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Emergy Assessment of Ethanol Production From Sugarcane in Brazil

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ABSTRACT

The present study assesses the environmental sustainability, or the ecosystem support, of ethanol produced from sugarcane and examines the environmental feasibility of a large-scale production through the use of: emergy methodology. The study includes agricultural and industrial stages, as well the sugarcane transport, and was accomplished for two scenarios: a) only the directly consumed resources were accounted; b) including negative externalities associated to the production system, such as global warming contribution, loss of native forest and intoxication by pesticide. The following indicators were obtained for ethanol: Transformity: 4.87E+05 seJ/J; Renewability: 30.9%; Emergy yield ratio: 1.57; Environmental loading ratio: 2.23; Sustainability Index: 0.71. The Renewability of ethanol is very low and the emergy indices indicate important environmental stress and resources consumption. Results for ethanol production considering negative externalities were: Transformity: 5.87E+05 seJ/J; Renewability: 25.7%; Emergy yield ratio: 1.43; Environmental loading ratio: 2.90; Sustainability Index: 0.50. Externalities accounted for 20% of total emergy input for the agricultural stage. These results evidence the importance of accounting for the externalities to evaluate the system's performance and, therefore, they should be included when assessing biofuels sustainability. Besides, they indicate that large scale ethanol production present low sustainability. The adoption of alternative production systems, such as agroecological models, could improve its environmental impacts and should be evaluated to allow the design of new models able to deliver more renewable energy with less environmental and social impacts.

INTRODUCTION

Biofuels, or fuels produced from biomass, usually from an agriculture crop, have been presented as an important option for energy supply, notably as a renewable replacer for fossil fuels. Since biomass can grow every year, they are considered a renewable and endless resource. Yet, there are some discordant voices that point out that any biomass production and industrial transformation requires the use of fossil fuel energy, in the form of fertilizers, agrochemicals, machinery, and for inputs and raw material transportation. Besides that, highly intensive monoculture, as the case of sugarcane production, result in many negative impacts to natural environment, for instance: natural ecosystem destruction and lost in biodiversity, soil degradation, water contamination, as well as emission of greenhouse gases (Pretty et al, 2000). Moreover, in this case, there is a competition among energy and food crops for arable land.

Ethanol produced from sugarcane has been used as an automobile fuel for many years in Brazil. Anhydrous form ethanol has been added to gasoline in different concentrations up to 25% while the hydrous form, starting in 1978 with the introduction of cars moved by ethanol, has been used as a sole fuel. Today, all the gasoline sold in Brazil has 25% of added ethanol and 6% of Brazilian fleet is composed by flex automobiles that can use either gasoline or ethanol (ANFEVA, 2007). To supply this market, together with the sugar market, 7.1 billions of hectares were used to grow sugarcane in 2006. In the same year the Brazilian production of ethanol was 15.8 billion of liters, 85% of which was destined to the internal market (IBGE, 2007).

The objective of this study was to asses the ecosystem support or environmental sustainability, of ethanol produced from sugarcane and to examine the environmental feasibility of a large-scale biofuels production through the use of Emergy Assessment.

MATERIAL AND METHODS

Sugarcane production in Brazil is very intensive in the use of industrial fertilizers, pest control substances, and machinery, presenting high productivity per area. As presented in Figure 1, the agricultural production of sugarcane is fully integrated to the industrial production of ethanol: vinasse and other industrial by-product are recycled to agricultural phase to be used as fertilizer. Chemical fertilizers only complement fertilization of sugar fields and there are no industrial residues.

Different industrial productivity can be found, depending on technology adopted. For this research the average condition observed in São Paulo State, the main sugarcane producer in Brazil, was used for both agricultural and industrial phases. For sugarcane agricultural production a 6 cuts cycle was considered, with an average productivity of 80 tones of sugarcane per hectares. The harvest was mainly manual (85%), which includes burning of sugarcane before the harvest. The remainder portion (15%) was mechanically harvested without burning. Sugarcane was bulk transported from field to industry, about 40 km, by 60 tones capacity truck. As the study included recycling of byproducts, their transport from industry to field was included as part of agricultural phase.

