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Sustainability assessment of large-scale ethanol production from sugarcane

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ABSTRACT

The present study assesses the sustainability of ethanol produced from sugarcane and examines the environmental feasibility of a large-scale production through the use of: fossil fuel embodied energy and Emergy Assessment including farm and industrial production phases. The study indicates that about 1.82 kg of topsoil eroded, 18.4 l of water and 1.52 m^2 of land are needed to produce 1 l of ethanol from sugarcane. Also, 0.28 kg of CO_2 is released per liter of ethanol produced. The energy content of ethanol is 8.2 times greater than the fossil-based energy required to produce it. The transformity of ethanol is about the same as those calculated for fossil fuels. The Renewability of ethanol is 30%, a very low value; other emergy indices indicate important environmental impacts as well as natural resources consumption. The results obtained indicate that sugarcane and ethanol production present low renewability when a large-scale system is adopted.

1. Introduction

Biofuels have been presented as an important option for energy supply, notably as renewable substitutes for fossil fuels. They are considered a renewable and endless resource, since they are produced from biomass, usually from an agricultural crop, reputed as renewable. Besides, it is a current belief that, by replacing oil products, their use could reduce greenhouse gases emissions. Yet, there are some discordant voices that point out that any biomass production and industrial transformation require the use of fossil fuel energy – in the form of fertilizers, agrochemicals, machinery, and for inputs and raw material transportation. Moreover, monoculture might result in soil degradation, natural ecosystem destruction and, in this case, there is a competition for the use of arable land between the production of energy and food crops.

Ethanol produced from sugarcane has been used as an automobile fuel for many years in Brazil. Anhydrous form ethanol (99.3° GL) has been added to gasoline (up to 25%, volume/volume) while the hydrous form (96° GL) has been used as a sole fuel since 1978, with the introduction of cars powered solely by ethanol. Today, all the gasoline sold has 25% of added anhydrous ethanol; 16% of the Brazilian fleet is comprised of flex automobiles that can use either gasoline or ethanol [1]. To supply this market, along with the sugar market, 7.1 million hectares (71 thousand square kilometers) were used to grow sugarcane in 2006. In the same year, the Brazilian production of ethanol was 15.8 billion liters, 85% of which was used within the internal market [2].

The objective of this study was to assess the sustainability of ethanol produced in large-scale from sugarcane and to examine its environmental feasibility through the use of fossil fuel embodied energy and Emergy Assessment.

2. Methods

The embodied energy analysis method (EEA) considers the energy from petroleum necessary to prepare the industrial inputs used in a transformation process. This method was the precursor of Emergy Analysis. Emergy Analysis (EMA) has been frequently used to evaluate production systems, mainly because it takes into account all the inputs necessary to drive a process: nature's contributions (rain-water, ground-water, soil, sediments, and biodiversity) and the inputs supplied by human economy (chemicals, raw-materials, machinery, fuel, services, payments, etc.). Besides, EMA's results provide quantitative information about the impact caused by the studied system in the associated environment and it can be used to calculate its carrying capacity, or support area [3,4].

Life cycle assessment (LCA) adopts a "cradle-to-grave" approach by evaluating all stages of a product's life, from raw material acquisition to waste disposal, identifying, quantifying and evaluating the cumulative environmental impacts (resources consumption, and emissions and wastes release into the environment)

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resulting from all stages in the product life cycle. It is an important tool and represents significant progress when compared to conventional economic analysis.

The combined use of EA and Life LCA methodologies has been proposed by some authors studying different systems [5–7]. LCA focuses on the impact of industrial production on the environment, but does not consider nature's services consumed by the system, such as rainfall and pollution abatement, essential to assess environment impacts [5]. EMA, on the other hand, focuses on nature's services used by the system. Both methods are, therefore, complementary and can be used in an integrated assessment.

Emergy evaluation of the ethanol production and consumption chain was accomplished as described by Odum [8]. In summary, the steps are: preparation of the system diagram (as presented by Fig. 1); identification and quantification of the system's input and output flows (mass, energy, and services); analysis of these flows; calculation of emergy indices and performing interpretations of the data. These calculations are presented in detail elsewhere [8,9].

