Risks Associated with Increasing the Harvest Area for the Production of Brazilian Ethanol Fuel

Cristina Mariaca[a] *and Noam Lior*[b]

[a] *The Joseph H. Lauder Institute of Management & International Studies*
University of Pennsylvania, Philadelphia, USA
[b] *Department of Mechanical Engineering and Applied Mechanics*
University of Pennsylvania, Philadelphia, USA

Abstract: This analysis aims to evaluate the environmental and economic risks associated with the Brazilian government's commitment to support tripling ethanol exports by 2014 and fostering growth in the industry. The study finds that growth in Brazilian ethanol production is very likely to result in the growth of the land area used for sugarcane harvest. We identify three significant risks that can be expected as a result, and that would be highly counter-productive to Brazil's sustainable development. First, land used for sugarcane harvest for ethanol production in the Amazon grew 5% between the 06/07 and 07/08 harvests, and continued growth could lead to a direct negative impact on the rainforest. Second, an evaluation of the growth in harvested land for Brazil's ten key food crops shows that the land used for all food crops except those used for fuel is decreasing, while the land used for fuel crops is increasing. This indicates that fuel crops may be displacing food crops, which could lead to a decrease in the food supply and increase in prices. Third, several studies have linked the change of land-use to severe environmental impacts. While the government argues that there are more than 100 million hectares of degraded pastures that are currently unused and could be utilized for sugarcane, research suggests that the change in land-use causes erosion of up to 30 tons of soil per hectare per year, a loss of soil organic carbon and high levels of GHG emissions. Based on these findings, we recommend changes in policy that focus on two objectives: 1) better management of land use, and 2) better support for other renewable sources. For the first point, a sustainability analysis is needed in order to identify the regions where sugarcane harvest area should or should not increase. Legislation should deter growth in those areas where conversion to sugarcane is not sustainable, and to minimize harmful environmental effects in the areas where land would be converted for sugarcane harvest. On the second point, policy should be centered on providing continuous incentives for diversification in the country's fuel supply, fomenting growth in more innovative methods to generate power, and partnering with other countries to continue to promote a steep learning curve in the field of biofuels.

Keywords: Ethanol; Sugarcane; Biofuels.

1. Introduction

This analysis aims to evaluate the environmental risks associated with the Brazilian government's commitment to supporting growth in ethanol supply and tripling ethanol exports by 2014. We conducted an analysis of Brazilian government data and academic research and found three environmental threats that could result from a further increase in the land area used for sugarcane harvest. First, land used for sugarcane harvest for ethanol production in the Amazon region has been growing at a rate of 5%, as evidenced by government data on the 06/07 and 07/08 harvests. Continued growth could lead to a direct negative impact on the rainforest. Second, an evaluation of the growth in harvested land for Brazil's ten key food crops shows that the land area for all food crops except those used for fuel is decreasing (Table 6), while the land area for fuel crops is increasing. This indicates that fuel crops may be displacing food crops, which could lead to a decrease in the food supply and increase in prices. Furthermore, growth in land used for sugarcane creates an indirect threat to the rainforest, since there is an incentive to use that land to raise cattle or harvest crops that would have alternatively been harvested in land used for sugarcane. Third, we present several studies that have linked the change of land-use to severe environmental impacts. While the government argues that there are more than 100 million hectares of degraded pastures that are currently unused and could be utilized for sugarcane, research suggests that land-use change causes erosion of up to 30 tons of soil per hectare per year, a significant loss of soil organic carbon and high levels of GHG emissions that last over several decades.

Based on these findings, this study concludes that current aggressive growth targets for ethanol production could be detrimental to the environment and the food supply.

2. Brazilian Ethanol Export Forecast

Brazilian President Luiz Inacio Lula da Silva has consistently promoted the country's ethanol industry since taking office in 2003, and has recently supported trade agreements with Asia and Europe to foment ethanol exports [1-2]. In 2007, Brazil's Agriculture Minister Luis Carlos Guedes Pinto announced the government's objective of raising investments of $13.4 billion to boost the country's current ethanol output and triple ethanol exports by 2014 [3]. During the first meeting between President Lula and President Obama in March 2009, their conversation turned to the topic of ethanol trade between the two countries [2]. President Obama acknowledged that the US$0.54 tariff per gallon of Brazilian ethanol levied by the US is a "source of tension" [2] between the two countries, while President Lula expressed a great interest in increasing Brazilian ethanol exports to the US as a lever for the country's and the ethanol industry's development.

Furthermore, several countries have recently expressed interest in biofuel conversion. In 2005, the EU started to require that gasoline be blended with 2% of ethanol, with the blend increasing to 5.75% by 2010 [4]. Sweden, which has been importing Brazilian ethanol for years, now offers consumers a 20% tax break in the purchase of FlexFuel cars, as well as other incentives such as parking privileges for environmentally friendly vehicles [4]. In Japan, new laws will require a 3% ethanol blend in fuels and the country has been negotiating a trade deal to boost imports of Brazilian ethanol during much of the past decade [4]. China, where E10 blends are mandated in some provinces [5-6], has also been negotiating ethanol trade with Brazil [4]. Though the country is starting to develop its own ethanol production facilities, growth is very much controlled by the government. Government subsidies maintain gas prices low, and there is a general fear of the impact on food prices that would result from high levels of production of biofuels, and thus Chinese domestic production of ethanol is still very low [7].