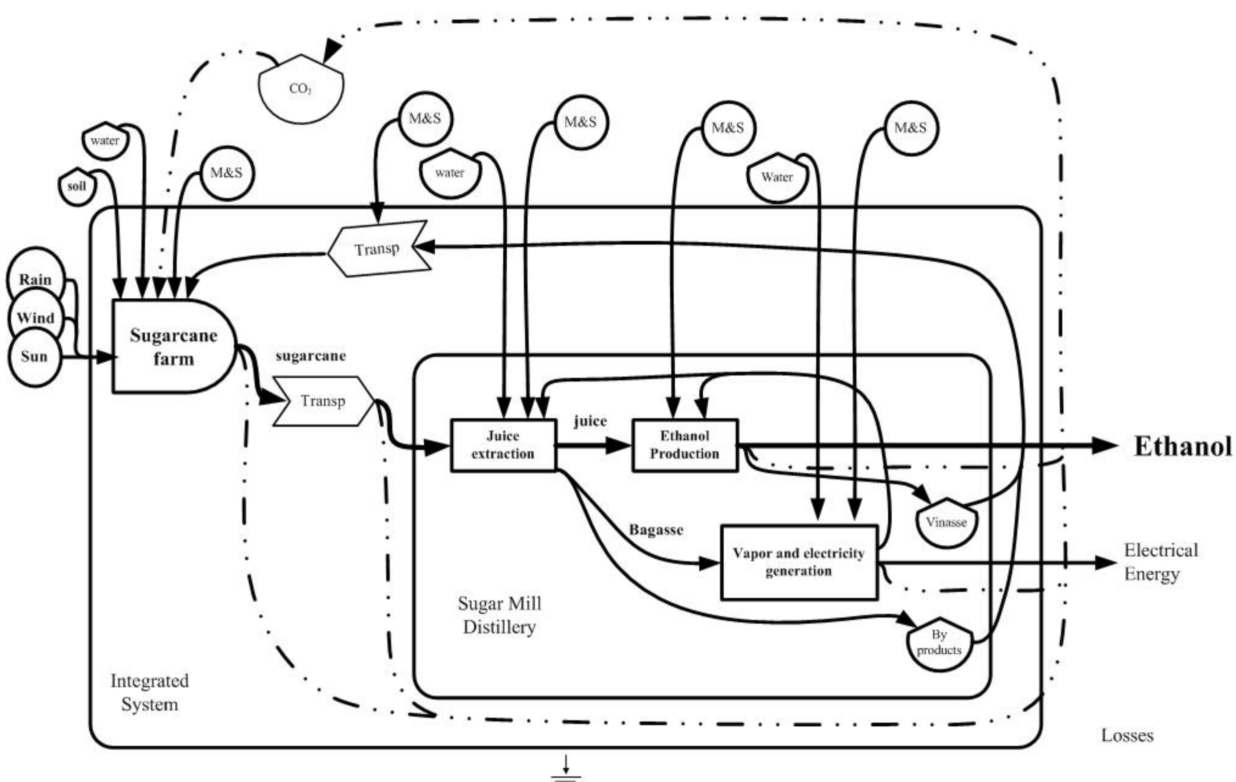

Figure 1: *Resumed diagram of agricultural and industrial large scale ethanol production system. . Where: M &S is Material and Services from economy; and Transp is Transportation.*

An industrial mill with capacity to process 8200 tones of sugarcane per day was considered for the ethanol production industrial phase. An area of 22 thousand hectares of cane field was required to supply this mill. The productivity was 82 liters of ethanol per tone of sugarcane crushed. The bagasse was used to produce steam and electricity and, therefore, no fossil fuel oil or electrical energy is bought from regular supply system.

Emergy evaluation of ethanol production chain was accomplished as described by Odum (1996). Some materials and services from economy present a renewable portion. For this reason renewable portion of resources supplied by the economic system was considered for modified renewability calculations, as described by Ortega et al. (2002 and 2005).

