Review

BRAZILIAN GREENHOUSE GAS EMISSIONS: THE IMPORTANCE OF AGRICULTURE AND LIVESTOCK

Carlos Clemente Cerri[1]; Stoecio Malta Ferreira Maia[2]; Marcelo Valadares Galdos[2]; Carlos Eduardo Pellegrino Cerri[3]*; Brigitte Josefine Feigl[1]; Martial Bernoux[4]

[1]*USP/CENA - Lab. de Biogeoquímica Ambiental, Av. Centenário, 303 - 13400-970 - Piracicaba, SP - Brasil.*
[2]*USP/ESALQ - Programa de Pós-Graduação em Solos e Nutrição de Plantas.*
[3]*USP/ESALQ - Depto. de Ciência do Solo, Av. Pádua Dias, 11 - 13418-900 - Piracicaba, SP - Brasil.*
[4]*Institut de Recherche pour le Développement - IRD, UMR Eco&Sols "Functional Ecology & Soil Biogeochemistry" (INRA-IRD-SupAgro), Bat. 12, 2 Place Viala, 34060 - Montpellier Cedex 1 - France.*
**Corresponding author <cepcerri@esalq.usp.br>*

ABSTRACT: Data from the 1990-1994 period presented in the "Brazil's Initial National Communication" document indicated that the country is one of the top world greenhouse gas (GHG) emitters. A large majority of Brazil's GHG emissions come from deforestation mainly of the Amazon biome for agriculture and livestock land uses. This unique inventory is now out of date. Thus, the aims of this review were (i) to update estimates of the GHG emissions for the Brazilian territory, (ii) to estimate the sinks to provide calculations of the GHG net emissions for the 1990-2005 period, (iii) to calculate the actual and estimate shares of agricultural and livestock activities, and (iv) to discuss in light of the new figures and patterns the best mitigation options for Brazil. Total emissions in CO_2-eq increased by 17% during the 1994-2005 period. CO_2 represented 72.3% of the total, i.e. a small decrease, in favour of non-CO_2 GHG, in relation to 1994 when its share was 74.1%. The increase of all GHG excluding Land Use Change and Forestry (LUCF) was 41.3% over the period 1994-2005. Climate Analysis Indicators Tool (CAIT) - World Resources Institute (WRI) estimated a higher increase (48.9%) that classified Brazil at the 69th position. Using our estimates Brazil will fall to the 78th position. But in both cases Brazil increased in clearly lower values than the tendency calculated for China and India, two major emitters, with increases of 88.8% and 62.1%, respectively. Brazil's increase is less than those presented for some countries in Annex 1 that are submitted to a quota of reduction, e.g. Spain with 55.6% of increase and New Zealand with 45.8%. Brazil also is below the average increase shown by non-Annex I countries, estimated to be 61.3%, but above the world average (28.1%). Besides the effort to curb emissions from the energy and deforestation sectors, it is now a top priority to implement a national program to promote mitigation efforts concerning the agricultural and livestock sectors. These mitigation options should not be only focused on emission reductions, but also prone enhancement of the carbon sink. Such a program would be easy to be implemented, because several mitigation strategies have already proven to be efficient, simple to adopt and economically viable.
Key words: CO_2-equivalent (CO_2-eq), soil, inventory, land use change and forestry

EMISSÕES DE GASES DO EFEITO ESTUFA DO BRASIL: IMPORTÂNCIA DA AGRICULTURA E PASTAGEM

RESUMO: Os resultados referentes ao período de 1990-1994 apresentados na Comunicação Nacional brasileira indicam que o país é um dos maiores emissores de gases do efeito estufa (GEE) do mundo. O documento também estabelece que a maior parte da emissão de GEE advém do desmatamento, principalmente do bioma Amazônia, para dar lugar á agricultura e pecuária. Este único inventário está agora ultrapassado. Os objetivos desta revisão foram: (i) atualizar a estimativa da emissão de GEE para o território brasileiro; (ii) estimar a possível fixação de C que permita calcular a emissão líquida de GEE para o período de 1990-2005; (iii) calcular a contribuição efetiva e compartilhada das atividades agrícolas e pecuárias; e (iv) discutir sob a luz dos novos conhecimentos as melhores opções de mitigação para o Brasil. A emissão total de GEE em equivalente em CO_2 aumentou em 17% durante o período de 1994-2005. O CO_2 foi responsável por 72,3% do total, ou seja, houve uma pequena diminuição em relação aos outros GEE, uma vez que em 1994 sua participação foi de 74,1%. O aumento de todas as fontes dos GEE, excluída mudança do uso da terra e reflorestamento, foi de 41,3% durante o período

de 1994-2005. Climate Analysis Indicators Tool (CAIT) - World Resources Institute (WRI) estimaram um crescimento maior (48,9%), que classifica o Brasil na 69ª posição no ranking mundial de emissores. Utilizando as estimativas deste estudo, o Brasil ocuparia a 78ª posição. Em ambos os casos, porém, o Brasil claramente aumentou suas emissões num ritmo menor do que os que foram calculados para a China e Índia, dois dos maiores emissores, com aumentos de respectivamente 88,8 e 62,1%. O Brasil reduziu suas emissões em taxa maior do que alguns países do Anexo I, sujeitos a uma quota de redução. É o caso da Espanha e a Nova Zelândia que aumentaram em 55,6% e 45,8% suas emissões. O Brasil também está abaixo da média de aumento apresentado pelos países que não são do Anexo I, o qual foi estimado em 61,3%. No entanto, está acima da média global que foi de 28,1%. Além de trabalhar pela redução das emissões dos setores de energia e desmatamento, o Brasil deve agora ter como meta prioritária a implantação de um programa nacional de incentivo ás mitigações nos setores agrícola e pecuário. Tais opções de mitigação não deverão se concentrar somente na redução das emissões, mas também favorecer a fixação de carbono. Tal programa seria de fácil implementação, pois diversas estratégias de mitigação já provaram ser eficientes, fáceis de adotar e economicamente viáveis.
Palavras-chave: equivalente em CO_2 (CO_2-eq), solo, inventário, mudança do uso da terra e reflorestamento

INTRODUCTION

The Land Use, Land-Use Change and Forestry (LULUCF) is a key sector of Climate Change, being at the same time responsible for an important amount of greenhouse gases (GHGs) released but also representing an important role and potential in climate change mitigation (Cerri et al., 2004). The agricultural sector alone (i.e. Land Use) is responsible for about 14% of the total global anthropogenic GHGs emissions and is expected to have high emission growth rates, driven mainly by population and income increases. Deforestation is responsible for an additional 17%, setting the total contribution of the LULUCF sector to nearly one third of the current total global emissions (IPCC, 2007).