In the following tables, we present data collected from [8] in an effort to present the tons of sugarcane produced by the top 20 sugar markets in the world, as well as the harvested area and tons of sugarcane produced per hectare in each market. From the data in Table 1 we see that Brazil yields almost twice as much sugar as the second largest producer, or about 36% of the production by the top 20 supplying countries.

Table 1. Sugarcane Producers, 2006.

		2006 Production Quatity (tons)	2006 Area Harvested (ha)	Tons/ha
1	Brazil	457,245,516	6,144,286	74
2	India	281,171,800	4,201,100	67
3	China	100,435,041	1,215,300	83
4	Mexico	50,675,820	679,936	75
5	Thailand	47,658,097	965,333	49
6	Pakistan	44,665,500	907,300	49
7	Colombia	39,000,000	420,000	93
8	Australia	38,169,000	415,000	92
9	United States	27,033,200	367,780	74
10	Indonesia	25,200,000	350,000	72
11	Philippines	24,345,106	392,280	62
12	South Africa	20,275,430	420,000	48
13	Argentina	19,000,000	285,000	67
14	Guatemala	18,721,415	233,334	80
15	Egypt	16,000,000	135,000	119
16	Viet Nam	15,678,600	285,100	55
17	Cuba	11,060,000	397,100	28
18	Venezuela	9,322,937	123,470	76
19	Sudan	7,500,000	72,000	104
20	Myanmar	7,300,000	140,000	52

Source: Authors; data extracted from [8]

Table 2. Ethanol Producers, 2006.

Country or Area	2006 Production (1000 Metric tons)	2006 Imports (1000 Metric tons)	2006 Exports (1000 Metric tons)
United States	15,077	2,192	0
Brazil	14,229	0	2,760
Germany	870	15	4
Sweden	349	0	0
France incl. Monaco	235	0	0
Colombia	196	0	0
Canada	184	40	21
Spain	179	0	0
Poland	119	2	33
Netherlands	106	342	0
Austria	73	0	0
Cuba	58	0	0
Australia	41	0	0
Belgium	33	33	0
Hungary	19	0	0
Lithuania	10	3	4
Bulgaria	9	0	0
Paraguay	7	0	0
Latvia	5	0	3
Ireland	3	0	0

Source: Authors; data extracted from [8]

Table 2 presents the top 20 countries that produce ethanol, as well as their exports and imports. As shown, Brazil and the US are the only two countries that produce significant amounts of ethanol. Furthermore, while all of the US production is consumed domestically, the country also imports additional ethanol (from Brazil) to meet its needs. Brazil, on the other hand, is the only country that is exporting significant amounts of ethanol. As other countries that lack the resources to produce biofuels establish regulation to foment the use of ethanol, there is an incentive for Brazil to increase its ethanol exports.

Given thus that Brazil will now face a strong incentive to increase its ethanol production capacity, it is important to note that growth in supply can be achieved in two ways: use of more land to harvest more sugarcane, or increase in efficiency of production per hectare of land.

Table 3 presents historical growth rates for ethanol production in Brazil. From 1990 to 2005, the compounded annual growth rate (CAGR) in ethanol (alcohol) production was 2.2%, most of which came through the use of more land area to harvest more sugar (2.1% CAGR for harvested land versus 0.1% CAGR for productivity in terms of metric tons per hectare). As will be further presented in Section 3.1 and Table 4, between the 06/07 and 07/08 sugarcane harvests in Brazil, the increase in sugarcane harvest area was 7.4%. Even though, as shown in Table 3, there have been productivity improvements in terms of metric tons of sugarcane per hectare of harvest land, growth in ethanol supply has always been derived from an increase in the area of sugarcane harvest land.

The high interest from other countries in importing Brazilian ethanol and the Brazilian government's commitment to support high growth in supply, provide a clear incentive for Brazilian farmers and ethanol producers to maintain high production objectives. As the key industry players face high incentives to increase production, there will be pressure to continue to increase the area of land used for harvesting sugarcane for ethanol production. In Section 3 we evaluate current trends in the use of ethanol land area and attempt to quantify the three key threats associated with increasing the land area used for sugarcane harvest: 1) deforestation in the Amazon, 2) displacement of food crops, and 3) erosion of soil. Our objective is to bring awareness to these threats in an effort to encourage policy-makers to enforce legislation that will curtail growth in sugarcane land area and foster safe agriculture.

Table 3. Ethanol Productivity in Brazil, 1990-2005.