Emergy analysis was accomplished for two scenarios: a) only the directly consumed resources were accounted; b) including negative externalities associated to the agricultural production system as additional services. Externalities were calculated based in their cost to society, and were estimated in U$ 345,00 per hectare per year (Ortega et al., 2005). This value includes damage to natural capital (to water sources, to air, to soil) lost in biodiversity and landscape, damage to human health due to pesticide toxicity, and social damage (rural exodus) (Ortega et al., 2005).

The data used in this work was obtained from literature, official database information, actual farm data, a standard project of an ethanol plant, and interviews with sugarcane producers, industry technicians and experts, and equipment suppliers' technicians.

RESULTS AND DISCUSSION

Table 1 presents the emergy table for ethanol production including the cost of externalities. Table 2 presents a summary of emergy analysis for both cases, with and without the inclusion of externality costs.

The emergy analysis provides an interesting overview of the chain. The main contributing step is the agricultural stage, accounting for 84% of all flows used by the studied system. The industrial step accounted for 15% and sugarcane transport for only 2%. When the costs with externalities are included, the agricultural phase participation raises to 86% of total emergy flows and industrial step drops to 12%. This result indicates the importance o agricultural production and, specially, shows that the environmental impacts occur mainly at this stage, or at local and region level.

Materials (37%) were the main flows used by the system for the first scenario (no externalities). When the externalities costs were included as additional services, Services became the main type of used flow, 39%. For both scenarios the main individual contribution was from rainfall (28% without externalities and 24% including externalities), a renewable flow used without any financial cost. Soil correctives, fertilizers and herbicides were responsible for about 20% of all flows, while fossil fuels were responsible for 6%. Labor, either contracted or temporary, contributed with 10% of the overall flows. When accounted, externalities represented 17% of emergy flows used by the system, and 20% of agricultural flows, decreasing the relative participation of other resources.

Ethanol transformity was 48,700 seJ/J. When externalities were included it raised to 58700 seJ/J, increasing 20%. The comparison between ethanol and fossil fuels transformities indicates that they are of same greatness, around of 50.000 seJ/J (Bastianoni et al., 2005), while corn ethanol presented higher transformity, about 100.000 seJ/J (Ulgiati, 2001).

Renewability, the percentage of renewable resources used, decreased from 30.9% (no externalities) to 25.7% when externality costs was included in the calculations. Modified renewability, including the renewable portion of feedback flows, is 15% superior to the traditional renewability (35.4% and 25.4%, respectively). The higher the renewability the greater the chances of the system prevailing in the long run. Ethanol produced in Brazil presented higher renewability than sugarcane ethanol produced in the United States, 15.5% (Bastianoni and Marchettini, 1996), and than corn ethanol produced in Europe, 5.4% (Ulgiati, et al., 1997). Brazilian sugarcane better performance was due to the integration among rural and industrial phases and due to the use of bagasse to produce vapor and electrical energy for ethanol processing. Yet, ethanol presented low renewability value.

Table 1. Emergy table for ethanol production system including externalities costs.

