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Sustainable Directions for Fuel Ethanol in Brazil Based on Life Cycle Assessment

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Abstract

The ethanol agribusiness using sugar cane is one of the main financial resources for the Brazilian rural area economy, occupying large areas and providing a large potential for electricity generation. Renewable fuels are very important to decrease many environmental impacts, as global warming, but to determine their real benefits, the entire life cycle should be assessed. This paper assesses the environmental impacts of the life cycle of fuel alcohol including the production of electricity from sugar cane in Brazil and indicates some improvements towards a more sustainable system. First a qualitative analysis of all environmental impacts caused by the life cycle of alcohol is presented, using a matrix of impacts, which shows the positive and negative impacts caused by the processes, including the agricultural activities, the industrial activities, distribution, co-generation of electricity and steam, use of fuel, and industrial by-products recycling to irrigate sugar the cane field. Next, a quantitative assessment of the environmental impacts from the life cycle of fuel ethanol is performed using the EDIP97 method (Environmental Development of Industrial Products) covering the emission-related impact categories: global warming, ozone formation, acidification, nutrient enrichment, ecotoxicity and human toxicity. The results from both methods indicate that the most harmful activities are related to the harvesting, mainly due to the burning of sugar cane during the harvest and by the Danish normalization, the main impact is photochemical ozone formation. The sustainable directions for the life cycle of fuel alcohol for energy production in Brazil are: sugar cane should not be burnt during harvesting; industrial by-products should be recycled to the field; half of the quantity of the sugar cane straw should be left on the field and the other half should be used to generate electricity; use of more environmentally benign agricultural conservative techniques; implementation of industrial water recycling systems and the use of fuel alcohol on tractors and transportation vehicles.

Keywords:
Ethanol, Fuel, LCA, Sustainability

1 INTRODUCTION

Currently, sugar cane is one of the main financial sources in the rural areas of Brazil, occupying almost 6 million of ha, annually producing 352.6 million of tons of sugar cane, 24.4 million tons of sugar, 14.6 million m3 of alcohol and around 619 MW of electricity surplus [1].

The conventional sugar cane agro-industrial model adopted in Brazil has been based, mostly, on a plantation system with extensive use of agricultural land, destruction of biodiversity by the use of single culture techniques, intensive use of fertilizers and pesticides, high water consumption, burning of sugar canes during harvest, and low employment quality.

Since 1985, the agricultural world productivity has been declining due to environmental degradation, such as: reduction of agricultural areas, loss of soil due to erosion and salt deposition, acid rain, and others [2]. These consequences represent nature's answer to industrialized agricultural systems with monoculture and intense use of machinery, agrochemical and fossil fuels [3]. During the last 50 years, approximately 66% of the world's agricultural soil was degraded and 40% of the world's agricultural area suffers degradation of high intensity [4].

Environmental concern is thus very timely to be included during the planning of the life cycle of a product – also an agricultural one - to optimize it and reduce its impact to humans and environment.

Sustainable directions should consider environmental, social (included cultural) and economical aspects.

Addressing the environmental aspects, a Life Cycle Assessment (LCA) is made for the fuel ethanol produced in the state of Sao Paulo, Brazil. The objectives of this LCA are to examine the environmental impacts of each stage of the life cycle in order to designate environmental focus points, where they lie in the life cycle processes, and to identify improvement potentials. As a co-product of ethanol production, electric energy from solid process waste is also assessed.

Some reasons to assess the fuel ethanol from sugar cane are: fuel ethanol has a high potential to substitute fossil fuel in automobiles; Brazil, mainly the state of Sao Paulo, has the most efficient conditions and technologies and the strongest experience to produce fuel ethanol from sugar cane; fuel ethanol made from sugar cane is based on renewable resources in contrast to other types of fuel; during the combustion in vehicle engines, fuel ethanol emits less pollutants than fossil fuel; the activities in the life cycle of ethanol have been the same for a long period of time (60 years) causing a number of environmental problems: burning of crop residues, emission of pesticides to the surrounding environment, high water consumption, inadequate waste disposal, just to mention some of the more prominent; nowadays, society is looking for a renewable fuel with environmental qualities; it is possible to co-generate electricity (renewable) from the solid waste (biomass) of some activities of the life cycle; it is possible to have better environmental interactions among the life cycle activities, such as recycling, and others, with higher efficiency.