	Historical Ethanol Productivity				
	1990	2000	2005	*90-05 CAGR*	*00-05 CAGR*
Tot Area (mill ha)	845.9	845.9	845.9		
Area for Arable and Permanent Crops (mill ha)	57.4	65.2	66.6		
Ethanol Area Harvested (mill Ha)	4.3	4.8	5.8	*2.1%*	*3.7%*
% Ethanol Area Harvested / Tot Arable	*7.4%*	*7.4%*	*8.7%*		
Alcohol - production (metric tons, mill)	9.3	8.6	12.8	*2.2%*	*8.4%*
Metric Ton / Ha	2.2	1.8	2.2	*0.1%*	*4.6%*
Density ethanol (g/mL) (1)	0.8				
L / Ha	2,759.6	2,237.5	2,800.8		
Liters per year (billion)	11.8	10.8	16.3	*2.2%*	*8.4%*

Notes: CAGR refers to Compounded Annual Growth Rate; Tot refers to total; mill ha refers to millions of hectares.
Sources:
Authors, except where noted. Data extracted from [8].
(1) [10]

3. Environmental Risks

The Brazilian government's commitment to ethanol production could be met under two scenarios: 1) productivity would increase at an annual rate of 9.3% from 2005 to 2018; or 2) Brazil's sugarcane harvested land area would increase, either in unused land or in land that could otherwise be used for other crops, cattle-raising, rain forests, or reforestation. As discussed in Section 2, the underlying productivity improvement assumptions in the government's supply commitment is aggressive if compared to historical productivity improvement rates. For the supply target to be met, more harvest land would probably be needed. This section will quantify the environmental threat of expansion in the sugarcane harvested land area in an effort to raise awareness to this issue.

According to Brazil's President Lula, the Brazilian Sugarcane Association [12] and the former Minister of Agriculture Roberto Rodrigues [5-6], sugarcane expansion in Brazil is taking place in degraded pastures in the Center-South of the country and the use of this land does not displace other crops because it is land that is not currently being used. Reference [5-6] argues that, of the approximately 850 million hectares of land in Brazil, about 106 million hectares of land are not being exploited and thus concludes that sugarcane, which currently uses about 6 million hectares of land [8], still has plenty of room for growth.

As will be explained in detail in this section, data from the Brazilian government shows that there are irregularities in these arguments for three reasons:

1. The area used for growing sugarcane in the Amazon is increasing, and this will be quantified in section 3.1;
2. Sugarcane is replacing other crops and growing in territory once used for the agriculture of important food crops, as will be quantified in detail in section 3.2; and
3. There are negative environmental impacts of harvesting sugarcane, such as a deterioration of soil and water supplies and higher GHG emissions. Even if growth were to be concentrated in the unused lands referred to by [5-6], using more land for sugarcane agriculture could threaten the environment. This point will be analyzed in section 3.3.

3.1 Sugarcane in the Amazon

Folha de São Paulo, one of Brazil's largest newspapers, has reported that large ethanol conglomerates have been lobbying the government to allow them to buy large areas of land around the Pantanal, a biologically diverse area of tropical wetlands in western Brazil [9]. In the Amazon region, growth in land area used for ethanol production is already a reality. To quantify this threat, we evaluated sugarcane harvest data from the Brazilian government, part of a frequent series of surveys conducted by CONAB (National Supply Company), a public entity linked to the Ministry of Agriculture, Livestock and Supply and part of Brazil's federal government [14]. In its first survey on the 2007/2008 harvest, conducted between April 29th, 2007 and May 12th, 2007, 40 CONAB employees visited 398 businesses related to sugar production and ethanol distillation across all of Brazil, which include all of the businesses related to ethanol production in the country [14]. Each of these businesses completed a survey and provided key production metrics.

The CONAB data shows that in the 2007/2008 sugarcane harvest there were almost 21 thousand hectares of land within the Amazon basin (i.e., within the North region of Brazil) used for sugarcane agriculture, an increase of 5% compared to the 2006/2007 harvest. Furthermore, during the 2007/2008 harvest there were 271 thousand acres of land dedicated to sugarcane agriculture within the states of Maranhão and Mato Grosso, where large areas of rainforest exist, an increase of over 8% compared to the 2006/2007 harvest. The growth within these two states is larger than the national average growth of 7.4% and the growth in the state of São Paulo (+5%), where most sugarcane agriculture takes place.

Within the presented tables, we calculated the share of total land used for sugarcane agriculture within each of the selected states. While the land area used for sugarcane in the Amazon basin is still small, it is growing. It now adds up to more than 0.3% of the total harvested land in the country.

Below the Harvest Area table, we also present tables on Production (in thousands tons of sugarcane) and Productivity (kg of sugarcane per hectare). The key takeaway from this part of the analysis is that productivity levels in the North are low (56,000-70,000 kg/ha vs. national average of 77,000 kg/ha) and improving only slowly (0-2% improvement across the North vs. 3.5% average). The land used in the Amazon basin is being used inefficiently, and it could be used for better purposes such as for planting food crops to nourish the region.

Table 4. Historical trend in land allocation and ethanol production in selected states of Brazil, 1990-2007.