Brazil is one of the top world greenhouse gas (GHG) emitters, and a large majority of Brazil's GHG emissions, which contribute to global warming, comes from burning linked to deforestation of the Amazon biome, and not from fossil fuels which are the main culprit in most countries (Cerri et al., 2007). Brazil suffered and still regularly suffers pressure to curb destruction of the Amazon rainforest. The latest official Brazilian data on GHG emissions and sinks were published in 2004 in the report entitled "Brazil's Initial National Communication to the United Nation Framework Convention on Climate Change" (Brazil, 2004). The second part of this report included the first GHG inventory but comprehended only the period from 1990 to 1994. This report showed that the sub-sector "Forest conversion" (known as the Land-Use Change and Forestry LUCF sector) from the bulk LULUCF Sector was the main contributor in 1994, representing 55% of the total GHG sources, which totalised 1728 Mt CO_2-eq (CO_2 equivalent), and nearly 82% of the sole emissions of CO_2. This last percentage is reduced to 75% when considering the net result, which includes a CO_2 sink of 251 Mt.

The agricultural sector is now facing a crossroad of issues linked to food security, rural livelihoods, environmental sustainability, bio-energy, climate change adaptation and mitigation, in a context of important and difficult negotiations for a future regime for LULUCF under the United Nation Framework Convention on Climate Change in a post-2012 international agreement.

According to the Climate Analysis Indicators Tool (CAIT) from the World Resources Institute (WRI, 2009), Brazil ranked 69th for the year 2009 with total GHG emissions of 1005 Mt CO_2-eq, including CH_4 and N_2O emissions, but excluding LUCF (deforestation). No recent data are provided for the LULUCF sector in Brazil. In the last ten years LULUCF activities in Brazil underwent important changes, therefore in this new context where the agricultural sector is more than ever central in the international agenda of negotiations, it is important to identify the actual share of GHG emissions and potential sinks.

The main focus of the majority of the National Inventories is on GHG emissions. However, in Brazil we do include sinks in our net GHG emissions. The sinks are mainly due to carbon fixation in soils and phytomass resulting from advanced agricultural management practices, reforestation and land abandonment.

Thus, the objectives of this review are (i) to update estimates of the GHG emissions for the Brazilian territory, (ii) to estimate the sinks to provide calculations of the GHG net emissions for the 1990-2005 period, (iii) to calculate the actual and estimated share of agriculture and livestock activities, and (iv) to discuss the best mitigation options for Brazil in light of the new figures and patterns.

Brazil's Initial National Communication

Data for 1990-1994 period, i.e. the period covered by the "Brazil's Initial National Communication" (BINC) document, were calculated following, in broad lines, the format and the IPCC methodologies of the National Communications. In most cases the methodology employed followed the approach proposed by the Revised 1996 Guidelines for National Greenhouse Gas inventories (IPCC, 1997).

The estimates were made separately for the five main sectors (Energy, Industry, Agriculture and Livestock, LUCF and Waste treatment) by specialists of each area that produced background reports (all the reports are available at http://www.mct.gov.br/index.php/content/view/20233.html). In total 15 reports were elaborated, of which five were related to the Agriculture and Livestock sector and four additional the LUCF sectors. Each report provides in detail the data used, and the steps followed in the calculation, thus enabling the possibility to update the results with the same methodology. Both the methodology and results were submitted to a peer-review process and in most cases they were published in scientific journals. For instance the report that covered the emissions and removals of CO_2 by soils from land use change and liming were published in three articles (Bernoux et al., 2001, 2002 and 2003) and as a background report entitled "Emissions and removals of carbon dioxide by soils from land use change and liming", part of the Brazil's Initial National Communication (Cerri et al., 2002).

Calculation procedures for recent and forecasted GHG emission

Actual and recent data and forecast values (from 2005 to 2020) were obtained from two main internationally recognized sources:

- Climate Analysis Indicators Tool (CAIT) from the World Resources Institute (WRI, 2009), available on line at http://cait.wri.org.

- Emission Databases for Global Atmospheric Research (EDGAR) from the Netherlands Environmental Assessment Agency (http://www.mnp.nl/edgar/model/).

Specifically for Brazil, data of the CAIT from WRI were derived from individual sectors. For the CO_2 emission, fossil fuel emissions for the period 1971-2005 were obtained from IEA (2007). The emissions from cement manufacture and gas flaring were included for the year 1980 and subsequent years. CO_2 emissions for the period 1950-2000 were calculated from Houghton (2003). Finally CH_4 and N_2O emissions each five years for the period 1990-2005 were estimated using EPA (2006).

Concerning the EDGAR database, two principal databases were used. Data for the years 1990 and 1995 where derived from the EDGAR 3.2 database (Olivier et al., 2002) that provides global annual emissions per country of Kyoto Protocol greenhouse gases CO_2, CH_4, N_2O, and F-gases (HFCs, PFCs and SF_6). Data for the year 2000 were obtained from the EDGAR 3.2 Fast Track 2000 dataset that incorporated updated values from EDGAR 3.2. Most data in EDGAR derived from IEA, FAO and UN databases.

Emissions for the LULUCF sectors were calculated and updated for the years 2000 and 2005 using the same methodologies described in the background reports of the BINC. Details of the methodologies are provided in each report, but they are all based on steps proposed by the Revised 1996 Guidelines for National Greenhouse Gas inventories (IPCC, 1997). The estimates of GHG emissions associated with the LULUCF sector were updated for the 2000-2005 period according to data availability. The LULUCF sector was subdivided into the following two broad sub-sectors: Land-use change and Forestry, and Agriculture. The former represented the GHG emissions and removals due to deforestation of the native vegetation, changes in forest and other woody biomass stocks, abandonment of managed areas, and from soils. The agriculture sub-sector represented the emissions of GHG from the enteric fermentation, manure management, rice cultivation, field burning of agricultural residues, and agricultural soils. Agricultural soils include the emissions produced by the use of synthetic N fertilizers; organic N applied as fertilizer (e.g., animal manure, compost, sewage sludge, rendering waste); urine and dung deposited on pasture, range and paddock by grazing animals; crop residues, including from N-fixing crops. The GHG emissions from the agriculture sub-sector were estimated based on the procedures and parameters adopted in the Brazil's Initial National Communication.

