1st INTERNATIONAL WORKSHOP ADVANCES IN CLEANER PRODUCTION
IV SEMANA PAULISTA DE P+L CONFERÊNCIA PAULISTA DE P+L

Sustainability Assessment of 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 analysis and Emergy Assessment adopting Life Cycle concept. The study indicates that about 1.82 kg of topsoil eroded, 18.4 liters of water and 1.52 m^2 of land are needed to produce 1 liter of ethanol from sugarcane. Also, 0.79 kg of CO_2 is released per liter of ethanol produced. The energy content of ethanol is 7.2 times greater than the fossil-based energy required to produce it. The transformity of ethanol is about the same of those calculated for fossil fuels. The Renewability of ethanol is 31%, 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 adopting large scale systems present low sustainability.

Keywords: Emergy Analysis, Life Cycle Assessment, biofuels, ethanol.

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 believe 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 requires the use of fossil fuel energy, in the form of fertilizers, agrochemicals, machinery, and for inputs and raw material transportation. Besides that, monoculture might result in soil degradation, natural ecosystem destruction and, 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 (99.3^o GL) has been added to gasoline (up to 25%) while the hydrous form (96^o GL), starting in 1978 with the introduction of cars moved by ethanol, has been used as a sole fuel. Today, all the gasoline sold has 25% of added anhydrous ethanol, 16% 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.

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 Emergy Assessment adopting Life Cycle concept.

2 Methods

Embodied energy analysis (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 and it is used by many researchers.

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 resulting from all stages in the product life cycle. It is an important tool and represents significant progress when compared to conventional economic analysis. LCA focuses on the impact of industrial production on the environment, but does not consider nature's services consumed by the system, while EA focuses on nature's services that are used by the system. Both methods are complementary and can be used in an integrated way since EA is deficient in the evaluation of undesired impacts to the environment. The combined use of EA and Life LCA methodologies has been proposed by some authors studying different systems (Hau and Bakshi, 2004; Bargigli and Ulgiati, 2003; Bastianoni and Marchettini, 1996).

Emergy Analysis (EMA) is used by researchers to evaluate production systems, because it considers all the inputs necessary to drive a process, the nature's contributions (rain, water, water springs, soil, sediments, biodiversity) and the inputs supplied by the human economy (chemicals, raw-materials, machinery, fuel, services, payments, etc.). Emergy evaluation of ethanol production and consumption chain was accomplished as described by Odum (1996). The LCA concept was used to delimitate the ethanol system under study (Fig. 1). In addition, the inputs flows (water, eroded soil, land need, oil equivalent) as well as CO_2 emissions were calculated for two functional units, 1 kg of sugarcane and 1 liter of ethanol, as described by Ulgiati (2001).

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

Nowadays, in Brazil the agricultural production of sugarcane is fully integrated to the industrial production of ethanol, as shown in Fig 1. For agricultural production, this study considered a 6 cuts cycle, with average productivity of 80 tones of sugarcane per hectare. 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 field to industry, about 40 km, using 60 ton capacity trucks. The study included the byproducts transport from industry to field.

For of 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 liters of ethanol per tone of sugarcane was considered. The bagasse was used to produce steam and electricity.

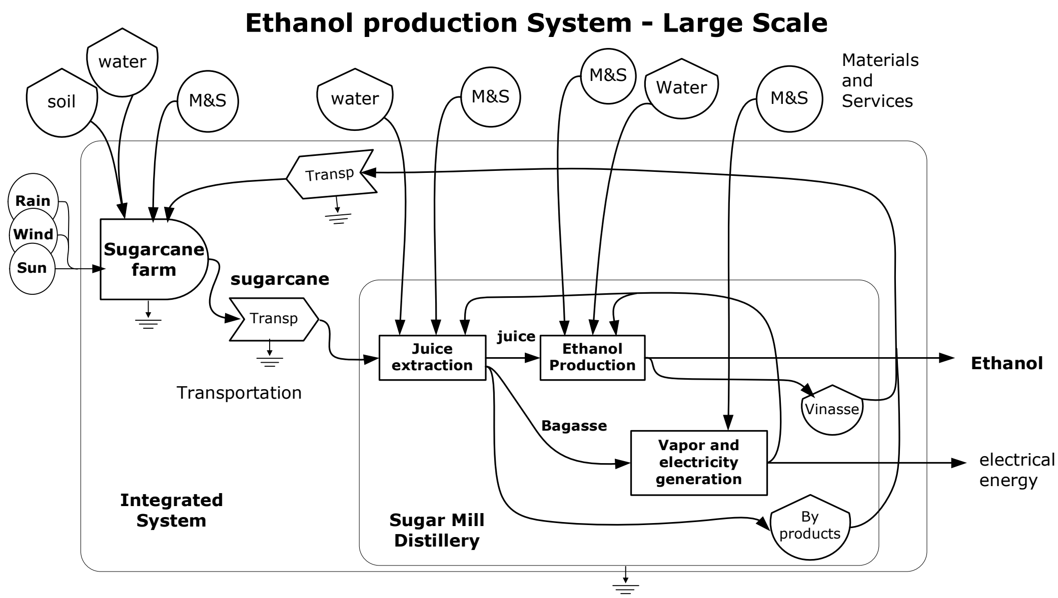

Fig. 1: Resumed diagram of agricultural and industrial ethanol production system**.**