			Harvested area (1000 ha)				
Region	State	Abbrev.	06/07 Harvest	06/07 %/TOT.	07/08 Harvest	07/08 %/TOT.	Y/Y VAR.%
	Amazonia	AM	4.8	0.1%	5.2	0.1%	8.3%
	Pará	PA	10.5	0.2%	10.5	0.2%	0.0%
	Tocantins	TO	4.5	0.1%	5.1	0.1%	13.3%
NORTH			**19.8**	0.3%	**20.8**	0.3%	5.1%
	Maranhão	MA	40.3	0.7%	40.3	0.6%	0.0%
NORTHEAST			**1,123.4**	18.2%	**1,138.3**	17.2%	1.3%
	Mato Grosso	MT	209.7	3.4%	230.7	3.5%	10.0%
CENTRAL WEST			**604.5**	9.8%	**698.9**	10.6%	15.6%
	São Paulo	SP	3,288.2	53.4%	3,452.6	52.2%	5.0%
SOUTHEAST			**3,928.2**	63.7%	**4,164.5**	62.9%	6.0%
SOUTH			**487.3**	7.9%	**597.6**	9.0%	22.6%
BRAZIL			**6,163.2**	100.0%	**6,620.1**	100.0%	7.4%

			Production (1000 tonnes)					Productivity (kg/ha)			
Region	State	Abbrev.	06/07 Harvest	06/07 %/TOT.	07/08 Harvest	07/08 %/TOT.	Y/Y VAR.%	06/07 Harvest	07/08 Harvest	Y/Y VAR.%	% Ethanol/ TOT Sugarcane
	Amazonia	AM	273.1	0.1%	303.0	0.1%	10.9%	56,900.0	58,500.0	2.8%	45.0%
	Pará	PA	736.7	0.2%	736.7	0.1%	0.0%	70,160.0	70,160.0	0.0%	57.1%
	Tocantins	TO	252.1	0.1%	291.1	0.1%	15.5%	56,030.0	57,200.0	2.1%	100.0%
NORTH			**1,261.9**	0.3%	**1,330.8**	0.3%	5.5%	**63,732.0**	**64,073.0**	0.5%	**63.3%**
	Maranhão	MA	2,341.4	0.5%	2,341.4	0.4%	0.0%	58,100.0	58,100.0	0.0%	92.2%
NORTHEAST			**62,860.3**	13.2%	**65,011.4**	12.3%	3.4%	**55,954.0**	**57,112.0**	2.1%	**41.5%**
	Mato Grosso	MT	14,073.6	3.0%	15,642.1	3.0%	11.1%	67,100.0	67,800.0	1.0%	76.3%
CENTRAL WEST			**45,473.0**	9.6%	**53,544.2**	10.1%	17.7%	**75,219.0**	**76,610.0**	1.8%	**70.2%**
	São Paulo	SP	284,825.6	60.0%	309,010.4	58.5%	8.5%	86,620.0	89,500.0	3.3%	57.7%
SOUTHEAST			**329,204.2**	69.3%	**360,948.2**	68.4%	9.6%	**83,806.0**	**86,673.0**	3.4%	**57.4%**
SOUTH			**36,001.0**	7.6%	**47,142.0**	8.9%	30.9%	**73,879.0**	**78,886.0**	6.8%	**56.3%**
BRAZIL			**474,800.4**	100.0%	**527,976.6**	100.0%	11.2%	**77,038.0**	**79,754.0**	3.5%	**56.9%**

Source: Authors; 06/07 and 07/08 data extracted from [14].

Also shown in the Tables, in the bottom right column, is our calculation of the share of tons of sugarcane production that is used to supply sugar specifically to the ethanol industry. Not all growth in the sugarcane harvested area is due to growing demand for ethanol but, as the data shows, harvests in the Amazon basin are mainly supplying sugar for ethanol production. This data was also extracted from [14], but from a different survey. This data was presented in the third survey carried out and pertains to information solely on the 2008 harvest. This recent survey does not provide productivity or harvested area information, but does break down production tons into those used for sugar versus ethanol. It is interesting to note that many surveys, such as those from UNICA, state that about 50% of Brazilian sugar is used by the ethanol industry [11-13], while this recent survey from CONAB presents a significantly higher share of 56%. Furthermore, the average in the North region is even higher at 63%; the state of Maranhão is at 92% and Mato Grosso at 76%. Clearly, it is the ethanol industry that is driving the growing use of the Amazon for sugarcane harvest.

It is important to note that the tables following the map present data only for selected states of Brazil to highlight those in the Amazon basin as well as the state with the highest production of ethanol (São Paulo). Other states are not included in the table, but are included in the totals provided for each region of Brazil. Therefore, the sum of each region cannot be obtained by summing the few states presented. Information for all states can be found in the CONAB 2008 report.

There are important caveats regarding this data. Since the data collected by CONAB is provided by the ethanol manufacturers, there is always a doubt as to the validity of the data.

