187

9 Siqueira, O.J.W.: "Efeitos potenciais das mudanças climáticas na agricultura brasileira e estratégias adaptativas para algumas culturas", *in*: Lima, M.A. de; Cabral, O.M.R.; Miguez, J.D.G. (Eds.): *Mudanças climáticas globais e a agropecuária brasileira*, Jaguariúna, SP, EMBRAPA Meio Ambiente, 2001, pp. 65-96

10 Siqueira, O.J.W.; Farias, J.R.B. de; Sans, L.M.L.: "Potential effects of global climate change for Brazilian agriculture and adaptative strategies for wheat, maize and soybean", Revista Brasileira de Agrometeorologia, 2, 1994, pp. 115-129

Amazon (i.e. expansion of the *cerrado*, or savannah to the north) and even towards the *caatinga* of part of the subarid area becoming a semi-desert. Generally, there is a projected expansion of savannah areas in the tropical South America and a decrease in the *caatinga* area. Four of the five scenarios point to a decrease in the area covered by the Amazon Rain Forest. In particular, the HADCM3 model is the one providing the most extreme scenario for the Amazon, going as far as to speculate about a possible complete disappearance of the Amazon Rain Forest.[8]

An analogous reasoning could be used in respect to the impact of such projected climate changes on the agroecosystems. For the most part, except for the GFDL, there is a trend towards decreased availability of water in parts of the Amazon, the Northeast and the Center-West, which could adversely affect agriculture, especially in the Northeast and the Center-West. In the South and Southeast, those projections point to much smaller changes in the water system. However, in order to project the impacts on agriculture and, as a result, evaluate the vulnerability, the effects of the temperature and the concentration of carbon dioxide (CO_2 "fertilization"), should be considered. A sharp increase in the mean temperature is usually harmful to the crops if outside the optimum range, but in the other way around, an increase in CO_2 concentration usually results in higher productivity for the crops.

There are only a few studies dealing with the impacts of climate changes on the Brazilian agriculture. Some of the studies used future climate change scenarios based on global climate models. These studies sought to calculate the negative and positive effects on the productivity of wheat, corn and soybean crops[9, 10, 11] or the impact of climate changes in the occurrence of pests in wheat crops in the south of Brazil.[12] Other studies analyzed the agroclimatic risk to coffee crops at climate extremes.[13, 14] In São Paulo State, for example, it was calculated that with an increase of 3 °C in the mean temperature and 15% in rainfall, only 15% of the state's area would be favorable to the Arabic coffee culture (compared to today's 40%), even considering that there would be no risk of frosts in these scenarios.

For the most part, the studies of the impacts on the agricultural productivity of corn, wheat and soybean crops do not allow the conclusion to be safely reached that the effect of temperature rises contributes to productivity decreases, even including the possibility of the greater occurrence of pests. To some extent, this can be compensated for by the increased concentration of carbon dioxide. Effects on soil (new physicochemical and biological balances, influencing fertility) also need evaluation. It is noted that all studies have used mathematical models to estimate the impacts on agriculture, but their results lack further validation by field experiments.

8 see p. 98

9 see p. 98

10 see p. 98

11 Travasso, M. *et al.*: "Expected impacts of climate change on crop yields in the Pampas region of Argentina, Brazil and Uruguay" (AIACC Project No. LA27), Second AIACC Regional Workshop for Latin America and the Caribbean, Buenos Aires, Argentina, 24-27 August 2004

12 Fernandes, J.M. *et al.*: "Expected impacts of climate change on the incidence of crop disease in the Pampas region of Argentina, Brazil and Uruguay: Modeling fusarium head blight in wheat under climate change using linked process-based model" (AIACC Project No. LA27), Second AIACC Regional Workshop for Latin America and the Caribbean

13 Marengo, J.A.: "Impactos das condições climáticas e da variabilidade e mudanças do clima sobre a produção e os preços agrícolas: ondas de frio e seu impacto sobre a cafeicultura nas regiões Sul e Sudeste do Brasil", *in*: Lima, M.A.; Cabral, O.M.R.; Miguez, J.D.G. (Eds.): *Mudanças climáticas globais e a agropecuária brasileira*, Jaguariúna, SP, EMBRAPA Meio Ambiente, 2001, pp. 97-123

14 Pinto H.S.; Assad, E.D.; Zullo Jr.; Brunini, O.: "O aquecimento global e a agricultura", Revista Eletrônica do Jornalismo Científico, COMCIENCIA - SBPC, vol. 35, 2002, pp. 1-6

Considering the possibility of more frequent, more severe rainfall and temperature extremes, the important effects on agriculture would be increased soil erosion (more intense rainfall), and the effects of hail and high-speed, high-turbulence winds.

4.4 Greenhouse gas emissions in Brazil

In late 2004, Brazil submitted its initial national communication to the UN Framework Convention on Climate Change, as expected. The first part provides an overview of the country, its priorities, and its complexity. The second part provides the first national inventory in respect to greenhouse gas emissions for the 1990-94 period. The third part shows some of the steps the country has already taken towards reducing emissions.