The LCA concept was used to delimit the ethanol system under study (Fig. 1). In addition, the input flows (water, eroded soil, land need, oil equivalent), as well as CO_2 emissions were calculated for three functional units, 1 kg of sugarcane and 1 l of ethanol, as described by Ulgiati [10], and 1 J of ethanol.

The data used in this work were obtained from literature, official database information, actual farm data, and interviews with sugarcane industry producers and experts, as well as with equipment suppliers.

2.1. The system

The agricultural production of sugarcane is fully integrated to the industrial production of ethanol in Brazil, as shown in Fig. 1. For agricultural production, this study considered a 6-cut cycle, with average productivity of 80 tones of sugarcane per hectare per year. Fertilization was provided by the use of vinasse and other ethanol industry by-products and complemented with chemical fertilizers. The harvest was mainly manual (85%), which includes burning of sugarcane before the harvest. The remainder 15% was mechanically harvested without burning. Sugarcane was transported from the field to the processing facility, about 40 km, using 60-ton capacity trucks. The study also included the by-products transported from the processing facility back to the field.

For ethanol production an industrial mill with capacity to process 8200 tones of sugarcane per day, corresponding to an area of 22 thousand hectares, and a productivity of 82 l of ethanol per tone of sugarcane was considered. The bagasse was used to produce steam and electricity.

Emergy calculations to obtain the results, presented here, are not included in this work, but are available upon request from the authors.

3. Results and discussion

As presented on Table 1, the production of 1 l of ethanol from sugarcane requires approximately 18.4 L of water, 0 07 kg of crude oil equivalent, and 1.52 m^2 of annual land use. It causes the loss of 1.8 kg of soil due to erosion. These results are impressive, especially when the Brazilian ethanol production – 16 billion liters in 2006 [2] – is considered. The soil loss is of utmost importance, since the ability to grow sugarcane, or any other crop, is directly related to this natural non-renewable resource. Part of this loss is compensated by organic material deposition and by the use of increasing amounts of fertilizers. According to the Brazilian National Association for Fertilizers Diffusion (ANDA) [11] the fertilizer use per hectare increases in average about 1.4% every