Furthermore, one could argue that the growth in sugarcane harvested area in the Amazon is not causing deforestation, because it could be taking place in land that had already been cleared for other agriculture or for raising livestock. As a counterargument, though it would be much harder to prove, is the fact that if more and more land that had already been cleared is being used for sugarcane, then it is limiting the use of that land for other resources. Indirectly, this could eventually lead to further deforestation.

We do not suggest that sugarcane and ethanol growth in the Amazon is high, but to show that it is significant. The few inefficient sugarcane plants in the Amazon should be monitored by regulators to deter further growth. Not only would further growth result in deforestation in areas of rich biodiversity, but also reduce earth's carbon dioxide absorption capacity as the forest is replaced by other crops.

It is important to compare at this point the harvested land area growth rate of 7.4% reported by [14]. This growth rate reinforces the assumption we make in Section 2 that growth in ethanol supply will come from growth in the area of land used for sugarcane harvest, and not only from productivity improvements. The Brazilian government's commitments to triple ethanol exports by 2014 and support high growth in production will lead to further growth in the area of land used for sugarcane harvest. In Section 3.2 we continue to quantify the risks of growth in land area used for ethanol production.

3.2 Land displacement

Data from [8] presented in Table 5 shows that growth in sugarcane harvested land is a highly-threatening issue at the national level. The authors collected data from [8] on harvested land area for forests, all food crops, and total arable land. As shown, from 1990 to 2005 the proportion of Brazilian land covered by forest has fallen from 61% to 56%, or more than 42 million hectares. During this same time period, there was a growth in the area for arable and permanent crops of about 9 million hectares, meaning that land that was previously used for other purposes (forests, cattle, etc) is now being used for harvesting crops.

In further analysis of this data from [8], we discovered that even though there was an increase in the country's total arable land, the land area used for almost every one of Brazil's key food crops decreased. The only three food crops for which harvested area increased were the three crops related to biofuel production – soybean, sugarcane, and maize.

Table 5. Historical trend in land allocation in Brazil, 1990-2007.

	1990	2000	2005	2006	2007	*2005/1990 CAGR%*
Land Area (1000 ha)	845,942	845,942	845,942	845,942	845,942	
Land covered by forest (1000 ha)	520,027	493,213	477,698	n.a.	n.a.	***-0.6%***
% Forest / Land area	*61%*	*58%*	*56%*	*n.a.*	*n.a.*	
Area for Arable and Permanent Crops (1000 ha)	57,408	65,200	66,600	n.a.	n.a.	***1.0%***
% Arable and crop / Land area	*7%*	*8%*	*8%*	*n.a.*	*n.a.*	
Soybeans area harvested (1000 ha)	11,487	13,640	22,949	22,047	20,638	***4.7%***
% Soybean / arable and crop area	*20%*	*21%*	*34%*	*n.a.*	*n.a.*	
Sugarcane area harvested (1000 ha)	4,273	4,846	5,806	6,144	6,712	***2.1%***
% Sugarcane / arable and crop area	*7%*	*7%*	*9%*	*n.a.*	*n.a.*	
Maize area harvested (1000 ha)	11,394	11,615	11,549	12,613	13,828	***0.1%***
% Maize / arable and crop area	*20%*	*18%*	*17%*	*n.a.*	*n.a.*	
Beans, dry area harvested (1000 ha)	4,680	4,332	3,749	4,034	3,907	***-1.5%***
% Beans / arable and crop area	*8%*	*7%*	*6%*	*n.a.*	*n.a.*	
Rice, paddy area harvested (1000 ha)	3,947	3,655	3,916	2,971	2,901	***-0.1%***
% Rice / arable and crop area	*7%*	*6%*	*6%*	*n.a.*	*n.a.*	
Coffee, green area harvested (1000 ha)	2,909	2,268	2,326	2,312	2,284	***-1.5%***
% Coffee / arable and crop area	*5%*	*3%*	*3%*	*n.a.*	*n.a.*	
Cassava area harvested (1000 ha)	1,938	1,722	1,902	1,897	1,945	***-0.1%***
% Cassava / arable and crop area	*3%*	*3%*	*3%*	*n.a.*	*n.a.*	
Wheat area harvested (1000 ha)	2,681	1,066	2,361	1,560	1,818	***-0.8%***
% Wheat / arable and crop area	*5%*	*2%*	*4%*	*n.a.*	*n.a.*	
Seed cotton area harvested (1000 ha)	1,904	802	1,263	899	1,110	***-2.7%***
% Cotton / arable and crop area	*3%*	*1%*	*2%*	*n.a.*	*n.a.*	
Oranges area harvested (1000 ha)	913	856	806	806	799	***-0.8%***
% Oranges / arable and crop area	*2%*	*1%*	*1%*	*n.a.*	*n.a.*	

Source: Authors, based on data extracted from [8].