GHG emissions estimates associated with the Forest sub-sector for the 1990-1994 period were derived from the use of remote sensing, which covered for this period the land cover situation in the main Brazilian biomes (Amazônia, Cerrado, Mata Atlântica, Caatinga, and Pantanal). However, only the Amazônia and Mata Atlântica biomes have a regular and consistent land cover monitoring system (remote sensing), that allows estimating the annual deforestation rates. In the case of Amazônia, monitoring has been conducted by the National Institute for Space Research (INPE), while that for Mata Atlântica it has been conducted by "SOS Mata Atlântica" in association with INPE through the Atlantic Forest Remaining Atlas. Thus, for these two biomes, the GHG emissions during the 2000-2005 time period were estimated using a direct ratio between the emission and deforested area in 1990-1994. For example, during the period of 1990-1994 there was an annual gross emission of 43.3 Tg CO_2 from a deforested area of 65714 ha of Mata Atlântica, so, we extrapolated this ratio for the period of 2000-2005, and the same idea was used for the Amazônia data.

For the other biomes (Cerrado, Caatinga and Pantanal) it was necessary to use specific assumptions to calculate the GHG emissions for 2000-2005. First, for the Cerrado biome we assumed an annual deforestation rate of 0.67% provided by an International Conservancy report (Machado et al., 2004), which was obtained from remote sensing information as well as literature review. The deforested area in the Caatinga was estimated based on the average agricultural expansion (cropland and pasture) during the period of 1996-2006 (IBGE, 2008) in the Brazilian states located in this biome. In the case of the Pantanal biome, owing to the lack of updated information about the rates of deforestation, we used the same rate as for the 1990-1994 period.

The CO_2 emissions from soils were estimated according to the approach proposed by the Revised 1996 Guidelines for National Greenhouse Gas Inventories (IPCC, 1997) and adapted by Bernoux et al. (2001). The estimate was based on the variations in soil C stocks due to the land-use changes for the time period of 1985-2005, assuming a linear change in C storage. The 20-year period, the soil depth (0-30 cm) and the units of measurement (Mha for land areas and Mg C ha^{-1} for soil C) suggested by the IPCC were used in the present study. The calculation was performed by state and more details about the parameters adopted and procedures can be found in Bernoux et al. (2001). CO_2 emissions due to the organic soils cultivation were also included, using the same methodology used in the Brazil's Initial National Communication, assuming as organic soils the lowlands cultivated with rice, and adopting the IPCC emission factors (IPCC, 1997).

All results are expressed in CO_2 equivalent (CO_2-eq) using the official global warming potential (GWP) considered for the 1st commitment period, i.e. 21 for methane and 310 for nitrous oxide. The latest IPCC assessment report provided revised values (25 for CH_4 and 298 for N_2O).

Official (1994 baseline) greenhouse gas emission results and comments

The Brazilian National Communication reported that, in 1994, net anthropogenic greenhouse emissions were estimated at 1030 Tg CO_2, 13.2 Tg CH_4, and 0.55 Tg N_2O. Other minor GHG emissions (CF_4, C_2F_6, SF_6, HFC-23 and HFC-134a) were also reported but these emissions corresponded to less than 0.7% of the total emissions in CO_2-eq, and thus will not be considered throughout this review. Between 1990 and 1994, total emissions of CO_2, CH_4 and N_2O increased by 5%, 6% and 12%, respectively. This net amount included a sink (only concerning CO_2 emission) of 251 Mt CO_2 mainly due to Abandonment of Managed Lands (204 Mt CO_2-eq) and secondarily to Changes in Forest and Other Woody Biomass Stocks (47 Mt CO_2). Considering only sources, CO_2 emissions amounted to a total of 1280.8 Mt CO_2, and the corresponding total for all GHG is 1728 Mt CO_2-eq. Figure 1 details reparation by sectors.

In 1994, CO_2 was responsible for 74% of the total amount in CO_2-eq, followed by CH_4 representing an additional 16%. Nitrous oxide emissions were the less important among these three gases representing circa 10% of the total. An analysis of the main contributors (Table 1) revealed that, as it was already largely reported and discussed by the civil society and scientists, deforestation of Forest was the first individual contributor, being alone responsible for more than half of the total Brazilian GHG emissions. There were only four contributors higher than 100 Mt CO_2-eq (Table 1), and they represented about 90% of the total and covered the three main GHG. However, if sinks due to reforestation and land abandonment are also considered in the calculations, the net emissions for Forest and Grassland Conversion would be 742.4 Mt CO_2-eq, which corresponds to 48.8% of the total emissions. In this case, the relative contribution of Fossil Fuel Combustion, Enteric Fermentation and Agricultural Soil would be 15.8%, 13% and 9.8%, respectively, evidencing the present tendency to reduce the emission from deforestation in relation to the other sectors.

A detailed analysis of each main contributor showed that there was an unequal distribution of the origin of the emissions within each sub-sector. Concerning the Fossil Fuel Combustion, the Transportation sub-sector alone led the rank with 39.3%, followed

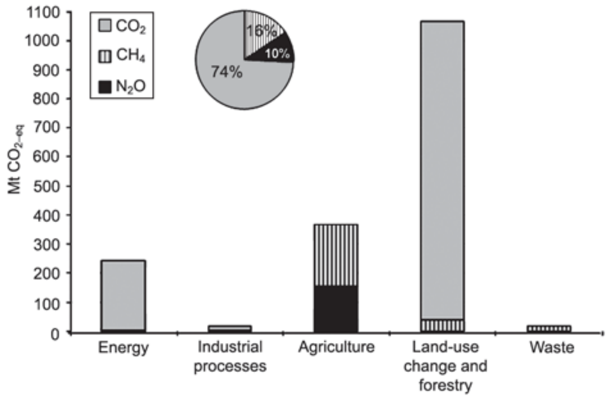

Figure 1 - Sources of GHG for the year 1994 according to the 1st Brazilian National Communication.