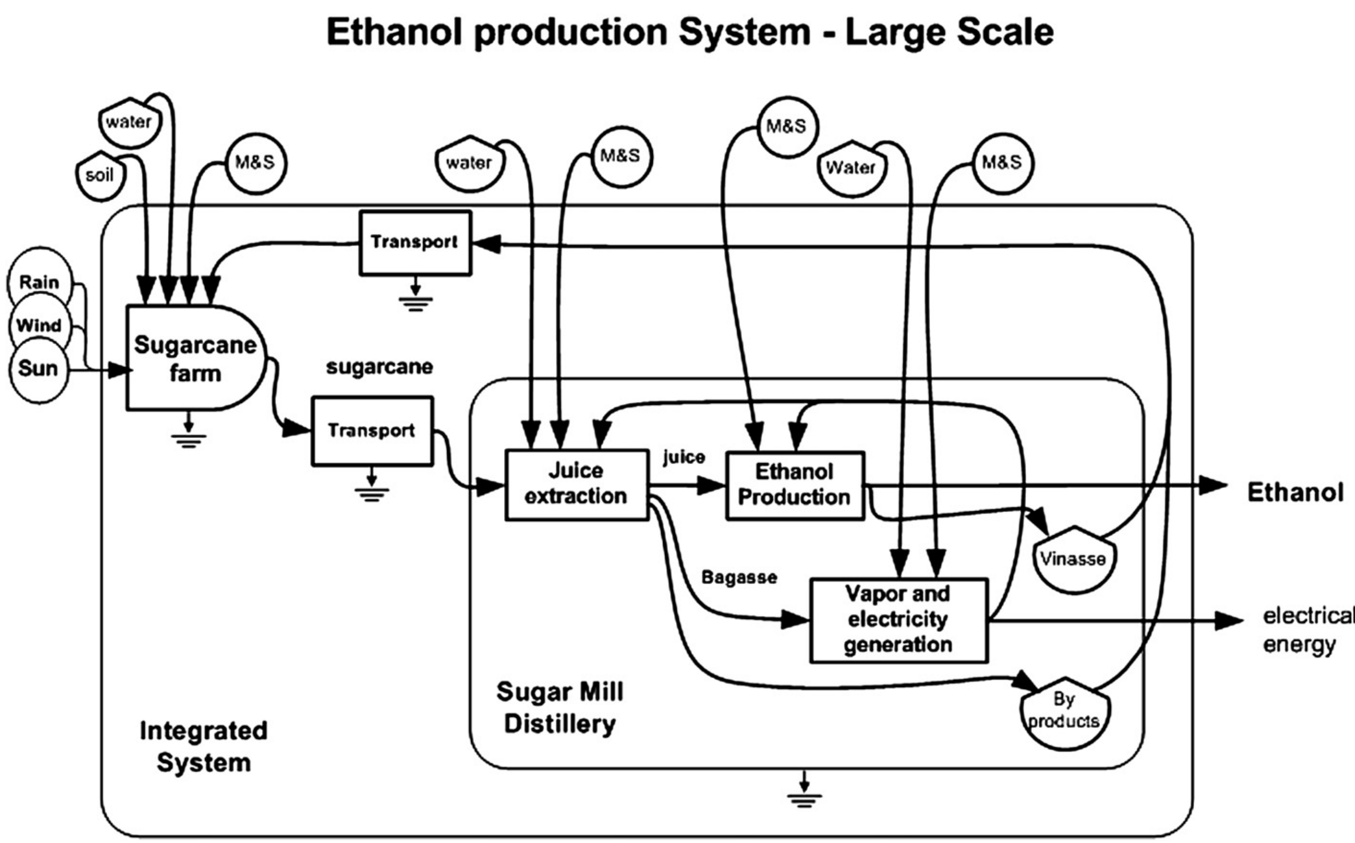

Fig. 1. Resumed diagram of agricultural and industrial ethanol production system.

Table 1
Flows and ratios of matter and energy for sugarcane ethanol.

Indicators	Sugarcane	Ethanol		Unit
	FU in kg	FU in L	FU in J	
Inputs				
Land demand	0.125	1.52	6.74×10^{-8}	m^2/FU
Water demand	0.01	18.4	8.13×10^{-7}	L/FU
Fuel oil demand	0.004	0.07	2.92×10^{-9}	kg/FU
Output				
Product	80 000	5576		kg/ha yr
	8	0.56		kg/m^2 yr
Net embodied	200 960	130 100		MJ/ha yr
fuel energy yield	20	13		MJ/m^2 yr
Soil eroded	0.15	1.82	8.03×10^{-8}	kg/FU
CO_2 released	0.018	0.278	1.23×10^{-8}	kg CO_2/FU
Output/Input				
Embodied Energy efficiency	16.0	8.2		

Where FU is Functional Unit (1 kg of sugarcane, 1 l of ethanol or 1 J).

year in sugarcane production. Besides, the loss in fertility is also responsible for the move of this culture to other Brazilian regions such as the Cerrado (Brazilian savannah) and to the Rain Forest area – thus being responsible for its devastation.

From the point of view of Fuel Embodied Energy, the energy efficiency of ethanol calculated on the global scale is 8.2 J of net energy per joule invested. This result is due to the integrated production system and to the efficient use of by-products.

Likewise, petroleum use is an important issue since of the associated greenhouse gas emissions. Considering the sugarcane ethanol chain, the carbon balance is null because atmospheric carbon absorbed by the sugarcane biomass growing, and stored in the ethanol, in the bagasse (also used as fuel in the mill) and in the residues (used for soil fertilization), is released to the atmosphere during the ethanol and bagasse combustion, due to sugarcane burning before harvest and during industrial processing (fermentation). Thus, the carbon cycle can be considered closed because all the sequestered carbon in the plant is emitted as CO_2 by agricultural handling (pre-harvest burning), transformation (fermentation to produce ethanol) and the use of the products – both ethanol and bagasse burning. When there is no pre-harvest burning, part of the organic material from sugarcane is left and is incorporated into the soil and could represent an increase in soil carbon. However, according to Campos [12] it will be decomposed and, therefore, it will be emitted to the atmosphere during subsequent crop cycles. His study also indicates that the carbon stock on soil is stable.