This paper presents sustainable directions for the production of fuel ethanol in Brazil based on two methods of life cycle assessment, a qualitative and a quantitative one, and on cleaner production strategies.

2 METHODS

The general and qualitative impacts of the environmental, social and economical aspects of life cycle of fuel alcohol with electricity production from sugar cane are assessed by the matrix of impacts. The analysis has been based on a comprehensive bibliographic study combined with visits on sugar cane plantations and industrial plants, investigations of legal processes addressing the fuel ethanol business, and consultations of contacts at environmental protection agencies. The environmental characteristics are analyzed taking a Precautionary approach (i.e. giving environment the benefit of the doubt), and the analysis addresses the atmospheric, land, aquatic and human environment.

For the Matrix of Impact method, the ethanol life cycle activities are divided in: 1) Acquisition of Land and Equipment; 2) Civil and Industrial Projects; 3) Civil and Industrial Buildings; 4) Soil Conventional Conservation; 5) Plantation; 6) Agrochemical Application; 7) Irrigation; 8) Harvesting; 9)Crop Rotation; 10) Industrial Production of Alcohol; 11) Energy Production; 12) Transport; 13) Use of Alcohol; 14) End of the Activity.

The quantitative method to assess the life cycle impacts of fuel ethanol is the EDIP97 (Environmental Design of Industrial Products) method [5]. For the EDIP assessment, focus is more narrowly on the sugar and ethanol production, and the activities of the Brazilian fuel ethanol life cycle are divided into the following stages:

Activity 1: Soil Preparation

Activity 2: Sugar Cane Plantation (manual)

Activity 3: Chemicals Application

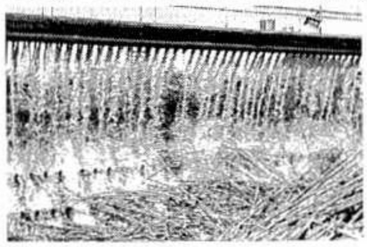
Activity 4: Harvesting

a) Burning to facilitate the sugar cane manual cutting (normally)

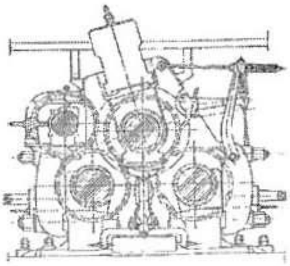
b) Mechanical (not so common)

Activity 5: Ethanol Industrial Process

5.1.Sugar cane preparation (washing)

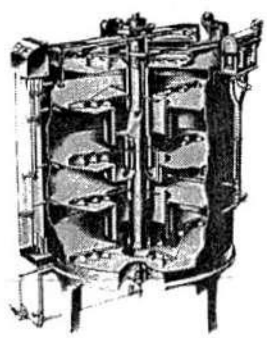


5.2. Sugar cane milling
(extraction of the juice)

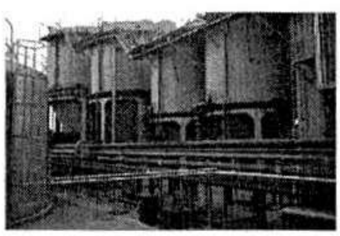


The products of the sugar cane milling are the juice, the filter cake and bagasse. The juice is used to produce alcohol; the filter cake is used as fertilizer in the field; and the bagasse is burned to generate vapor and electricity in co-generation plants.