Table 1 - Top sub-sector emission contributors for the year 1994.

Subsector	Sector	Greenhouse Gas Emission		
		Main GHG Associated	Mt CO_2-eq	% of total
Forest and Grassland Conversion	LUCF	CO_2	993.5	56.3
Fossil Fuel Combustion	Energy	CO_2	240.4	13.6
Enteric Fermentation	Agriculture	CH_4	196.9	11.3
Agricultural Soils	Agriculture	N_2O	147.6	8.4
Others	All sectors	-	191.3	10.4

by the Industrial sub-sector (31.3%). The Energy sub-sector represented only 12% of the Fossil Fuel Combustion.

Enteric Fermentation was the third contributor in CO_2-eq, but it is also by far the first contributor for CH_4 emission. Among the components, the non-dairy cattle is responsible for 82.2% of total enteric fermentation. Agricultural soil sub-sector gather different sources of nitrous oxide emissions, but one is dominant, namely "Grazing Animals" which corresponds to direct manure deposition on the field by animals. Grazing animals contribution is 46% of the sub-sector, of this 34% is from non-dairy cattle. Other direct N_2O emissions for the Agricultural soils sub-sectors are attributed to various individual sources, e.g. synthetic fertilizer, animal manure produced off-field, biological fixation, crop residue etc.

CO_2 recent emissions excluding Land Use Change and Forestry

WRI and EDGAR reported an increase in CO_2 emissions (excluding LUCF) for the years 2000 and 2005. WRI estimates are always lower than EDGAR values, but WRI estimates are really closer to values reported by the BINC in 1990, and in 1994/95. MCT (2008) compared results from the IEA calculation, which are used by WRI, and Brazilian calculations made under the responsibility of the Brazilian Ministry of Science using the software "bal-eec" and data from the National Energy Balance. Both results from bottom-up and top-down approaches were compared. MCT (2008) showed that differences, by both approaches, are at the maximum 1% for the period 1990-2005. WRI estimates appeared therefore more consistent with Brazilian estimates. Emissions in 2000 ranged from 328 to 367 Mt CO2-eq, i.e. increase of circa 57% in relation to 1990 levels. Only WRI reported emission for the year 2005, with an increase of 69% in relation to 1990 and a corresponding amount of 352 Mt CO_2-eq (Figure 2). Using these average percentages of increase applied to the 1990 level calculated by the BINC, the projected levels would be 346 and 372 Mt CO_2-eq for the years 2000 and 2005, respectively.

Table 2 - Available estimates for CO_2 emissions from Land Use Change and Forestry sector

Source of data	1990	1995	2000
	--------------- Mt CO_2 ---------------		
WRI	1956	1507	1372
EDGAR	456.3	359.6	759.9
BINC	993	1027.5	

WRI: World Resource Institute; EDGAR: Emission Databases for Global Atmospheric Research; BINC: Brazil's Initial National Communication

CH_4 and N_2O recent emissions for all sub-sectors

Both estimates from WRI and EDGAR for methane are very similar. The detailed calculation made by the BINC lead to results for the years 1990 and 1994 10.3% lower, compared to WRI estimates. Considering this same correction in percentage, using WRI estimates as references, the methane emissions in Brazil would have been 327.9 and 349.0 MtCO_2-eq for 2000 and 2005, respectively.

The N_2O emission values proposed by EDGAR are systematically 20-25% higher than WRI estimates. In order to maintain consistency with the preceding estimates, WRI estimates were used as references. BINC values for 1990 and 1994 are about 14.6% lower than WRI numbers. Using this correction leads to estimates for N_2O emissions of 199.9 and 219.0 Mt CO_2-eq for the years 2000 and 2005, respectively (Figure 2). Total estimates for bulk emissions of CO_2 excluding LUCF, N_2O and CH_4 are therefore 873.8 and 940.0 Mt CO_2-eq for the years 2000 and 2005.

CO_2 recent emissions exclusively from Land Use Change and Forestry

CO_2 from LUCF are completely different between WRI, EDGAR and BINC (Table 2). BINC calculated intermediary values between WRI and EDGAR (Table 2). Moreover, there is also no consistency in the trends, WRI showed a regular decrease whereas there is a sharp increase in 2000 for EDGAR. Also the methodologies used are not detailed, mainly for EDGAR. Thus, no global values can be estimated for this sector using the same preceding approach. Main estimates could be obtained by using updated calculations based on the BINC approach

Updated CO_2, N_2O and CH_4 emission values for Land Use Change Forestry sector

Results obtained performing updates of the calculation used in the BINC, for each greenhouse gas, are presented in detail by sectors and sub-sectors in Tables 3 and 4. Table 3 presented values from 1990 to 2005 for the CO_2 emissions for LUCF. For 2000 and 2005 only the total results of the sink are estimated without distinction of the origin. Results of CO_2 emissions from the Land Use Change and Forestry sector (Table 3), including more specifically the emissions from soils and forest and grassland conversion also include the sink from changes in forest and other woody biomass stocks and abandonment of managed lands. Considering the gross emission, it was observed that forest and grassland conversion was responsible for 93.7% and 94% of the CO_2 emitted in 2000 and 2005, respectively, while the emissions from soils represented only 6.3% and 6%, respectively. In terms of net emission (i.e. excluding the CO_2 removed) our study found that there was a net emission of 846,417 Mt CO_2 and 861,019 Mt CO_2 in 2000 and 2005, respectively. The data also showed a reduction in the amount of absorbed CO_2 (sinks) in 2000 and 2005, mainly when compared with the year 1994. This was essentially due to the substantial decreased in the sink from the Mata Atlântica biome (data not shown).

N_2O and CH_4 emissions expressed in CO_2-eq for Agriculture and LUCF sectors (Table 4), show that the Agriculture sector increased in 21% and 24% the emissions of CH_4 and N_2O for the years 2000 and 2005, respectively. For CH_4, the main contributor for this increase was the sub-sector Enteric fermentation, which was responsible for more than 93% of the CH_4 released in both years. Therefore, it represents the most important source of CH_4 to the atmosphere.