Although the popular belief is that ethanol production systems release no net CO_2, they actually do because of direct and indirect oil consumption: this system uses external inputs, such as fertilizers, other chemical inputs such as pesticides, equipment, infrastructure and so on, that demand petroleum in their production, operation and maintenance. Moreover, at the agricultural step, there are CO_2 emissions due to eroded soil oxidation. Our estimate is that there is a release from the soil, of 0.28 kg of CO_2 per liter of ethanol produced.

Table 2 shows the emissions along the different links of the chain expressed in kg of CO_2 per liter and per MJ of ethanol. The results indicate that the agricultural phase is responsible for 80% of all CO_2 emissions (weight basis) owing to the direct use of fossil fuels (22%), soil oxidation (23%) and materials use (35%), indicating the importance of agricultural performance.

Emergy analysis provides an interesting overview of the whole chain. Table 3 presents a summary of the emergy flows for an ethanol production system, and Fig. 2 presents the relative contribution of each link in the chain.

Table 2
CO_2 emission balance for ethanol production using sugarcane.

Stage	Use	kg of CO_2/l of ethanol	g CO_2/MJ	%
Plantation	Fossil fuels direct use	0.06	2.72	22
	Soil oxidation	0.07	2.85	23
	Materials	0.09	4.34	35
Total farm step		0.22	9.91	80
Transport	Fossil fuels direct use	0.02	0.87	7
	Materials	0.03	1.24	10
Industrial	Materials	0.01	0.37	3
Total		0.28	12.39	100

The main contributing step is the agricultural stage, accounting for 83% of all emergy flows used for producing ethanol from sugarcane. The industrial step accounts for 15% and sugarcane transport for 2%. When the complete chain is considered, resources from the economy, materials (36.7%) and services (26.9%) were the main flows used by the system. However, the main individual contribution was from rainfall (28%), a renewable flow used without any financial cost. Soil additives, fertilizers and pesticides were responsible for about 20% of all flows, while fossil fuels were responsible for 6%. Labor, either contracted or temporary, contributed 10% of the overall flows. All percentages presented were in sej basis, solar equivalent joules, or solar emergy [8].

Table 4 presents the emergy indices calculated for sugarcane and ethanol. Transformity is defined as the amount of input emergy expressed as solar emergy (sej) per unit of output energy (joules). It increased from 2.8×10^4 sej/J for sugarcane in the farm, to 4.87×10^4 sej/J for ethanol in industry. This result was expected, according to Odum's emergy theory. During the agricultural stage, the biomass production through the use of renewable flows of nature (solar light, rain, biodiversity) and of the economy (fertilizers, pesticides, fossil fuels) occurs. The sugarcane transformity reflects the efficiency of the agricultural system. The industrial stage represents a new transformation, when biomass, sugarcane, is transformed, through fermentation, to ethanol. This process uses non-renewable materials and energies with high transformities, therefore increasing the total emergy input. Thus, ethanol transformity should be larger than that of biomass.

When comparing two or more productive systems, transformity can be used as a measure of system productivity: the greater the transformity, the lower the system efficiency. The comparison between sugarcane ethanol and fossil fuel transformities indicates that they are of the same order of magnitude – around 50,000 sej/J for fossil fuels [13] – while corn ethanol presents a higher transformity, about 100,000 sej/J [10], indicating that the sugarcane system is more efficient.

Renewability is defined as the percentage of renewable resources - like sun light, rain, water, soil nutrients - directly and

Table 3
Emergy indices in sugarcane ethanol production.

	Sugarcane		Ethanol	
	1×10^{14} sej/ha y	%	1×10^{14} sej/ha y	%
Renewable (R)	21.24	35.4	22.34	30.9
Non-Renewable (N)	4.00	6.7	4.00	5.5
Material – Renewable portion (M_R)	0.75	1.2	0.75	1.1
Material–Non-Renewable portion (M_N)	19.56	32.6	25.73	35.6
Service – Renewable portion (S_R)	2.22	3.7	2.49	3.5
Service –Non-Renewable Portion (S_N)	12.27	20.4	16.91	23.4
Total (Y)	60.03		72.23	

