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24

Emergy Assessment of Biodiesel from Conventional, Organic, and Agroecological Soybean

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ABSTRACT

This paper presents emergy assessment of biodiesel production in Brazil using conventional, organic and agroecological grown soybean. For the conventional soybean biodiesel the indicators are: Transformity: 5.05E+05 seJ J^{-1}; Renewability: 24.1%; Emergy yield ratio: 1.40; Environmental loading ratio: 3.15. These values indicate high demand of non renewable resources and low sustainability degree, it is because the crop production and its industrial conversion are supported by non-renewable resources s chemicals, goods, and process energy. It also reinforces global warming due to direct and indirect fossil fuel use, soil oxidation, waste treatment, substitution of forest area by agriculture, etc. Negative externalities account for 12.7% of the biodiesel produced from conventional soybean transformity. The biodiesel from organic soybean (small scale, family managed) present better indicators: Transformity: 4.25E+05 seJ J^{-1}; Renewability: 36.4%; Emergy yield ratio: 1.63; Environmental loading ratio: 1.74. Negative externalities accounted for only 2.2% of the transformity value in this case. The biodiesel from agroecological soybean production (small scale, family managed, ecological principles) present the better indicators: Transformity: 3.09E+05 seJ J^{-1}; Renewability: 49.5%; Emergy yield ratio: 1.92; Environmental loading ratio: 1.02. These results showed that biodiesel produced from organic and agroecological soybean are better alternatives for energy supply. However, the biofuel production policy implemented in Brazil supports the conventional energy intensive system and, as result, the large scale monoculture farms are stimulated to reproduce and substitute traditional food production farming. Therefore, it is possible to observe that Brazilian biodiesel production policy moved to the opposite direction of their original objectives: clustering biodiesel production with more sustainable systems of vegetable oil production (lower scale, ecological mode of production and more working places).

INTRODUCTION

Biofuels production has increasing importance on world discussion on energy alternatives. One of the main reasons presented to promote biofuels production is that they are clean (or “green”) because they are produced from renewable natural sources and, therefore, could supply a virtually infinite amount of energy for an infinite period of time.

However, if one takes a closer look at the complete biofuels production chain, the benefits do not appear so clear anymore. Biofuel production requires the use of fossil fuel energy, in the form of fertilizers, agrochemicals, machinery for both agricultural and industrial stages, as well as transportation of raw materials, inputs and distribution of biofuel for final use. This high amount of non renewable resources compromises the biofuel sustainability.

Cavalett and Ortega (2007b) showed that the environmental impacts of biodiesel production from conventional soybean are very high and the production system has low degree of sustainability. Studies also showed that agricultural stage is the most important stage for biodiesel production chain (it is responsible for approximately 85% of the biodiesel transformity) (Cavalett and Ortega 2007a; 2007b). Therefore, the agricultural stage has expressive influence in these results. Moreover, the emergy assessment performed by Ortega et al. (2002; 2005) also indicated that conventional soybean production system has low degree of sustainability and it causes high load pressure on the environment. Because of that is very important to evaluate alternative soybean production options in order to provide sufficient insight for more sustainable biodiesel policy making.

The objective of this study is to discuss the environmental performance of biodiesel production from different soybean production systems in Brazil by using the emergy accounting methodology. Emergy synthesis is a very appropriate tool for such an evaluation, since it generates environmental performance indicators that allow us to assess the resources used for the production and processing systems. In this paper the emergy indicators for the conventional soybean biodiesel (CSB) production are compared with more sustainable alternatives. As more sustainable soybean production alternatives it was considered the organic (OSB) and agroecological (ASB) systems.

MATERIAL AND METHODS

Emergy Synthesis

At the core of an emergy evaluation of a given production system or process is a mass and energy flow analysis in which the flows are adjusted for energy quality using the appropriated conversion factors (transformity, specific emergy, emdolar). Odum (1996) and Brown and Ulgiati (2004) give a detailed explanation of the application of emergy accounting procedures for a variety of systems. Emergy accounting is particularly suitable for studies in agriculture, as it is a system in which natural and man-made contributions interact in order to obtain the final product, emphasizing the role of ecological inputs (Brandt-Williams, 2002).

The materials and services were not totally considered as nonrenewable resources. In this assessment the partial renewability of economy resources was considered in the emergy calculation (Ulgiati et al., 1994; Ortega et al., 2002; 2005; Agostinho et al., 2007; Cavalett et al., 2006; Castellini et al., 2006).