In terms of N_2O emissions, the sub-sector Agricultural soils represented more than 95% of N_2O emissions for the years 2000 and 2005 (Table 4). The Agricultural soils sub-sector includes direct N_2O emission sources such as grazing animals, synthetic fertilizer,

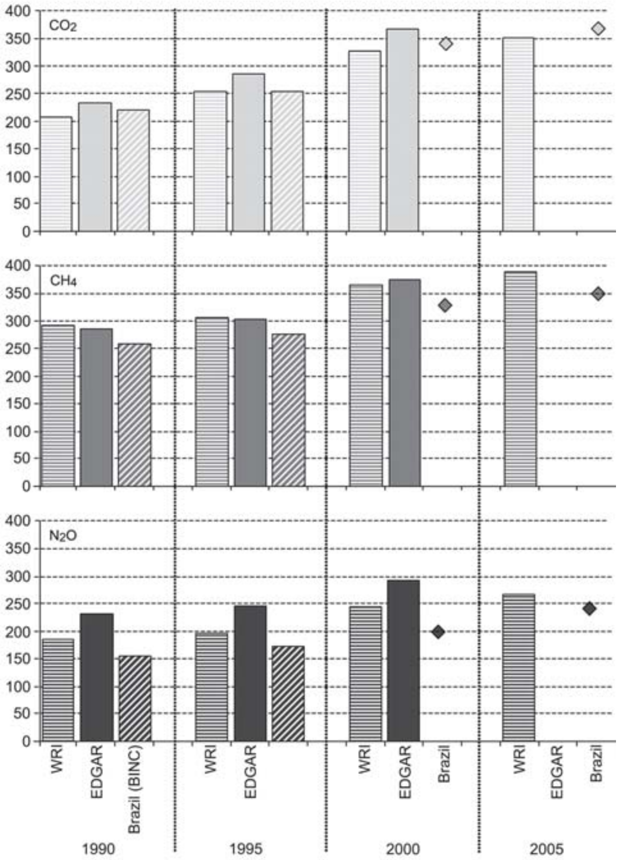

Figure 2 - Bulk estimates for emissions of CO_2 excluding Land Use Change and Forestry, CH_4 and N_2O by WRI and EDGAR, compared with Brazilian estimates from BINC (dashed bars) and estimates obtained in this study (diamonds).

Table 3 - Sources, sinks and net emissions of CO_2 in the Land Use Change and Forestry sector in 1990-2005.

Land use change and forestry	1990	1994	2000	2005
	---------- Mt CO_2 ----------			
Sources				
Forest and Grassland Conversion	882,477	951,873	1003,541	1026,067
Emissions and Removals from Soils	110,233	75,613	67,912	65,146
Total	992,710	1027,486	1071,453	1091,213
Sinks				
Changes in Forest and Other Woody Biomass Stocks	-45,051	-46,885		
Abandonment of Managed Lands	-189,378	-204,270		
Total	-234,429	-251,155	-225,036	-230,194
Net CO_2 emission (sources-sinks)	758,281	776,331	846,417	861,019

Negative values indicate the removal from the atmosphere to the biosphere.

animal manure produced off-field, biological fixation, crop residue etc, and also indirect N_2O emission sources that include leaching, runoff, and atmospheric deposition. However, grazing animals is still the main contributor, accounting for about 40% of the sub-sector, similarly of what occurred in the 1990-1994 period. The CH_4 and N_2O emissions from the Land Use Change and Forestry sector were also estimated. Changes between 2000 and 2005 were minimal (Table 4). One possible explanation is that deforestation rates for both years were similar, leading to CH_4 and N_2O emissions of the same magnitude.

Table 5 presents the total emission in CO_2-eq and the evolution for the periods 2005-1990 and 2005-1994 for the Agriculture and Land Use Change and Forestry sectors. Within the Agriculture sector, the enteric fer-

Table 4 - Emissions of N_2O and CH_4 for the Agriculture and Land Use Change and Forestry sectors for the 1990-2005 period.

Sector	Greenhouse Gas Emission							
	CH_4				N_2O			
	1990	1994	2000	2005	1990	1994	2000	2005
	Mt CO_2-eq							
Agriculture								
Enteric Fermentation	184,947	196,917	204,759	248,399				
Manure Management	7,098	7,728	7,265	8,854	5,890	6,200	5,955	7,257
Rice Cultivation	5,040	5,943	5,017	5,445				
Field Burning of Agricultural Residues	2,541	2,793	2,253	2,585	1,860	2,170	1,733	1,988
Agricultural Soils					132,060	147,560	155,400	192,908
Total	199,626	213,381	219,294	265,283	139,810	155,930	163,088	202,154
Land-Use Change and Forestry								
Total	33,915	37,905	43,948	43,818	3,410	3,720	4,364	4,351

Table 5 - Emissions from Agriculture and Land Use Change and Forestry, sinks from Land Use Change and Forestry expressed in CO_2 equivalent for the period 1990-2005.

Sector	Year				Emission Change	
	1990	1994	2000	2005	2005-1990	2005-1994
	Mt CO_2-eq					
Sources						
Agriculture						
Enteric Fermentation	184.9	196.9	204.8	248.4	34.3	26.1
Manure Management	13.0	13.9	13.2	16.1	24.0	15.7
Rice Cultivation	5.0	5.9	5.0	5.4	8.0	-8.4
Field Burning of Agricultural Residues	4.4	5.0	4.0	4.6	4.5	-7.9
Agricultural Soils	132.1	147.6	155.4	192.9	46.1	30.7
Total	339.4	369.3	382.4	467.4	37.7	26.6
Land Use Change and Forestry						
Forest and Grassland Conversion	919.8	993.5	1051.8	1074.2	16.7	8.1
Emissions and Removals from Soils	110.2	75.6	67.9	65.1	-40.9	-13.8
Total	1030.0	1069.1	1119.7	1139.3	10.6	6.5
Sinks						
Land Use Change and Forestry						
Changes in Forest and Other Woody Biomass Stocks	-45.1	-46.9				
Abandonment of Managed Lands	-189.4	-204.3				
Total	-234.4	-251.2	-225.0	-230.2	-1.8	-8.3
NET EMISSION (Sources-Sinks)	795.6	818.0	894.7	909.1	14.2	11.1

Negative values indicate the removal from the atmosphere to the biosphere.

mentation and agricultural soils were the most important CO_2-eq sources. They were responsible on average for 53.3% and 41%, respectively, of the total emission, while the other sources accounted for the rest of 5.7% (i.e. these values represent the average for 2000 and 2005). Additionally, the emission in the 1990-2005 period was higher than in 1994-2005. These results are associated exclusively with the increase in the livestock population, which was higher between 1990 and 2005 than 1994 and 2005.