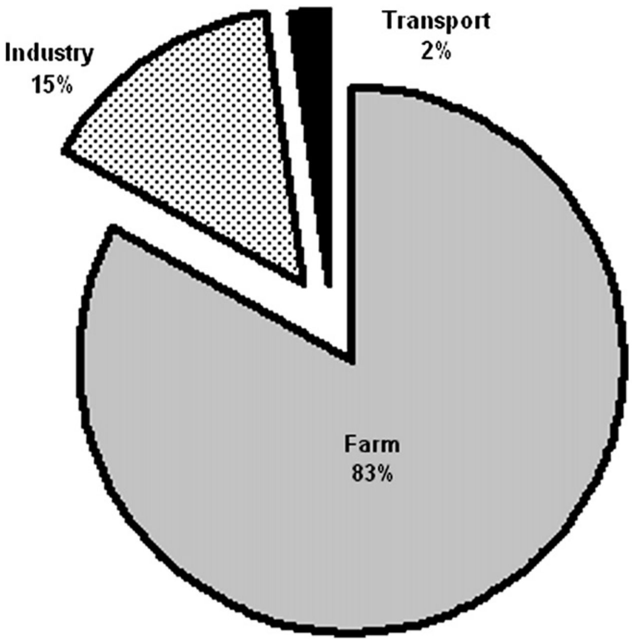

Fig. 2. Emergy flow distribution by ethanol production step.

indirectly used by the system. It is calculated dividing renewable flows by total flows, in sej bases [4]. Table 3 presents the system flows (the complete emergy table is presented at Appendix 1). Renewability decreases from 35.4% for sugarcane to 31% for ethanol. Again, these results were expected since renewable resources are used mainly by farm processes – particularly free nature resources – and each subsequent step adds non-renewable emergy through the consumption of materials and services from human economy. This system presented a higher renewability than that obtained with sugarcane ethanol produced in the United States: 15.5% [7]; and than corn ethanol produced in Europe: 5.4% [14]. Yet, the observed sugarcane and ethanol renewabilities have low values and do not fit the image of a renewable energy.

Brazilian sugarcane ethanol model, due to better results when compared to other biomass fuels, has been presented as an important option to be replicated by other countries in order to replace fossil fuels, especially as a transport fuel [15]. However, its renewability was questioned mainly due to fossil fuel dependence of crop production [7,14,10,16]. Some authors agree that biomass production, and its transformation to fuel, should exclude non-renewable sources of energy and includes a more efficient biomass use, as electricity and heat generation, in order to be labeled as "sustainable renewable energy sources" [10,16]. Therefore renewability measured by emergy analysis can be used to clarify this discussion since it indicates the actual renewability of the system, or the amount of renewable resources indeed used. The present work indicates that even with a better use of resources, electricity generation and by-products recycling, less than 50% of resources are actually renewable. To achieve a better result, crop production should be less fossil fuel dependent which means to replace it by other renewable energy source and to increase in efficiency in the use of energy.

Emergy Yield Ratio (EYR) is the ratio of total emergy of the output of the system (Y) divided by the feedback or purchased inputs, materials (M) and services (S). It is a measure of the system's ability to utilize local resources. For the studied system the EYR were 1.73 for sugarcane (farm system) and 1.57 for ethanol (agricultural and industrial). It indicates that because of the use of industrial inputs, such as equipment and fuel oil, the net yield is not so high, but the system shows an ability to use the local natural renewable resources' potential. Again, the performance of agricultural stage is fundamental for the performance of the whole chain. Moreover, the improvement of this index depends on the decrease in the use of resources from the economy. Some studies indicate that the adoption of more ecological agricultural methods, that uses less purchased inputs consuming and recycling internal products and by-products, like the organic system and polycultural rotation systems, can result in better use of local resources, presenting EYR as high as 12 for organic family farm [17,18].

Environmental Loading Ratio, ELR, a measure of ecosystem stress due to the process, increased from 1.83 (farm system) to 2.23 (ethanol). According to Brown and Ulgiati [19], ELR values close to 2 indicate relatively low load, which means that the impacts can be "diluted" over the system area. While ELR values between 3 and 10, indicate a moderate impact, and values greater than 10 indicate a very concentrated environmental impact. Therefore, the environmental impact due to industrial and transport operations could still be considered as moderate. However, when the extensive area of sugarcane cultivation needed to supply the ethanol market is considered, this impact becomes highly significant. In 2005, 5.6 million hectares were used in this culture [2]. In the state of Sao Paulo, during last year, there was a 15% increase of area dedicated to grow sugarcane; it means a 15% decrease in the area devoted to produce food, cattle or ecosystem services.