While harvested land for soybeans, maize and sugarcane increases, Brazil is losing land that used to be covered by forest or for the production of essential foods. Based on the data from [8], the area used for harvesting sugarcane has been increasing at an increasing rate since 2000 (from 1% compounded annual growth from 1990-2000 to 9% growth from 2006-2007). That growth has been necessary to supply the growing demand for sugarcane, of which production grew 12% from 2006 to 2007, and the growing demand for ethanol, of which production grew 11% from 2005 to 2006. Even though the efficiency of sugarcane production has improved, as shown by the improvement in tons of sugarcane produced per hectare of harvested land from 73 to 77 tons/ha, the need for more hectares of harvested land has outweighed those improvements in efficiency. The data implies that fuel crops are displacing land used for Brazil's key food crops. Figure 1 presents graphically these quantities from the previous table in an effort to clarify this point. We use the total land for arable and permanent crops present by FAO as a proxy for the total harvestable area of Brazil. In blue, green and yellow, we have indicated the proportion of total arable land used by fuel crops in 1990, 2000, and 2005. As shown, that proportion is increasing rapidly, at the expense of food crop land. It seems that there are incentives for farmers to use more land for harvesting fuel crops, while there seem to be weak incentives for increase of food crop land.

Eight-percent of the area used for arable land and harvested crops in Brazil is already used for sugarcane production, and only about 50% of the motor vehicle combustion fuel market is being met by ethanol. The aggressive growth forecasts that would need to be met to meet expected domestic and international demand would require a substantial improvement in efficiency or a substantial increase in land harvested, or both. Unless there are policy incentives to control this growth, then there would be an incentive to continue extending sugarcane harvest over land previously used by other food crops or forests.

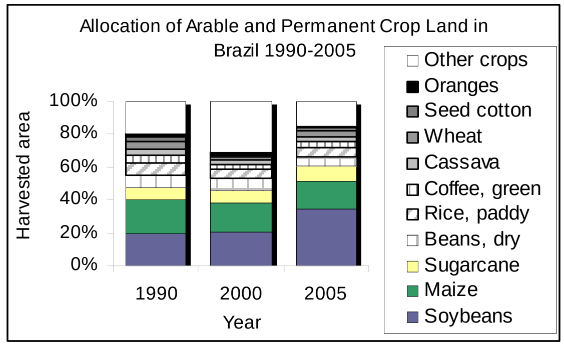

Fig. 1. Brazilian allocation of arable land.
Source: Authors, with data extracted from [8].

If the displacement of food crops continues, there could be a reduction in the food supply and an increase in prices. Though supporters of ethanol point out that food production has not fallen over the past few years because the efficiency of agriculture has improved and productivity per acre has increased (this has been confirmed by the authors using FAO 2009), there is a threat that the demand for more land for sugarcane agriculture will result in a decrease in the harvested land used for food crops. It is important to note that, according to FAO 2009, there has been no increase in food imports into Brazil since 1990. If food crop harvesting decreases and imports do not increase, then the general food supply would fall and prices would rise.

Though it is out of the scope of this paper, since we have chosen to focus on ethanol rather than all types of biofuels, it is important to note the high amount of land used in Brazil for soybeans, the food crop used for biodiesel production. The same risks that exist with growth in ethanol production as presented in this study exist with growth in the biodiesel industry in Brazil.

3.3 Soil and Water Deterioration

References [5-6] defend growth in the ethanol industry by using the data shown here in Table 6.

Table 6. Unused Available Land in Brazil, 2007.

	Million Hectares
Total area of Brazil	851
Amazon	345
Grazing fields	220
Protected area	55
Cities, lakes and roads	20
Cultivated forests	5
Other used land	38
Arable Crops	47
Permanent Crops	15
Unexplored land, available for harvest	**106**

Source: [5-6].

According to [5-6], while all of the harvested land (arable and permanent crops in Table 6) in Brazil amounts to about 62 million hectares, there are an additional 106 million hectares of land currently available for harvest. During the past five to ten years, the government has been using calculations presented by [5-6] to defend the idea that ethanol growth has not displaced other crops or forests and has much more room for growth in unused land. Even though we have shown in Section 3.1 that sugarcane land area is in fact growing in the Amazon and in Section 3.2 that it is growing in land area previously used for other food crops, we will present in Section 3.3 the potential threats of conversion of unused land for sugarcane harvesting. They relate to three categories: 1) the deterioration of land, 2) the deterioration of the water supply, and 3) higher GHG emissions.

Regarding the deterioration of land, [15-17] report that there is ample evidence that sugarcane fields suffer from high soil erosion. Reference [15] mentions that in São Paulo state, with the highest concentration of sugar plantations, it is estimated that erosion is up to 30 tons of soil per hectare per year (or up to 3 mm/year). Soil erosion is a result of having extensive areas of bare soil that are exposed to wind and rain, which occurs in the initial preparation of a field for sugarcane planting, during the period between harvesting and re-growth, and also when sugarcane stalks are replaced every 5-6 years [16]. Another negative impact on the soil is that of compaction, which can occur as a result of the constant traffic of heavy machinery over the soil. Contraction destroys soil porosity and density, decreases water infiltration, and further increases soil erosion. Reference [18] states that erosion conditions are severe or extremely severe in areas of land where sugarcane cultivation has taken place for many decades.