For the Land Use Change and Forestry sector, the most important source was the sub-sector Forest and Grassland conversion as mentioned before. The emissions from soils contributed only with 6% to the gross emissions, and moreover, decreased substantially over time, mainly when evaluated for the period 1990-2005 (Table 5). This could be expected if we take into account that carbon emissions from soils are estimated considering the land use change in a period of 20 years (IPCC, 1997), and that the advance of the Brazilian agricultural frontier was more intense during the 90s.

Comparing the emission changes rates between the gross and net emissions in the LUCF sector (Table 5), we found higher rates in the net emission estimates, which are due to the differences between the sinks, when a reduction occured in the years of 2000 and 2005 comparatively to 1994 and 1990. However, the sink estimates were roughly performed, and future studies must be conducted aiming at improving these estimates.

Updated GHG inventory for Brazil

A tentative proposal is presented in Table 6 for the Brazilian main greenhouse gas (CO_2, CH_4 and N_2O)

Table 6 - Greenhouse gas emissions related to Energy, Industrial Processes, Agriculture, Land Use Change and Forestry and Waste for the 1990-2005 period.

Sector	Greenhouse Gas											
	CO_2				CH_4				N_2O			
	1990	1994	2000	2005	1990	1994	2000	2005	1990	1994	2000	2005
	Mt CO_2-eq											
Energy												
Fossil Fuel Combustion	198.0	231.4	316.2	336.6	7.0	6.2	5.6	7.4	2.5	2.8	3.0	3.0
Fugitive Emissions	5.4	5.1	5.0	5.0	2.2	2.3	2.3	2.3				
Total	203.4	236.5	321.2	341.6	9.2	8.4	7.9	9.7	2.5	2.8	3.0	3.0
Industrial Processes												
Cement Production	10.2	9.3	19.0	14.2								
Other	6.7	7.5	9.0	14.6								
Total	16.9	16.9	28.1	28.9	0.1	0.1	0.1	0.1	2.5	4.3	6.0	8.0
Agriculture												
Enteric Fermentation					184.9	196.9	204.8	248.4				
Manure Management					7.1	7.7	7.3	8.9	5.9	6.2	6.0	7.3
Rice Cultivation					5.0	5.9	5.0	5.4				
Field Burning of Agricultural Residues					2.5	2.8	2.3	2.6	1.9	2.2	1.7	2.0
Agricultural Soils									132.1	147.6	155.4	192.9
Total					199.6	213.4	219.3	265.3	139.8	155.9	163.1	202.2
Land Use Change and Forestry												
Forest and Grassland Conversion	882.5	951.9	1003.5	1026.1								
Emissions and Removals from Soils	110.2	75.6	67.9	65.1								
Total	992.7	1027.5	1071.4	1091.2	33.9	37.9	43.9	43.8	3.4	3.7	4.4	4.4
Waste												
Total					15.5	16.9	18.9	20.7	3.7	3.7	3.7	3.7
TOTAL	1213.0	1280.9	1420.7	1461.7	258.3	276.6	290.2	339.5	151.9	170.5	180.2	221.2

Global Warming Potential for CH_4 and N_2O were 21 and 310, respectively.

emissions for the 2005-1990 period based on the above results for LUCF, amended with sectors estimated for the other categories (Energy, Industrial Processes and Waste). The most crucial sector to be estimated is the Energy because of the importance of its share. Our estimate is based on the results calculated for the national carbon balance in the energy sector (MCT, 2007). The authors calculated the emission from fossil fuel combustion using both bottom-up and top-down approaches for the 1970-2005 period, and also compared their results to BINC values. They concluded that their results systematically underestimate the values from the BINC in 5%. Therefore, in our calculations, the estimates for the Energy sector for CO_2 and CH_4 derived from their proposed values for the year 2000 and 2005 were corrected by this coefficient (5%). For the other emissions of the Energy sector (Fugitive emissions, and N_2O emissions from fossil fuel combustion) a conservative approach was used considering the level unchanged in relation to 1994.

Cement production is the main contributor of the Industrial Processes. Emissions from this sub-sector were calculated according to the energy inputs in the processes (reported by MCT, 2007). The total emissions for the Industrial Processes were estimated in the same manner, and emissions from Other Activities were calculated by difference. N_2O and CH_4 emissions from Cement production were calculated using a linear trend. This last approach was also used in the case of the Waste sector.

Table 6 does not include the CO_2 fixation by the phytomass from reforestation and abandoned lands. If these sinks are accounted in the calculations, the net emissions for the Land Use Change and Forestry decreases by about 26%, from 1189.5 to 936.7 Mt CO_2. Then, the total net emission for 2005, adjusted considering the mentioned removals, would be 1231.5 against 1461.7 Mt CO_2, which is about 19% lower in relation to only the emission scenario.

Discussion on recent emission trends

Global emissions in CO_2-eq increased by 17% during the 1994-2005 period. CO_2 represented 72.3% of the total, i.e. a small decrease, in favour of non-CO_2 GHG, in relation to 1994 when its share was 74.1%. The increase of all GHG excluding LUCF was 41.3% over the period 1994-2005. CAIT-WRI estimated a higher increase (48.9%) that classified Brazil at the 69th position. Using our estimates Brazil will fall to the 78th position. But in both cases Brazil increased in clearly lower values than the tendency calculated for China and India, two major emitters, with increases of 88.8%and 62.1%, respectively. Brazil's increase is lower than those for some Annex 1 countries that are submitted to a quota of reduction, e.g. Spain with 55.6% of increase and New Zealand with 45.8%. Brazil also is below the average increase shown by non-Annex I countries, estimated to be 61.3%, but above the world average (28.1%). Results in Table 7 can be also compared to bulk estimates, For the year 2000 the difference between the two approaches is 54.1 Mt CO2-eq for 2000, but only 8.7 Mt CO2-eq for the year 2005. The share of the top four increased from 89.6% in 1994 to 90% in 2005 (Table 8).