Emergy Sustainability Index (ESI), 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 [20], an ESI value lower than 1 indicates consumer systems, while ESI values greater than 1 indicates systems with net contribution to society without heavily affecting associated ecosystem equilibrium, or low environmental pressure. The ESI values calculated in this work were 0.94 for sugarcane and 0.71 for ethanol. These results indicate that even the agricultural subsystem is a consumer system which means that, although it has the ability to provide net emergy to the economy, it occurs at the expense of the environmental equilibrium. Moreover, EIS values decrease with the increase of the system size, so that transport decreases this value, even more.

Emergy Exchange Ratio (EER) of a trade operation is defined as the ratio of delivered emergy and emergy received in the exchange. It indicates the advantage that an operator (seller or buyer) takes in relation to the other one. The EER was 1.45 for sugarcane producers and 0.68 for ethanol producers, indicating that sugarcane producers were delivering higher amounts of emergy than they received back in the trade operation, while the ethanol companies are receiving higher amounts of emergy when selling the ethanol.

Table 4
Emergy Indices for sugarcane and ethanol.

Emergy Indices	Sugarcane	Ethanol	unit
Transformity (Tr)	2.80 E +04	4.87 E+04	sej/J
Renewability (%R)	35.4	30.9	%
Emergy Yield Ratio (EYR)	1.73	1.57	
Environmental Loading Ration (ELR)	1.83	2.23	
Emergy Sustainability index (ESI)	0.94	0.71	
Emergy Exchange Ratio (EER)	1.45	0.68	

3.1. Support area

These results indicate that the present ethanol production model, though extremely efficient in energy and residues use, especially the farm-industry integration, is not sustainable due to resource consumption and residue emissions. Moreover, in spite of recycling CO_2, this is a net CO_2 emitter system. Therefore, in order to be sustainable, these impacts should be compensated by the incorporation of a support area to the cultivated area able to absorb the emitted greenhouse gases.

Besides gas emissions, production systems also are responsible for other important environmental impacts. Brown and Ulgiati [4] suggested that carrying capacity, defined as the maximum size of species population that a determined area can support without reducing its ability in maintaining this specie for an undefined time period [21], could be expressed as the land area required to support an economic activity solely on a renewable base. Agostinho et al. [22], assuming that carrying capacity of a system is determined by the environment's ability to supply the required emergy, suggested converting the non-renewable emergy used by the system into a forest-equivalent area. They proposed to use the ratio of the process's non-renewable emergy demand by the renewable empower, or emergy flow, density of the referred region, in order to calculate the necessary area of the surrounding region that would be required, in case the economic activity used only renewable emergy inputs.

Using the renewable empower density to the study region (São Paulo State) presented by Agostinho et al. [23], 2.19×10^{15} sej/ha/year, our estimation is that an area of 2.2 hectares of forest vegetation for every hectare of sugarcane cultivated is needed to support environmental impacts. In other words, only 30% of the area should be cultivated, while the other 70% should be maintained as native vegetation. This is an important result, especially when compared to the current Brazilian legal requirement, of native vegetation being only 20% of the total farm area.

It is also important to point out that the adoption of more sustainable systems, like organic farming, rotational systems and intercropping planting, can most likely result in the need of a smaller support area. This reduction is the result of a combination of factors. First, some researches have demonstrated that greenhouse gas emissions are smaller for organic agriculture than for conventional systems [17,24]. Additionally, organic manure applications, cover crops, periods of fallow, among other practices, allow organic handling to increase soil organic matter content, therefore resulting in lower net CO2 emissions. Besides, these procedures result in healthier soil and plants, needing lower use of fertilizers and pest control substances. Moreover, these systems usually consume less energy to produce the same amount of product, and more important, use less non-renewable sources [7,17,18,24]. In the specific case of sugarcane, the rotational crop system, integrating soybean and peanut crops to the main sugarcane production, has been introduced in São Paulo fields and in the long run may result in better soil yield and lower environmental impacts.