5.3. Juice Treatment (Decanter)



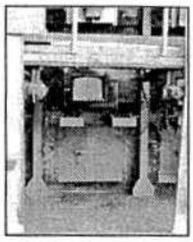
5.4. Fermentation

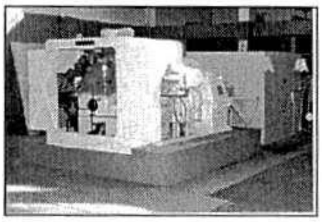


5.5. Distillation

The products of the distillation are alcohol and vinasse the latter of which is used as fertilizer together with filte cake at the sugar cane crop area.

Activity 6: Electrical Energy Cogeneration Plant from milling sub-products to supply Ethanol Industrial Processes





Activity 7: Irrigation with Recycled waste products from distillation

Activity 8: Ethanol transportation

Activity 9: Use of fuel ethanol

The boundaries of the LCA are drawn around the main rural and industrial activities needed in order to produce fuel ethanol from sugar cane, taking in account the production of calcium carbonate for liming the soil, fuels, equipment and vehicles used on rural activities. The production of fertilizer has not been included in the model yet.

Most of the data has been collected from Brazilian farms and from industry installed in the São Paulo State. Data from the production of carbonate, fuels, equipment and vehicles used in rural activities are from the EDIP97 life cycle database. Where allocation of data is needed, it has been made according the mass flux.

The impact categories assessed are: global warming, photochemical ozone formation, acidification, nutrient enrichment, ecotoxicity and human toxicity.

3 RESULTS

The results are divided between the qualitative and more general results of the Matrix of Impacts, and the quantitative results from the EDIP97 method, more specific to some impact categories.

Matrix of Impacts

The results of the general and qualitative method - the matrix of impacts - are presented in table 1 and indicate that Activity 8 - Harvesting - is the most harmful one for the environment, mostly because of the burning before the cutting of the sugar cane. Burning is used to facilitate the cut and to improve the efficiency, mainly when it is hand-operated. But, on the other hand, it creates environmental and health problems because of the air emissions: CO_2; CO; O_3; SO_2; particulate material; Polycyclic Aromatic Hydrocarbons, PAH's; dioxins; furanes and PCBs [6; 7; 8; 9; 10;11].

Aromatic Hydrocarbons (PAH's); dioxins; furanes and PCBs are considered as potentially mutagenic gases by the USEPA (Environmental Protection Agency, USA) [6].

Considering that 80% of the total sugar cane in Brazil is burned, this represents over 200 millions of tons sugar cane burnt. With an estimated average emission of particulate material of 3.6 kg/ton of sugar cane burnt, the airborne emissions of particles from the total area with sugar cane burned in Brazil, can be estimated at more than 740,000 tons per year [12]. For CO, the estimated emissions are around 7.2 million of tons annually. For Hydrocarbons, they are 1 million of tons annually and for NOx, 618,000 tons annually.

Although the part of the Carbon which is released by the burning as CO_2 is considered neutral in global warming (as it is absorbed by the sugar cane plant or other vegetation during growth), there are other global warming and toxic gases emitted by the burning. Besides, there are the air emissions from the tractors, trucks and buses used in this operation.

In sugar cane regions, during the harvesting period, at 2 km of altitude, concentrations of 80 ppbv (part per billion of volume) and 580 ppbv of O_3 and CO respectively have been found, while the normal concentration should be 40 ppbv for O_3 and 100 ppbv for CO [13].

In relation to the soil environmental impacts at harvesting, [6]; [8] and [14] have shown that burning results in losses of organic matter and microorganisms from the soil. This again leads to increased rates of erosion and loss of vegetation and animals.

In addition, the dense fumes cause road accidents, and serious occupational exposures of the field workers. Indeed, it is considered by a Brazilian jurist as an illegal and criminal activity because causes many human health problems and animal death burned [15].