Note	Flow	% R	Amount (unit/ha.y)	Unit	seJ/unit	Solar Emergy (E13 sej/y) Ren	NonRen	Total	%
RENEWABLE FLOWS (R)								223.4	**25.7**
Farm system								*212.4*	*24.4*
1	Sunlight	100	$5.22x10^{13}$	J	1	5.2	0.0	5,2	0.6
2	Rain	100	$6.77x10^{10}$	J	$3.06x10^{4}$	207.1	0.0	207.1	23.8
3	Water	100	$2.50x10^{6}$	J	$1.85x10^{5}$	0.05	0.0	0.05	0.01
Industrial system								*11.1*	*1.3*
4	Water (river)	100	$6.00x10^{8}$	J	$1.85x10^{5}$	11.1	0.0	11.1	1.3
NON RENEWABLE FLOWS (N)								40.0	4.6
Farm system							*40.0*	*40.0*	*4.6*
5	Top Soil losses	0	$3.23x10^{9}$	J	$1.24x10^{5}$	0.0	40.0	40.0	4.6
TOTAL FROM NATURE (I)						223.	40.0	263.5	30.3
PURCHASED GOODS (M)								264.8	30.4
Farm system								*203.1*	*23.3*
6	seedling	35	$2.80x10^{3}$	kg	$7.50x10^{10}$	7.5	13.5	21.0	2.4
7	Limestone	0	$2.44x10^{8}$	J	$2.72x10^{6}$	0.0	66.5	66.5	7.6
8	Nitrogen	0	$1.58x10^{4}$	g	$6,38x10^{9}$	0.0	10.1	10.1	1.2
9	Phosphate	0	$9.87x10^{1}$	kg	$6.55x10^{12}$	0.0	64.6	64.6	7.4
10	Potassium	0	$2.16x10^{1}$	kg	$2.92x10^{12}$	0.0	6.3	6.3	0.7
11	Herbicides	0	$4.45x10^{1}$	kg	$2.48x10^{10}$	0.0	0.1	0.1	0.02
12	Diesel	0	$5.28x10^{9}$	J	$5.50x10^{4}$	0.0	29.0	29.0	3.3
13	Machinery (steel)	0	$4.33x10^{0}$	g	$1.13x10^{10}$	0.0	4.9	4.9	0.6
14	Tyres	0	$1.18x10^{0}$	kg	$4.30x10^{12}$	0.0	0.5	0.5	0.1
Transport Farm- Processing Plant								*14.9*	*1.7*
15	Machinery (steel)	0	$5.17x10^{0}$	kg	$1.13x10^{13}$	0.0	5.8	5.8	0.7
16	Tyres	0	$1.97x10^{0}$	kg	$4.30x10^{12}$	0.0	0.8	0.8	0.1
17	Diesel	0	$1.49x10^{9}$	J	$5.50x10^{4}$	0.0	8.2	8.2	0.9
Industrial System								*46.9*	*5.4*
18	Machinery (steel)	0	$5.05x10^{0}$	kg	$1.13x10^{13}$	0.0	4.6	4.6	0.5
19	Other inputs	0	$9.32x10^{1}$	g	$3.80x10^{12}$	0.0	35.4	35.4	4.1
20	Installation deprec	0	$1.85x10^{1}$	U$	$3.70x10^{12}$	0.0	6.9	6.9	0.8
SERVICES (S)								342.4	**39.3**
Farm system								*293.2*	***33.7***
21	Labor	38	$5.66x10^{7}$	J	$2.80x10^{6}$	6.0	9.8	15.8	1.8
22	Temporary labor	38	$1.52x10^{8}$	J	$2.80x10^{6}$	16.1	26.3	42.5	4.9
23	Administ. expenses	0	$1.95x10^{2}$	U$	$3.70x10^{12}$	0.0	72.3	72.3	8.3
24	Governamental taxes	0	$3.85x10^{1}$	U$	$3,70x10^{12}$	0.0	14.2	14.2	1.6
25	Externalities	0	$3.45 x10^{2}$	U$	$3.70x10^{12}$	0.0	148.4	148.4	17.0
Transport Farm-Processing Plant								*1.30*	*0.1*
26	Labor	38	$4.65x10^{6}$	J	$2.80x10^{6}$	0.5	0.8	1.30	0.1
Industrial System								*47.9*	*5.5*
27	Labor	38	$1.37x10^{7}$	J/	$2.80x10^{6}$	1.5	2.4	3,8	0.4
28	Temporary Labor	38	$7.45x10^{6}$	J	$2.80x10^{6}$	0.8	1.3	2.1	0.2

Table 1. Continued.

Note	Flow	%	Amount	Unit	seJ/unit	Solar Emergy (E13 sej/y)			
						Ren	NonRen	Total	%
TOTAL FROM ECONOMY (F)						32.4	574.8	607.2	69.7
TOTAL (Y)						255.	614.8	70.6	
	Production								
	Ethanol		6560	Liters	$1.48x10^{11}$ J				

Reference for transformity values used: Notes 1, – Odum, 1996;
Notes 2, 5, 7, 8, 9,11, 13, 15, 18 - Brown and Ulgiati, 2004;
Notes 3, 4, 6, 14, 16, 19 - LEIA, 2006
Note 10 - Brandt-Williams, 2002
Notes 12 e 17 - Bastianoni et al. 2005;
Notes 20, 23, 24, 25, 29 - Coelho et al. 2003
Notes 21, 22, 26, 27, 28 – Brown, 2003

Table 2. Emergy indices of sugarcane ethanol for two scenarios: a) only resource consumption included and b) with the inclusion of externalities cost.