4. Conclusions

The use of Emergy Analysis and some Life Cycle Assessment tools indicates that the present ethanol production system, although it is extremely efficient in energy and residues use – especially the farm-industry part of the system - is not renewable, therefore, it can not be sustained in the long term. The agriculture subsystem presented poor indices. This outcome was due to the use of huge amounts of inputs, particularly diesel fuel for farm operations. Therefore, the adoption of more sustainable design and practices, like organic farming and rotational and intercropping planting, during agricultural stage will result in improvement of the environmental performance of ethanol.

The use of ethanol is associated to significant consumption of natural resources such as water, soil loss and the necessary arable area for the sugarcane production. Those resources are not usually accounted when mass flows, embodied fuel energy and economical studies are carried out. However, they do have great environmental impact at the local and regional level. Likewise, ethanol production from sugarcane releases CO_2, due to the use of fuels and other industrial inputs during agricultural and industrial processing as well as by transportation. Moreover, it is important to keep in mind that the production of ethanol, at large scale, will reduce arable land for food crop production.

In order to compensate for all the impacts associated to the ethanol production, a forest area (even a recovering natural vegetation area) should be incorporated into the cultivated area. Our estimates are that this area should be at least twice the size of the sugarcane crop, or should correspond to 70% of the farmland. These support area can be reduced by the adoption of more sustainable practices, like organic farming, capable of reducing resources consumption, especially non-renewable resource.

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Appendix. Emergy table of sugarcane ethanol.

Note	Flows	% R.	Data	Unit	sej/unit	Solar Emergy (sej/ha yr)		
						Ren Portion	Non Ren Portion	Total
Renewable environmental resources (R)						2.23×10^{15}	0.00	2.23×10^{15}
Farm						2.12×10^{15}	0.00	2.12×10^{15}
1	Sunlight	100	5.22×10^{13}	J	1	–	–	–
2	Rain	100	6.94×10^{10}	J	3.06×10^{4}	2.12×10^{15}	0.00	2.12×10^{15}
3	Water (irrigation)	100	2.50×10^{6}	J	1.85×10^{5}	4.63×10^{11}	0.00	4.63×10^{11}
Ethanol mill						**1.11×10^{14}**	**0.00**	**1.11×10^{14}**
4	Water (river)	100	6.00×10^{8}	J	1.85×10^{5}	1.11×10^{14}	0.00	1.11×10^{14}
Non-renewable (N)						**0.00**	**4.00×10^{14}**	**4.00×10^{14}**
Fazenda						**0.00**	**4.00×10^{14}**	**4.00×10^{14}**
5	Topsoil losses	0	3.23×10^{9}	J	1.24×10^{5}	0.00	4.00×10^{14}	4.00×10^{14}
Materias from the economy (M)						**7.46×10^{13}**	**2.57×10^{15}**	**2.65×10^{15}**
Farm						7.46×10^{13}	1.96×10^{15}	2.03×10^{15}
6	Seedlings	40	2.80×10^{3}	Kg	7.50×10^{10}	7.46×10^{13}	1.35×10^{14}	$2.10 x10^{14}$
7	Limestone	0	2.44×10^{8}	J	7.72×10^{6}	0.00	6.65×10^{14}	6.65×10^{14}
8	Nitrogen	0	1.58×10^{4}	Kg	6.38×10^{9}	0.00	1.01×10^{14}	1.01×10^{14}

(*continued on next page*)

Appendix (*continued*)