More recently these trends should certainly at least be maintained, or even accentuated, as it is the case for deforestation for which recent trends showed that annual deforestation in the Brazilian Amazon fell below 10,000 square kilometres for the first time since record-keeping began, reported Brazil's Environment Minister Carlos Minc on June 2009. Minc said preliminary data from the country's satellite-based deforestation detection system (DETER) showed that Amazon forest loss between August 2008 and July 2009 would be below 10,000 square kilometres, the lowest level in more than 20 years. Official figures are due in August or September 2009.

Greenhouse gas mitigation options

Choosing a set of practices to mitigate greenhouse gases is one of the great challenges that Brazil faces in the coming years. The search for feasible options will require balancing cost-effectiveness and other objectives. Several mitig**ation** strategies in Brazilian agriculture and livestock have been identified as potential alternatives.

Conventional versus no-tillage system in agriculture

No-tillage can be defined as a crop production system where soil is left undisturbed from harvest to planting except for fertilizer application. No-tillage practices, cause less soil disturbance, often resulting in significant accumulation of soil C (Sá et al., 2001; Schuman et al., 2002) and consequent reduction of gas emissions, especially CO_2, to the atmosphere (Lal, 1998; Paustian et al., 2000) as compared to conventional tillage. There is a lot of controversy regarding whether no-till really does sequester much soil C, especially when the whole soil profile is considered (Smith et al., 1998; Six et al., 2002). The quantity of residues returned, variations in the practices implemented and perhaps the type of climate are factors likely to influence the outcome. According to Smith et al. (1998) only certain fixed amounts of soil C can be gained, up to a new equilibrium limit, which is reversible if management reverts to conventional tillage.

The total area in Brazil under no-tillage system is about 20 million ha, and the weighted average soil C accumulation rate due to no-tillage adoption is 0.5 t C

Table 7 - Greenhouse gas emissions for the 1990-2005 period for the Energy, Industrial Processes, Agriculture, Land Use Change and Forestry and Waste sectors.

Sector	1990	1994	2000	2005	2005-1994
	Mt CO_2-eq				%
Energy					
Fossil Fuel Combustion	207.4	240.4	324.9	347.0	44.4
Fugitive Emissions	7.6	7.4	7.3	7.3	-0.5
Total	215.1	247.7	332.2	354.3	43.0
Industrial Processes					
Cement Production	10.2	9.3	19.0	14.2	52.5
Other	6.7	7.5	9.0	14.6	94.2
Total	19.5	21.3	34.1	36.9	73.6
Agriculture					
Enteric Fermentation	184.9	196.9	204.8	248.4	26.1
Manure Management	13.0	13.9	13.2	16.1	15.7
Rice Cultivation	5.0	5.9	5.0	5.4	-8.4
Field Burning of Agricultural Residues	4.4	5.0	4.0	4.6	-7.9
Agricultural Soils	132.1	147.6	155.4	192.9	30.7
Total	339.4	369.3	382.4	467.4	26.6
Land Use Change and Forestry					
Forest and Grassland Conversion	919.8	993.5	1051.8	1074.2	8.1
Emissions and Removals from Soils	110.2	75.6	67.9	65.1	-13.8
Total	1030.0	1069.1	1119.7	1139.3	6.5
Waste					
Total	19.2	20.6	22.7	24.4	18.5
TOTAL	1623.2	1728.0	1891.1	2022.3	17.0

Table 8 - Top emission sector contributors in 2005 (90%) and trends compared to 1994.

Sub-sector	Sector	Greenhouse Gas Emissions		
		Mt CO_2-eq	% of the total	Variation 2005-1994
Forest and Grassland Conversion	LUCF	1074.2	51.9	+ 8.1
Fossil Fuel Combustion	Energy	347.0	16.8	+ 44.4
Enteric Fermentation	Agriculture	248.4	12.0	+ 26.1
Agricultural Soils	Agriculture	192.9	9.3	+ 30.7
Others	All sectors	208.1	10.0	+ 8.8

ha^{-1} yr^{-1} in the first 10 cm layer, giving an estimated change in total soil C of about 10 Mt yr^{-1}. In addition we should include a C offset due to a significant reduction in fuel consumption (60 to 70%) compared to the conventional tillage system (EMBRAPA, 2006).

Sugar-cane agrosystem

The net contribution of the Brazilian sugar cane industry to the evolution of atmospheric CO_2 is a combination of three activities, two industrial and one agricultural.

The first activity is the substitution of gasoline by alcohol as a fuel. Since the early 1930's the Brazilian government has given incentives for alcohol production from sugar cane to be added to gasoline in the transportation sector (Sociedade Nacional de Agricultura, 2002). Due to oil crises in 1973-74, Brazilian authorities created new incentives through the Brazilian alcohol program (Proalcool) to increase the production of alcohol to 10.7 billion litres per year (Coelho et al., 2000). During 1975 to 2000, 156 million m^3 of hydrated alcohol and 71 million m^3 of anhydrous alcohol were produced. Considering that 1 m^3 of gasoline is substituted for 1.04 m^3 anhydrous alcohol and 0.8 m^3 hydrated alcohol and that gasoline contains on average 86.5% C (American Petroleum Institute, 1988) we calculate that during the 1975-2000 period, 172 Mt C were offset and consequently not emitted to the atmosphere, which gives an average annual offset of 6.8 Mt C. However, the alcohol production and consumption are increasing every year in Brazil. If data just for the last 10 years were used, the offset would be about 10 Mt C yr^{-1}.

The second associated mitigation factor in the sugar cane system is related to the use of plant residues as a fuel. At the mill, the cane stalks are shredded and crushed to extract the cane juice while the fibrous outer residue, known as bagasse, is burnt to provide steam and electricity for the mill (Luca, 2002). For instance, in 1998 approximately 45 Mt dry matter of sugar cane residues were produced in Brazil (Balanço Energético Brasileiro, 1999). Assuming that 2.35 t of residues substitute for 1 t of fossil fuel (Macedo, 1997) we estimate that 8 Mt C were offset in 1998 due to use of sugar cane residues at the mill instead of fuel. This renewable energy resource, found mainly in developing countries, has obvious appeal for international efforts to reduce carbon dioxide emissions. Moreover, the organic wastewater stream from alcohol production, known as vinasse, can be used as fertilizer or can be converted to methane gas through anaerobic digestion. The transportation fleets used in sugar factories and ethanol distilleries in Brazil have in some cases been powered by methane gas (Johnson, 2000). The production of alcohol has been viewed as a valuable means of saving foreign exchange in developing countries while at the same time providing local and global environmental benefits (Oliveira et al., 2005). In addition to climate mitigation and reduction of local pollutants, it can serve as an octane enhancer that might speed the phasing-out of leaded gasoline. The economic and environmental attractiveness of sugar cane as a renewable energy resource and the variety of options for increasing use of cane by-products and co-products could one day lead to sugar becoming the by-product rather than the main product.