The other activities of the life cycle that cause severe environmental hazards and that should be changed are: Activity 4, Conventional Soil Conservation; Activity 5, Plantation and Activity 6, Agrochemical Application. The impacts from these activities may be reduced by agricultural conservation techniques. These techniques, according to [16], intensify the biological life, they are less aggressive and use less fuel than conventional ones. The main idea is not to use huge equipment that desegregates the soil, to make the plantation direct at the part of the straw remaining on the ground from last harvest and to use biological pest control. The benefits are reduced erosion and herbicides usage, increased soil humidity and organic matter content and reduced environmental damage.

The main impacts in the preliminary activities shown in table 1 (acquisition of land and equipment; civil and industrial projects; and civil and industrial buildings) are due to their social implications, mainly caused by the concentration of huge areas owned by few people. The other problems in the preliminary activities are: industry construction near rivers; destruction of most of the vegetation and the acquisition of small farms by big farmers causing people who have been living at rural area to leave for the cities, resulting in urban problems.

Among the industrial activities, the main problems are caused by the high consumption of water and an effluent of the distillation of the ethanol named stillage or vinasse. The quantity of water used annually in the industry is 3.6 billion m^3 [17]. Stillage, which is rich in organic and mineral components, is produced in quantities of around around 15 liters for each liter of ethanol, resulting in around 160 million of tons produced annually. Water recycling is thus a cleaner production strategy which can result in the reduction of up to twenty times in water consumption [18].

The energy production from incineration of bagasse of sugar cane results in atmospheric net-emissions of CO_2 of around 0.084 kg CO_2/Kwh, much lower than for fuel oil, where the net-emissions are around 0.87 kg CO_2/Kwh., but the use of filters are necessary to reduce other emissions, like particulate matter.

The transportation of the products and auxiliary materials impacts the air quality through he use of fossil combustible.

The use of alcohol to replace a fossil fuel like gasoline has a positive environmental impact during combustion as shown at table 2:

Fuel	Pollutant (g/km)		
	CO	*HC*	*NO*
Ethanol	18,8	1,56	1,09
Gasoline	40,5	3,77	1,40

Table 2: Main Pollutant from ethanol and gasoline use [18]

The last activity analyzed in table 1 is the decommissioning of the sugar cane fields, an important issue mainly for the next generations. For this analysis the main impact is the unemployment of the former sugar cane workers and the necessity to recover the land to give it the same properties as it had before the beginning of the activity.

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Environmental System			Life Cycle Activities of the Fuel Alcohol with Energy Production													
Environmental Sub-system	Environmental Component	Environmental Factor	Preliminary Activities			Agricultural Activities						Industrial and After Industrial Activities				
			1	2	3	4	5	6	7	8	9	10	11	12	13	14
Atmospheric	Atmospheric	*Climate*				-	+			-					+	+
		Air Quality			-		+ -	-	-	-	+	-	-	-	+	+
Land	Physics	*Geology*														
		Geomorphology				-										
		Soil			-	-	-	- +	+	-	+	+				
		Agricultural				-	-			-						
		Erosion				-	-	- +	+	-	+					
	Biologic	*Vegetation*	-		-	-	-			-						
		Fauna			-		-	-		-						
	Occupation and Use		-		-	-	-			-	+					
Aquatic	Physic- Chemical - Biologic	*Rivers*			-	-	-	-	-	-		-	-	-		
		Groundwater			-	-	-	-	-			-		-		
		Aquatic Biology			-	- +	-	-	-	-		-		-		
Social – Economic - Cultural	Infrastructure	*Transport*			+			-	-	-				-		
		Water Use					-			-		-				
	Demography	*Population*							-	-						
		Migration	-			- +	-	-		-						-
	Economical Activities	*Agriculture*	- +		- +	+	- +	-	+	-	+	- +			+	- +
		Industry	+	+	+	+		+	-	-	+	+	+		+	-
		Business	- +	+	+					-		+	+	+	+	
	Life Quality	*Education*	-										+			
		Health	-					-	-	-		-	-	-		
		Employee	-			-		-		-		+	+			-
	Landscape / Historic / Cultural		-		-	-	-								+	
	Politic / Institutional		+	+	- +		- +	- +	-	-		- +	+	-	+	-