Soil erosion and degradation can lead to further deterioration in the surrounding water systems, because erosion can loosen sediments that are transported by wind or rain into nearby rivers, streams, or wetlands. Reference [19] presents the example of a sugarcane field that was planted near Piracicaba, in the State of São Paulo, near a reservoir. Twenty years after the first sugarcane harvest, the nearby reservoir could no longer be used as a water supply due to heavy sugarcane sedimentation in the water. Accelerated erosion can also result in sugarcane organic matter being transported to nearby water streams, which can severely impact the quality of the water.

Furthermore, there are two indirect factors that should be considered when estimating the impact of growth in ethanol production on the world's fresh water supply. First, 24% of sugarcane crops do require irrigation, and the area of those crops is increasing at 2.1% per year [8]. Second, increased deforestation may reduce rainfall in the region. A reduction in rainfall would lead to an increase in water use to irrigate the other 76% of sugarcane crops that are currently produced under rain-fed conditions [8].

Not only can sugarcane harvest have a negative impact on the quality of soil and nearby water, but it can also increase GHG emissions. Reference [20] points out that there is a significant loss of soil organic carbon and high levels of GHG emissions when degraded pasture land is converted to sugarcane cropland. Reference [21] quantifies these higher levels of GHG emissions and found that when there is a land-use change from grasslands or forests to agriculture of corn for the production of corn-based ethanol, the GHG emissions in the area nearly double over 30 years and these increases last for 167 years after the land conversion. It is important to note, as did [20], that these findings are based on several assumptions that are difficult to measure and define. It would be difficult to measure the exact impact of land conversion on the GHG balance of Brazil if unused degraded pasture land were to be replaced with sugarcane crops, but the findings of these studies certainly can be used as indications of the potential negative impact and justify the concern over land-use change in Brazil.

Though it is difficult to quantify the negative environmental impact that could occur from further growth in sugarcane harvest land area, it is important to discourage the premise that Brazil has an abundance of harmlessly available land for sugarcane growth. Brazil does have an abundance of available land, but converting that land to sugarcane fields could result in many indirect threats to the country's environment.

Though it is out of the scope of this paper, it is important to note that, in addition to the environmental risks associated with growth in the land area used for ethanol, there are social and economic risks. For example, in [20] it is noted that there is an industry trend in sugarcane agriculture of charging high fees from farm workers to pay for their transportation and lodging. This makes net real wages for labourers substantially lower than the national average. Furthermore, cane-cutting is an arduous job that imposes health risks and [22] states that, between 2002 and 2005, 312 sugar and ethanol workers died on the job and almost 83,000 suffered job-related accidents. Labourer workload has doubled in the last 30 years, as workers are now expected to cut 12 tons of cane per day vs. 6 tons per day in the 1970s [22]. Furthermore, productivity improvements could lead to an increase in unemployment in sugarcane harvest regions as the need for manual labour decreases.

4. Conclusions and recommendations

Our study presents three reasons that should discourage Brazilian policy-makers from pursuing their current plans for growth extent and rate of ethanol production. First, sugarcane harvest land area is growing in the Amazon Basin, which, as mentioned in Section 3.1, results in deforestation in a region of rich biodiversity and a decrease of earth's carbon dioxide absorption capacity. About 20,000 hectares are used in the region to harvest sugarcane, and that land area has recently increased by 5%. Second, sugarcane harvest seems to be replacing the harvest of important food staples. From 1990 to 2005, three out of the ten largest crops in Brazil were food products used in fuel production: soybean (biodiesel), sugarcane (ethanol) and maize (ethanol). The land area used for the agriculture of these fuel crops increased. The land area used for harvesting all of the other key food crops in Brazil – including rice and beans – decreased year per year from 1990 to 2005. The total amount of arable land in the country has not increased by the same amount, so within the total harvested land there is a displacement from food to energy crops. The third reason is that the Brazilian government defends growth in sugarcane ethanol by suggesting that there are over 106 million hectares of land of degraded pastures that could be made available for sugarcane. Several studies point to the environmental impacts of converting this land, including a deterioration of the soil and the nearby fresh water supplies, and a significant long term increase in the GHG emissions resulting from the land-use change.

In an effort to avoid further land displacement, reduction in food supply, increase in food prices, and deterioration of the environment, all of which are highly counter-productive to Brazil's sustainable development, Brazil's policies for the ethanol industry must be re-evaluated, applying rigorous sustainability analysis that analyzes carefully all of the economic, environmental and social aspects. Two obvious specific policy foci should be: 1) better management of land use, and 2) better support for other renewable sources, and, of hybrid and plug-n electric cars, which seems to be the current worldwide consensus direction for vehicular transportation, and not just focused on ethanol. For the first point, policy should focus on fomenting further improvements in productivity, managing land use and displacement, maintaining a closer relationship between government, farmers, and key industry players through regulation, and encouraging the export of processes rather than just of ethanol. Legislation should impose strict controls on which areas can be used for sugarcane harvest and where growth can take place, as well as enforce controls on land conversion procedures so that erosion can be minimized. On the second point, policy should be centered on providing continuous incentives for the diversification of renewable sources in the country's fuel supply, fomenting growth in the use of bagasse and more innovative methods to generate power, and partnering with other countries to continue to promote a steep learning curve in the field of biofuels. Furthermore, legislation should address labourers and ensure that working conditions are safe and fairly-compensated, as well as stimulate education and training of sugarcane workers so that they may develop skills that will sustain their development.