Emergy Indices	**No externalities**	**With externalities**	
Transformity	$4.87x10^4$	$5.87x10^4$	seJ/J
Specific Emergy	$1.10x10^{12}$	$1.33x10^{12}$	seJ/l of ethanol
Renewability	30.9	25.7	%
Modified Renewability	35.4	29.4	%
Emergy Yield Ratio	1.57	1.43	
Environmental Loading Ration	2.23	2.90	
Emergy Sustainability index	0.71	0.50	

Those numbers do not fit the image of a renewable energy source that is promoted by international media, energy enterprises and national governments as a renewable one.

Emergy Yield Ratio, the ratio of total emergy of the output of the system (Y) divided by the feedback or purchased inputs, materials (M) and services (S), indicates the ability of the system in exploring local resources. EYR of primary energy sources (oil, coal, gas) are high, greater than 5, while agricultural systems present lower EYR values, from 1.2 up to 3.5 depending on crop and handling procedures (Bastianoni and Marchettini, 1996; Ortega et al., 2005; Ulgiati, 2001). EYR for the studied system was 1.57 and decreased to 1.43 when the externalities were considered. Although the systems showed ability to use the natural renewable resources potential, EYR vales were low, indicating intensive use of industrial inputs, equipment and, mainly, fossil fuel, and, therefore, low yield. These results are important when comparing biofuels options.

Environmental Loading Ratio, ELR, a measure of ecosystem stress due to the process, increased from 2.22 (no externalities) to 2.90 (including externalities), indicating moderate impact, which means that the impacts can be “diluted” over the system area (Brown and Ulgiati, 2004). However, when the extensive area of sugarcane cultivation needed to supply the ethanol market is considered, this impact becomes relevant. In 2005, 5.6 million hectares were destined to this culture (IBGE, 2007). In the state of Sao Paulo (Brazil), during the last year, there was a 15% increase of area dedicated to grow sugarcane; it means a decrease in the area devoted to produce food, cattle or ecosystem services. Besides, the need for new areas is also responsible for the move of other cultures, as well as sugarcane, culture to other Brazilian regions such as the Cerrado (Brazilian savannah) and to the Rain Forest area – thus being responsible for its devastation.

Emergy Sustainability Index (EIS), the ratio of EYL to ELR, measures the potential contribution of a process to the economy per unit of environmental load. According to Brown and Ulgiati (2004), an EIS value lower than 1 indicates consumer systems, while EIS values greater than 1 indicate systems with net contribution without heavily affecting environmental equilibrium.

The EIS values calculated for ethanol production system in this work were 0.71 (no externalities) and 0.50 (externalities accounted). These results indicate that this production system is a consumer one: although it has an EYR greater than one, indicating its ability in providing net emergy to the economy, it occurs in detriment of the environmental equilibrium. Moreover, EIS values decrease when externalities are accounted reinforcing the importance of considering externalities when analyzing agricultural systems.

Due to this substantial participation, over 85% of all resources, the performance of agricultural stage is fundamental for the performance of the whole chain. Therefore, the improvement of these indices depends on the decrease in the use of resources from economy, particularly by the adoption of more environmental friendly methods.

CONCLUSIONS

Emergy Analysis indicated that the present ethanol production model, though extremely efficient in energy and residues use, especially the farm-industry integration, is not sustainable. This outcome was due to the use of huge amounts of inputs, particularly diesel for farm operations.

Sugarcane crop, and therefore ethanol production, is associated to significant environmental impacts, as loss of soil fertility, loss of natural ecosystems and biodiversity, contamination of water and soil by chemical compounds, and greenhouse gases emission. Those impacts are not usually accounted when Emergy analysis is accomplished. However, these externalities do represent important impacts and should be accounted as Additional Services.

Since agricultural phase is the one with higher resources consumption and environmental impacts, the adoption of more sustainable design and practices for this stage will result in improvement of the environmental performance of ethanol.

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