Table 1: Matrix of the Environmental Impacts of the Life Cycle of Fuel Alcohol with Energy Production

EDIP Method

The quantitative assessment of the fuel ethanol is performed for a functional unit of 1 kilometer of driving in a standard car using ethanol as a fuel, given that the product is a fuel and its function is to be used in vehicles for transportation.

The assumption is that the fuel ethanol is used in cars 1.6 liters, which is running around 10,000 km for a year period, with the consumption average of 8 km/l for an average running speed of 50 km/h for urban road use.

The life cycle assessment is performed using the EDIP method [5]. It is documented in [20], and the results of the life cycle impact assessment are shown for the activities of the life cycle for each impact category below.

Global warming (GW)

As shown in table 3, harvesting is the activity that contributes most to global warming, mainly because of burning and the vehicle used for products and labor transportation.

Activity	Global warming (g CO2 equiv. / km)
1. Soil Preparation	0.21
2. Sugar Cane Plantation	1.2
3. Chemicals Application	9.3
4. Harvesting	111.
6. Electrical Energy Cogeneration	0.15
7. Irrigation	7.0
8. Ethanol transportation	0.053
9. Use of fuel ethanol	42
Total	171

Table 3. Global warming impact potentials

Photochemical ozone formation (PO)

For photochemical ozone formation, harvesting is also the activity with the strongest contributions due to the burning (Table 4).

Activity	Photochemical ozone formation (g C2H4 equiv. / km)
1. Soil Preparation	0.0001
2. Sugar Cane Plantation	0.0002
3. Chemicals Application	0.0001
4. Harvesting	4.3
6. Electrical Energy Cogeneration	0.0029
7. Irrigation	0.0001
8. Ethanol transportation	0.0001
9. Use of fuel ethanol	1.5
Total	5.8

Table 4. Photochemical ozone formation impact potentials

Acidification (AC)

According to table 5, the acidification impact potential is mostly due to harvesting and the use of fuel ethanol because of the NOx emitted by the burning and by the combustion of ethanol.

Activity	Acidification (g SO2 equiv. / km)
1. Soil Preparation	0,018
2. Sugar Cane Plantation	0,015
3. Chemicals Application	0,011
4. Harvesting	8,0
6. Electrical Energy Cogeneration	1,5
7. Irrigation	0,010
8. Ethanol transportation	0,007
9. Use of fuel ethanol	7,6
Total	17

Table 5. Acidification impact potentials

Nutrient enrichment (NE)

The principal consequences of the intensive use of chemicals, mainly fertilisers, to the field is the high nutrient enrichment impact potential associated with this activity (Table 6).

Activity	Nutrient enrichment		
	g $N_{equiv.}$/ km	g $P_{equiv.}$/ km	g NO_3^- $_{equiv.}$/ km
1. Soil Preparation	0.0006		0.0027
2. Sugar Cane Plantation	0.61	0.92	6.8
3. Chemicals Application	7.5		33
4. Harvesting	0.0004		0.000003
5. Ethanol Industrial Process	0.013		0.057

Activity	Nutrient enrichment		
	g $N_{equiv.}$/ km	g $P_{equiv.}$/ km	g NO_3^- $_{equiv.}$/ km
7. Irrigation	[illegible]	[illegible]	[illegible]
Total	9.6	0.92	47

Table 6. Nutrient enrichment impact potentials

Ecotoxicity

The main activities that contribute to ecotoxicity impact potential come from the chemicals application during crop growth, because of the high quantity of pesticides applied (Table 7). This aspect has been considered according to the total amount spread on the field. So, it is assessed the maximum impact potential, as at the first application.