References

[1] Lula da Silva, L. I., 2007, *Our Biofuels Partnership*, Op Ed to The Washington Post, published on 03/30/07, p. A17.

[2] Mason, J., 2009, *Obama Reassures China on Bonds.*, Reuters, published 03/14/09, [online], URL:http://www.reuters.com/article/idUSTRE52 D0DH20090314.

[3] Sato, S., and Forster, H., 2007, *Brazil Plans to Triple Ethanol Exports in 7 Years*, Bloomberg, published 03/14/07, [online], URL: http://www.bloomberg.com/apps/news?pid=20601 086&sid=a1aRbSp18ly0.

[4] Martines-Filho, J.; Burnquist, H.; and Vian, C., 2006, *Bioenergy and the Rise of Sugarcane-Based Ethanol in Brazil*. CHOICES 2nd quarter 2006, issue 21(2).

[5] Rodrigues, R., 2008, *Facing Energy Security in the Americas through Agroenergy Sources*, XXX Lecture of the OAS Lecture Series of the Americas, 10/28/08.

[6] Rodrigues, R., 2007, *AgroEnergia*, Montevideo Capital Rural Energy Conference, 10/05/07.

[7] China Chemical Reporter, 2008, *Fuel Ethanol vs. Security of the Food Supply*, published 08/26/08, p.11.

[8] FAOSTAT Food and Agriculture Organization of the United Nations. Production Statistics Online Databases. Accessed on 03 Mar 2009 and 16 Mar 2009, [online], URL: http://faostat.fao.org/site/567/DesktopDefault.aspx ?PageID=567#ancor.

[9] Salomon, M., 2009, *Lula estuda liberar plantio de cana na borda do Pantanal.* A Folha de São Paulo, published on 04/11/2009.

[10] Whitten et al., 1996, *General chemistry*. Saunders College Pub., 1996, p.28.

[11] ÚNICA, 2007, *Venda de automóveis e vehiculos leves no Brasil*, [online], URL: http://www.unica.com.br/dadosCotacao/estatistica/

[12] UNICA, 2008, Sustainability Report, [online],URL: http://www.unica.com.br/dadosCotacao/estatistica/

[13] UNICA, 2009, Brazilian Sugarcane Map, [online],URL: http://www.unica.com.br/dadosCotacao/estatistica/

[14] CONAB (National Supply Company). Follow Up of Brazilian Harvests: 2007 1st Survey, May 2007; 2007 3rd Survey, Nov 2007; 2008 1st Survey, Apr 2008; 2008 3rd Survey, Dec 2008 (Online). Accessed on 16 Apr 2009. http://www.conab.gov.br/conabweb/index.php?PA G=133.

[15] Martinelli, L. A.; Filoso, S., 2007, *Polluting Effects of Brazil's Sugar-Ethanol Industry*. Nature 445/364, Published online 01/24/07.

[16] Martinelli, L. A.; Filoso, S., 2008, *Expansion Of Sugarcane Ethanol Production In Brazil: Environmental And Social Challenges*, Ecological Applications, 18(4), pp. 885–898.

[17] Martinelli, Luiz; Camara, Gilberto; Nobre, Carlos; Ometto, Jean Pierre. Biofuels in Brazil: Impact on Land Change. 4th IGBP Congress, Session D6: Land System Change: Competing for Food, Energy and Environmental Services. Cape Town, South Africa, 8 May 2008.

[18] Politano, W., Pissarra, T., 2005, *Evaluation of Areas of Different States of Accelerated Erosion of Soil in Sugar Cane Plantations and Citrus Orchards Utilizing Photointerpretation Techniques*. Engenharia Agrícola, vol.25, n.1, pp. 242-252.

[19] Fiorio, P., Dematte, J., and Sparovek, G., 2000, *Cronology and environmental impact of land use on Ceveiro Microbasin in Piracicaba region, Brazil.* Pesquisa agropecuaria brasileira., vol.35, n.4, pp. 671-679.

[20] Smeets, E., et al, 2008, *The sustainability of Brazilian ethanol: An assessment of the possibilities of certified production*. Biomass and Bioenergy 32.8, 781-813.

[21] Searchinger, T., et al, 2008, *Use of U.S. Croplands for Biofuels Increases Greenhouse Gases Through Emissions from Land-Use Change*. Science Express.

[22] Smith, M., Caminada, C. 2007, *Brazil Ethanol Boom Belied by Diseased Lungs Among Cane Workers*, Bloomberg, [online], URL: http://www.bloomberg.com/apps/news?pid=20601 082&sid=acyvyWb1Sk0Y.