Finally, the third activity associated with CO_2 mitigation in the sugar cane system is the switch of the harvesting practice. Sugar cane is a perennial crop that is harvested on an annual cycle, with up to six cycles before re-planting. Traditionally, sugar cane was burnt in the field before harvesting in order to facilitate manual cutting by removing leaves and insects (Thorburn et al., 2001). However, since May 2000 this common practice has been progressively prohibited by law in some areas in Brazil. In 1997 about 20% of the Brazilian sugar cane area was harvested by machines (Silva, 1997) and it is estimated that about 80% of the planted area in the most productive sugar cane region in Brazil will use mechanical harvesting in the next 20 years (CENBIO, 2002). By the return of crop residues to the soil surface the mechanical approach has indirectly favored soil organic matter accumulation (Thorburn et al., 2001; Luca, 2002) and gas emission reduction when compared to the burning system (Andreae & Merlet, 2001). For instance, Blair et al. (1998) found significant increases in the labile C fraction in green trash treatments compared to the trash burnt treatments in the surface soils of two green trash management trials in Australia. In Southern Brazil, Feller (2001) reported that an average of 0.32 t C ha^{-1} yr^{-1} was accumulated in 12 years in the first 20 cm depth of an Oxisol due to burn omitting. Other estimates exist, but for shorter period of no-burning. For instance, Luca (2002) reported increases ranging from 2 to 3.1 and 4.8 to 7.8 t C ha^{-1} respectively for the top 5 cm and 40 cm layers during the first 4 years following no-burning. The corresponding annual increase ranges from 0.5 to 0.78 t C ha^{-1} yr^{-1} for the 0-5 cm layer and 1.2 to 1.9 t C ha^{-1} yr^{-1} for the 0-40 cm layer. However, sugar cane is typically replanted each 6-7 years and tillage practices are commonly used. This procedure would probably reduce the high rates presented by Luca (2002) if the study had been for a longer period. In our estimate of C sequestration we have used the value found by Feller (2001) because it represents the longest period of harvest without burning in Brazil and incorporates cane replanting. Thus, considering the area under this management system and the mean annual C accumulation rate, a total of 0.48 Mt C yr^{-1} is sequestered in Brazil.

When sugar cane is burnt other greenhouse gases like CH_4 and N_2O are also emitted to the atmosphere. Macedo (1998) shows that 6.5 kg CH_4 ha^{-1} are released from the burning of sugar cane. Considering the total area with sugar cane under the no burning harvesting system (1.5 Mha) and that the methane has the global warming potential of 21, we have calculated that 0.2 Mt CO_2-equivalent (0.05 Mt C) that are not emitted annually to the atmosphere due to the adoption of no burning. The same calculation is required for N_2O emission; however, currently there are no adequate measurements of this gas in sugar cane.

In summary, when sugar cane is harvested mechanically without burning in Brazil, 0.48 Mt C yr^{-1} is sequestered in the soil and a methane emission equivalent of 0.05 Mt C yr^{-1} is avoided. This total of 0.53 Mt C yr^{-1} is the contribution of the agricultural sector. Moreover, the industrial sector contributes not only the 10 Mt C yr^{-1} offset due to substitution of fossil fuel by alcohol for transportation but also the 8 Mt C yr^{-1} by substituting fossil fuel for power generation at the mill. Combining the agricultural and the industrial sectors, sugar cane produced without burning gives a total of 18.5 Mt C yr^{-1} removed from the atmosphere.

Livestock

The beef production sector's challenge is to provide scientific research based information to help producers create "low cost - high profit" cattle that yield a product desired by the consumer and manage resources in a sustainable manner while maximizing profits. Nowadays, the profit per area is more important than per animal. Ranchers are assimilating the idea of obtaining a better knowledge of agribusiness and start to correctly plan the production processes. In consequence, the traditional extensive cattle breeding is one of the activities which mostly looses competitiveness. Day by day the herds are driven towards cheaper lands to maintain a small number of animals per area. The mean occupation of pastures in Brazil is 0.9 AU per hectare, a too low number to be sustained by expensive land (IBGE, 2008). Increase the occupation rate shows up as one of the most promising directives for beef cattle production. Beside genetic improvement to increase output, enhance product quality and increase disease resistance of the livestock, pasture quality is actually the main challenge. To be considered of high quality pasture must both support a high level of intake as well as have high concentrations of energy, protein and minerals. Pasture quality is influenced by plant species and age, soil fertility, seasons (drought), among other factors.

Nowadays one of the best ways to establish a low cost, sustainable and high quality pasture in the Amazon region is to adopt the integrated crop-livestock system. In this system the pasture renovation is made by the introduction of agriculture, with benefits to both. The adoption of feedlots can be another way to increase beef production. This system is specially appropriated to overcome dry periods, when fodder is scarce. Feedlots are thus an alternative to regulate beef production during the period in which beef offer is low and demand is high. The modernization process of the Brazilian beef cattle will result in productivity gains and consequently lower GHG emissions, from both enteric fermentation and higher pasture occupation.

CONCLUDING REMARKS

In Brazil most mitigation efforts focused on the energy and LUCF, i.e. mostly on the reduction of deforestation in the Amazon. The later aspect succeeded since deforestation rates decreased. On the other hand, despite the intensification of ethanol use (increasing percentage of flex fuel cars), the energy sector showed the highest level of increase (+44%). However, the energy-related programs and measures implemented in the 90's and thereafter have provided a broad range of benefits for the Brazilian economy, and helped to lower carbon emissions in relation to was considered business as usual in the yearly 90's.

Besides effort to curb emissions from the energy and deforestation sectors, it is now a top priority to implement a national program to incentive mitigation efforts concerning the agricultural sectors (+27%). These mitigation options should not be only focused on emission reductions, but also prone enhancement of the carbon sink. Such a program would be easy to be implemented, because several mitigation strategies have already proven to be efficient, simple to be adopted and economically viable.

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