3 Results and Discussion

Table 1: Mass, fuel energy and emergy indices in sugarcane ethanol production

Indicators	**Sugarcane**	**Ethanol**	**Unit[a]**
Inputs			
Land demand	0.125	1.52	m^2/FU
Water demand	0.01	18.4	l/FU
Fuel oil demand	0.003	0.04	kg/FU
Output			
Product	80.000	5.576	kg/ha.yr
Soil eroded	0.15	1.82	kg/FU
Net embodied fuel energy yield	200 960	130 100	MJ/ha.yr
CO_2 released	0.018	0.278	kg CO_2/FU
Output / Input			
Embodied Energy efficiency	15.1	7.2	
Emergy Indices			
Transformity	2.80 E +04	4.87 E+04	seJ/J
Specific Emergy	7.50 E +10	1.10E+12	seJ/FU
Renewability	35.4	30.9	%
Emergy Yield Ratio	1.73	1.57	
Environmental Loading Ration	1.83	2.23	
Emergy Sustainability index	0.94	0.71	
Emergy Exchange Ratio	1.45	0.68	

[a] The Functional Unit (FU) is 1 kg of sugarcane and 1 liter of ethanol

As presented by Table 1, the production of 1 liter 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 and results in the lost of 1.8 kg of soil due to erosion. These results are impressive, especially when the Brazilian ethanol production, 16 billion of liters in 2006 (Brazil, 2007) is considered. The soil lost is of utmost importance since the ability in growing sugarcane to ethanol production, or any other crop, is directly related to this natural non-renewable resource.

From the point of view of Fuel Embodied Energy, the energy efficiency of ethanol calculated on the global scale is 7.2 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 it is associated to greenhouse gases emissions. Considering the sugarcane ethanol chain, atmospheric carbon is absorbed by sugar-cane biomass growing so that this carbon is sequestered in the ethanol, in the bagasse (also used as fuel in the mill) and in the residues (used for soil fertilization). On the other hand, CO_2 is emitted to atmosphere during ethanol and bagasse combustion, due to sugarcane burn before harvest and during industrial processing (fermentation). Thus, the carbon cycle can be considered closed because the sequestered carbon in the plant and soil is emitted as CO_2 by the transformation and use of the products. Although the popular belief that ethanol systems have no net CO_2 emissions, they do have because of direct and indirect oil consumption; this system uses external inputs that demand petroleum in their production: fertilizers, equipments, chemical inputs, infra-structure and so on. Our estimate is that there is a release of 0.29 kg of CO_2 per liter of ethanol produced.

The emergy analysis provides an interesting overview of the whole chain. The main contributing step is the agricultural stage, accounting for 84% of all flows used for processing ethanol from sugarcane. The industrial step accounted for 13.5% and sugarcane transport only 2.3%. When the complete chain is considered, resources from 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 correctives, fertilizers and herbicides were responsible for about 20% of all flows, while fossil fuels were responsible for 6%. Labor, either contracted or temporary labor, contributed with 10% of the overall flows.

Transformity increased from 2.8×10^4 seJ/J for sugarcane at farm to 4.87×10^4 seJ/J for ethanol at industry. This result was expected. During the agricultural stage occurs the biomass production through the use of renewable flows of the nature (solar light, rain, biodiversity) and of the economy (fertilizers, pesticides, combustible). The sugarcane transformity reflects the efficiency of the agricultural system. The industrial stage, founded in the use of nonrenewable materials and energies, constitutes a process of transformation of sugar to concentrated ethanol. Therefore, 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 efficiency: the greater the transformity the lower the system efficiency. 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 is the percentage of renewable resources used; it 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 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). Yet, the observed sugarcane and ethanol renewabilities show low values. 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 (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 ability of the system in exploring local resources. For the studied system (farm 1.73; ethanol industry 1.57) it indicates that because of the use of industrial inputs and equipment and fuel oil the yield is not so high, but the systems show an ability to use the 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 economy by the adoption of ecological methods.

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 (1997), ELR values close to 2 indicate relatively low impact, 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 superior to 10 indicate a very concentrated environmental impact. Thereby, the environmental impact due to industrial and transport operations could still be considered as moderate. However, when the extensive area of sugarcane cultivation need 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, 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.

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 in y this work were 0.94 for sugarcane and 0.71 for ethanol. These results indicate that even the agricultural subsystem is a consumer system, although it has an EYR greater than one, indicating ability in providing net emergy to the economy, it occurs in detriment of the environmental equilibrium. Moreover, EIS values decrease with the increase of the system size so that transport will decrease this value even more.

Emergy Exchange Ratio (EER) of a trade operation is defined as the reason of received emergy and emergy received in the exchange. It indicates the advantage that an operator (seller or buyer) takes in relations 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 receiving back in the trade operation, while the ethanol companies are receiving higher amounts of emergy when selling the ethanol.

4 Conclusions

The use of Emergy Analysis using the concept of Cycle of Life indicates that the present ethanol production model, though extremely efficient in energy and residues use, especially the farm-industry integration, is not sustainable. Even the agriculture subsystem presented poor indices. This outcome was due to the use of huge amounts of inputs, particularly diesel for farm operations. Therefore, the adoption of more sustainable design and practices 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 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, they do however mean great environmental impact at local and regional level. Likewise, ethanol production from sugarcane release CO_2 due to the use of fuels and industrial inputs during agricultural and industrial processing. Besides that, it is important to keep in mind that the production of ethanol in large scale will reduce arable land to produce food crops.

Acknowledgments

The authors wish to acknowledge the financial support of FAPESP (The State of São Paulo Research Foundation). We are also grateful to Otávio Cavalett for the many ideas offered during the preparation of this paper.

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