Some difficulties with the computation methodology are highlighted. Most of them are due to the fact that the IPCC methodology is based on the experience of developed countries, where most of the emissions result from the *use of fossil fuels*. In Brazil, the *change in the use of land and forests* is more relevant. This required an adjustment to the proposed methodology. Several initiatives taken in the country, especially in the field of "renewable energy", particularly involving the sugar cane ethanol, are listed in the last part. Even though current information concerning the implementation of that Convention in Brazil was reflected in the report until the year 2000, several pieces of information for as late as 2002 were added.

Some of the results of the national greenhouse gas inventory are shown in **Table 1**. Although the inventory includes other gases (HFC, PFC, SF_6, and those having indirect effects: CO, NOx, NMVOCs), we have listed only the most important ones: CO_2, CH_4 and N_2O.

Table 1: Estimations of GHG emissions in Brazil, 1994

Sectors	Energy (Mt)	Industry (Mt)	Crops and live-stock (Mt)	Change in use of land & forests (Mt)	Waste treatment (Mt)	TOTAL (Mt)	Variation 1994/90 (%)
CO_2	237	17	-	776	-	1030	5
CH_4	0.4	-	10.1	1.8	0.8	13.2	7
N_2O	-	-	0.5	-	-	0.5	12

Source: Brazilian National Report to IPCC, Ministry of Science and Technology, Brasília, 2004

As demonstrated in **Table 1**, CO_2 emissions in 1994 were caused by *changes in the use of land and forests* (75%), followed by *energy* (23%). Methane emissions originated mainly from *crops and livestock* (77%, most of which from enteric fermentation by ruminants), which also accounted for 92 percent of the N_2O emissions. We point out that the "global warming power" of methane is 29 times as large as that of CO_2, while that of N_2O is 296 times as large as that of CO_2.

The figures above serve as a reference for comparison with GHG emissions from sugar cane production and processing, and with the emissions prevented by using ethanol and bagasse as fuels, as quantified in **item 4.5**.

4.5 GHG emissions by the sugar and ethanol industry in Brazil: current and expected values

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The energy products of sugar cane, i.e. ethanol and bagasse, have largely contributed to the reduction of the emissions of greenhouse gases (GHG) in Brazil, by substituting for fossil fuels, i.e. gasoline and fuel oil, respectively. Not only does the bagasse supply energy (thermal and electrical) for ethanol production, it is also used in sugar production (substituting for the fossil fuel that would be used in the alternative production from sugar beets, or starch) and other industrial sectors (such as orange processing).

Fossil fuels are consumed in sugar cane planting, harvesting, transportation and processing and emit GHG. Also, there are processes that have no connection with fuels, but generate emissions that are not compensated for by photosynthetic re-absorption as the sugar cane grows (non CO_2 gases in trash burning, fertilizer decomposition, etc.). A complete balance sheet of energy and emissions (in the life cycle) for evaluating the net results in ethanol production from sugar cane and its utilization as a fuel in transportation sector has been prepared and recently updated in Brazil.[15] In 2006 a new update included also some forecasts for the evolution (based on technical improvements) for the next years.[16]

The energy analysis is summed up in **item 1.4.1**, resulting in a mean ratio between the production of renewable energy and consumption of fossil energy of 8.9. For comparison, the energy ratio in the case of ethanol and corn in the United States was evaluated at 1.34 in 2002.

15 Macedo, I.C.; Leal, M.R.L.V.; Silva, J.E.A.: "Emissões de gases de efeito estufa (GEE) na produção e uso de etanol no Brasil: situação atual (2002)", SMA – Secretaria do Meio Ambiente de São Paulo, São Paulo, 2004

16 Seabra, J.E.; Leal. M.R.L.V.; Macedo, I.C.: The energy balance and GHG avoided emissions in the production / use of ethanol from sugar cane in Brazil: the situation today and the expected evolution in the next decade; XVI International Symposium on Alcohol Fuels, Rio de Janeiro, Nov 2006

For greenhouse gases, emissions from the use of fossil energy were evaluated at 0.20 kgCO_2 eq./m^3 ethanol anhydrous (on average), and emissions from other sources (non CO_2 gases from trash burning, fertilizer decomposition, etc.) 0.18 kgCO_2 eq./m^3 ethanol anhydrous. As a net result, the emissions avoided by the substitution of ethanol for gasoline, and of surplus bagasse for fuel oil, minus the foregoing values amount to 2.86 t CO_2eq. / m^3 of anhydrous ethanol and 2.16 t CO_2eq. / m^3 of hydrous ethanol, for the mean values. For the mills featuring the best performance, the values can be around 4 percent higher. These values consider anhydrous ethanol as an additive (added up to 24%) and hydrous ethanol for E100 cars.

These are very relevant results. Under these conditions, which reflect the current situation in Brazil, ethanol production from sugar cane is much superior compared to any other technology to produce biomass fuels worldwide. This is because of the "renewable energy obtained/fossil energy used" ratio and the very high rate of decrease in the emissions of GHG. For the Brazilian consumption of ethanol in 2003, i.e. 11.6 million m^3 per year (6.1 Mm^3 of which consisting of hydrous ethanol), ethanol was responsible for a reduction of around 27.5 million t CO_2 equivalent.