Note	Flows	% R.	Data	Unit	sej/unit	Solar Emergy (sej/ha yr)		
						Ren Portion	Non Ren Portion	Total
9	Phosphate	0	9.87×10^{1}	Kg	6.55×10^{12}	0.00	6.46×10^{14}	6.46×10^{14}
10	Potassium	0	2.16×10^{1}	Kg	2.92×10^{12}	0.00	6.31×10^{13}	6.31×10^{13}
11	Herbicides	0	4.45×10^{1}	Kg	2.48×10^{10}	0.00	1.10×10^{12}	1.10×10^{12}
12	Fuel	0	5.28×10^{9}	J	5.50×10^{4}	0.00	2.90×10^{14}	2.90×10^{14}
13	Machinery (steel)	0	4.33×10^{0}	Kg	1.13×10^{13}	0.00	4.89×10^{13}	4.89×10^{13}
14	Tyres	0	1.18×10^{0}	Kg	4.30×10^{12}	0.00	5.06×10^{12}	5.06×10^{12}
Sugarcane transport						**0.00**	$\mathbf{1.49 \times 10^{14}}$	$\mathbf{1.49 \times 10^{14}}$
15	Machinery (steel)	0	5.17×10^{0}	Kg	1.13×10^{13}	0.00	5.84×10^{13}	5.84×10^{13}
16	Tyres	0	1.97×10^{0}	Kg	4.30×10^{12}	0.00	8.46×10^{12}	8.46×10^{12}
17	Fuel	0	1.49×10^{9}	J	5.50×10^{4}	0.00	8.20×10^{13}	8.20×10^{13}
Sugarcane mill						**0.00**	$\mathbf{4.69 \times 10^{14}}$	$\mathbf{4.69 \times 10^{14}}$
18	Machinery (steel)	0	4.05×10^{0}	Kg	1.13×10^{13}	0.00	4.58×10^{13}	4.58×10^{13}
19	Industrial Inputs	0	9.32×10^{1}	G	3.80×10^{12}	0.00	3.54×10^{14}	3.54×10^{14}
20	Instal. Depreciation	0	1.85×10^{1}	U$	3.70×10^{12}	0.00	6.86×10^{13}	6.86×10^{113}
Human services (S)						$\mathbf{2.49 \times 10^{14}}$	$\mathbf{1.69 \times 10^{15}}$	$\mathbf{1.94 \times 10^{15}}$
Farm						$\mathbf{2.22 \times 10^{14}}$	$\mathbf{1.23 \times 10^{15}}$	$\mathbf{1.45 \times 10^{15}}$
21	Labor	38	5.66×10^{7}	J	2.80×10^{6}	6.02×10^{13}	9.82×10^{13}	1.58×10^{14}
22	Labor – Temporary	38	1.52×10^{8}	J	2.80×10^{6}	1.61×10^{14}	2.63×10^{14}	2.25×10^{14}
23	Other Services	0	1.95×10^{2}	U$	3.70×10^{12}	0.00	7.23×10^{14}	7.23×10^{14}
24	Taxes	0	3.85×10^{1}	U$	3.70×10^{12}	0.00	1.42×10^{14}	1.42×10^{14}
Sugarcane transport						$\mathbf{4.95 \times 10^{12}}$	$\mathbf{8.07 \times 10^{12}}$	$\mathbf{1.30 \times 10^{13}}$
25	Labor	38	4.65×10^{6}	J	2.80×10^{6}	4.95×10^{12}	8.07×10^{12}	1.30×10^{13}
Sugarcane mill						$\mathbf{2.25 \times 10^{13}}$	$\mathbf{4.56 \times 10^{14}}$	$\mathbf{4.79 \times 10^{14}}$
26	Labor	38	1.37×10^{7}	J	2.80×10^{6}	1.45×10^{13}	2.37×10^{13}	3.83×10^{13}
27	Labor – Temporary	38	7.45×10^{6}	J/ha.a	2.80×10^{6}	7.93×10^{12}	1.29×10^{13}	2.09×10^{13}
28	Taxes	0	1.13×10^{2}	U$	3.70×10^{12}	0.00	4.19×10^{14}	4.19×10^{14}
Total						$\mathbf{2.56 \times 10^{15}}$	$\mathbf{4.66 \times 10^{15}}$	$\mathbf{7.22 \times 10^{15}}$
	Production							
	Ethanol	6560	Liters		1.48×10^{11}	J		

Flows were calculated for one hectare of sugarcane production per year and the transformities used are 2000 emergy baseline.
Transformity values: Notes: 1 – Definition; 2, 5, 7, 8, 9, 13, 15, 18 – [20]; 3,4, 14, 16, 20, 23, 24, 28 – [25]; 10,11 – [26]; 12,17 – [13]; 21, 22, 25, 26, 27 – [27].
Field Data: Notes: 3, 4, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22,24, 25, 26, 27 and 28.
Data from Literature: Note 5 – [28].
Data from Database: Notes: 1, 2 – [29].

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