Activity	Ecotoxicity		
	ETWC (m^3 / km)	ETWA (m^3 / km)	ETSC (m^3 / km)
1. Soil Preparation	0.12	0.013	1.4
2. Sugar Cane Plantation	0.00007	0.0000004	330
3. Chemicals Application	0.096	0.0096	1680
4. Harvesting	0.0072		0.017
Total	0.23	0.023	2010

Table 7. Ecotoxicity impact potentials

Human toxicity

The activity that presents the highest impact potential for human toxicity is harvesting, as shown in table 8. This high potential is mainly due to the toxic gases emitted by the burning as dioxins, PAHs, furans and others.

Activity	Human toxicity		
	HTA (m^3 / km)	HTW (m^3 / km)	HTS (m^3 / km)
1. Soil Preparation	17	0.00007	0.0000005
2. Sugar Cane Plantation	45	0.000022	0.0000001
3. Chemicals Application	[illegible]	0.000057	0.0000004
4. Harvesting	$1,3{*}10^5$	0.0027	0.0013
6. Electrical Energy Cogeneration	$7,2{*}10^3$		
7. Irrigation	12	[illegible]	[illegible]
8. Ethanol transportation	8.9		
9. Use of fuel ethanol	$2,4{*}10^4$	[illegible]	[illegible]
Total	$1,6{*}10^5$	0.003	0.0013

Table 8. Human toxicity impact potentials

The results of EDIP method has shown that harvesting, mainly because of the burning, is the activity that presents the highest contribution for most of the impact potentials assessed.

Normalization

The impact potential results have been normalized using the Danish normalization references. The results show which of them are large and which are small relative to each other. As shown in Figure 1, the toxic impacts are quite insignificant compared to particularly photochemical ozone, nutrient enrichment and acidification, which are the big ones for the life cycle of fuel ethanol. The results are in mPE, which means milli-person equivalent, i.e. 1/1000 of a Person equivalent.

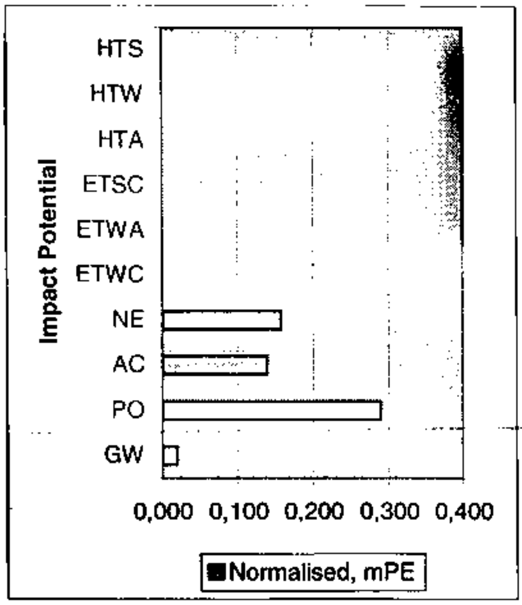

Figure 1: Toxic impact compared to photochemical ozone, nutrient enrichment and acidification

4 CONCLUSION

A sustainable activity should present environmental quality, good social condition and be profitable. According to the results presented from a life cycle perspective, some sustainable future directions for the life cycle of fuel ethanol in Brazil are: sugar cane should not be burnt during harvesting; bio digested vinasse with ashes and trash of filters should be recycled to field adequately; part of the straw should be left on the field, and most of it should be used to generate electricity; agricultural conservative techniques should applied, water should be recycled internally in the ethanol producing industry. The produced ethanol should replace fossil fuels for use in the vehicles for transportation, and finally, better labor conditions and a more equal land distribution should be created to make the fuel ethanol from sugar cane in Brazil truly sustainable. If followed, these directions will allow Brazilian fuel ethanol to be considered "green".

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