The emission of GHG from beet sugar production (energy based on coal or natural gas) is much larger than that from cane-sugar production. Although that difference cannot be used in CDM projects due to baseline definitions, it should nonetheless be pointed out. At the moment, beet processing takes less energy (on average) than sugar cane processing (the availability of bagasse has made sugar mills less energy-efficient). Modern beet sugar mills operate today with around 1.1 Gcal / sugar t (on average); using natural gas, the CO_2 emissions would amount to 0.26 ton CO_2 / sugar t. This is a conservative result. Compared to the emissions from beet-based sugar mills, the Brazilian mills have avoided emissions of 5.7 million tons CO_2 equivalent in 2003.

An analysis of the expected situation concerning emissions for the next few years[17] considers:

- Increased mechanical harvesting of sugar cane (increasing the consumption of fossil fuels), and reduced sugar cane burning (reducing some methane and nitrous oxide emissions
- Equivalences between ethanol and gasoline, for the various applications, being changed to include new compositions with the use of flex-fuel engines

17 Macedo, I.C.: "Estimativa da redução adicional de emissões de gases de efeito estufa (GEE) com o aumento da produção de cana e derivados no Brasil; 2010", Internal report, UNICA, São Paulo, 2004

• Future production (2010-): 34 Mt of sugar, 17.3 Mm^3 of ethanol (11.2 Mm^3 of hydrated ethanol), 535 Mt of sugar cane / crop.

In these cases, the emissions avoided by the use of ethanol would amount (possibly in 2010) to 46.7 Mt CO_2 equivalent. Therefore, the additional decrease in emissions thanks to ethanol use would amount to 19.2 Mt CO_2 equivalent.

The increase in sugar production through 2003 would lead to an additional decrease of 3.2 million tons CO_2 equivalent in emissions.

On the other hand, Brazilian mills are essentially independent in terms of electrical power, notwithstanding the purchase at the period between harvesting seasons (some energy is sold during the crop season). For the sugar cane production increase over the next years, and considering that 50 percent of it, on average, would be introducing C-E high-pressure generation systems (commercially available), with a 20-percent reduction of the specific steam consumption in the processes (over the current amount) and utilization of 10 percent of the trash, a surplus power of ~75 kWh / sugar cane t would be reached. The total surplus power would amount (for only half of the additional 217 million tons of sugar cane) to 8,140 GWh.

If this energy were to replace that generated by natural gas-based thermo-electrical power plants (a criterion not accepted by the CDM; an energy mix would be required), we would avoid emissions of 440-500 kg CO_2 eq. / MWh. The additional generation would lead us to avoid emissions of 4.1 Mt CO_2 eq., compared to natural gas-based thermo-electric power generation.

In short: every increase of 100 Mt of sugar cane / crop season, under the foregoing conditions, could lead to additional reductions in the emissions of of GHG equivalent to:

9.1 Mt CO_2 eq	(through ethanol use)
2.0 Mt CO_2 eq	(added electricity in 50% of the cases)
1.5 Mt CO_2 eq	(sugar cane sugar compared to beet sugar)

4.6 Summary and conclusions

• The 30-percent increase in the concentration of greenhouse gases in the atmosphere since pre-industrial times corresponds to an average increase of 0.6 °C in the surface temperature of the planet. In the 21st century, the mean temperature may increase by more than 3 °C if the current trend is not changed. The Kyoto Protocol represents one step towards (increasingly consensual) preventing an increase of up to 2 ºC by 2050.

• The still evolving global climate models all point to temperature rises for Brazil, but the uncertainties about the hydrology are substantial. The models indicate temperature increases of 1-4 ºC (low emission scenario) or 2-6 ºC (high emission scenario). There is no agreement on the results for rainfall, but climate extremes (droughts, severe storms) are expected to occur more often.

• In the models that indicate a greater amount of rainfall (GFDL, US) the savannah would expand to the Northeast. In the other scenarios (for example, the HADCM3, England), the savannah would expand to parts of the Amazon, and the *caatinga* biome in the Northeast would become a semi-desert.

• A vulnerability assessment of the agricultural sector should consider the simultaneous effects of the temperature (and rains) and the "fertilization" by the increased concentration of CO_2. There are only a few studies for Brazil, and they are only focused on coffee and wheat in specific regions.

• The evaluation of the emission of GHG from Brazil for the 1990-94 period indicates *change in the use of land and forests* as the factor accounting for the most emissions (75%), followed by *energy*, with 23%.

• In the sugar cane industry, the "renewable energy produced/fossil energy used" ratio is 8.9 for ethanol production. This is due to an extraordinary performance in the industry, which avoids the emission of GHG equivalent to 13 percent of the emissions from Brazil's entire energy sector (reference 1994).

Emissions avoided in 2003:	
With ethanol substituting for gasoline:	27.5 Mt CO_2 equivalent
Bagasse in sugar production:	5.7 Mt CO_2

• For every additional 100 Mt of sugar cane, emissions of 12.6 Mt CO_2 equivalent could be avoided over the next few years using ethanol, sugar cane bagasse and the added excess electricity.