In order to survive, the organic or agroecological systems must be able to compete with conventional systems. This requires the proper taxation of inputs and output. Therefore, the emergy accounting should consider the real values of the inputs; taking into account the damage done to the environment (negative externalities and loss of environmental services). Ortega et al. (2005) used the emergy methodology to evaluate four different soybean production systems in Brazil (organic, ecological, herbicide, chemical) and identify the external forces that influence the public policy of the soybean agriculture in Brazil. The work identified that besides the conventional soybean production system produces more negative externalities per unit area, powerful emergy flows act in the soybean agriculture to promote the conventional soybean as well other technological innovations instead of the organic and agroecological production systems.

The present study incorporates values of negative externalities in the emergy evaluation procedures. These negative externalities were accounted for in the emergy calculation as an additional service (measured as economical cost) that the agricultural production system should pay in order to compensate the society for the environmental and social damages caused by the production process. Negative externalities produced by conventional soybean production system were considered as 345 USD ha^{-1} $year^{-1}$ according Ortega et al. (2005). In this value costs for the soil erosion (83.00 USD $ha^{-1}year^{-1}$), nutrients lost due soil erosion (13.60 USD $ha^{-1}year^{-1}$), carbon dioxide emission (7.84 USD $ha^{-1}year^{-1}$), methane emission (20.52 USD $ha^{-1}year^{-1}$), nitrous oxide emission (32.00 USD $ha^{-1}year^{-1}$), effluent treatment (39.70 USD $ha^{-1}year^{-1}$), ecosystem destruction (98.50 USD $ha^{-1}year^{-1}$), intoxication due pesticide use (0.20 USD $ha^{-1}year^{-1}$) and rural exodus (50.00 USD $ha^{-1}year^{-1}$) were considered. Negative externalities produced by organic production system were considered as 39 USD ha^{-1} $year^{-1}$

according Pretty et al. (2005). The agroecological production system was considered without produce negative externalities (Ortega et al., (2005).

Soybean Biodiesel Production System

Figure 1 shows the system diagram of the biodiesel production process. The biodiesel production stages considered in this assessment were: soybean agricultural production; transport to industry; crushing process to produce soy oil and soy meal and trans-esterification of soy oil to produce biodiesel. The agricultural soybean production system in Brazil is detailed in Figure 2.

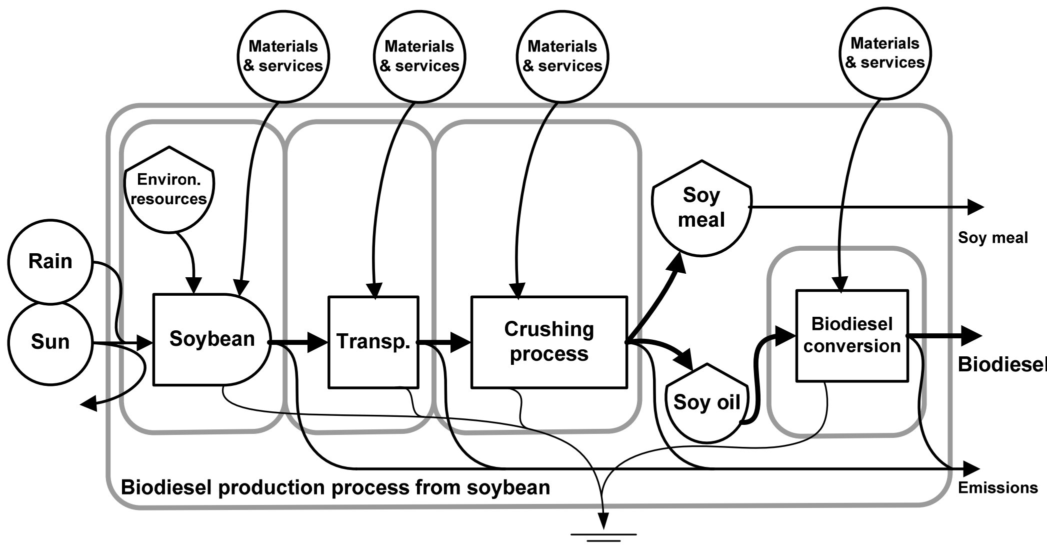

Figure 1: *Energy system diagram of the biodiesel production process from soybean.*

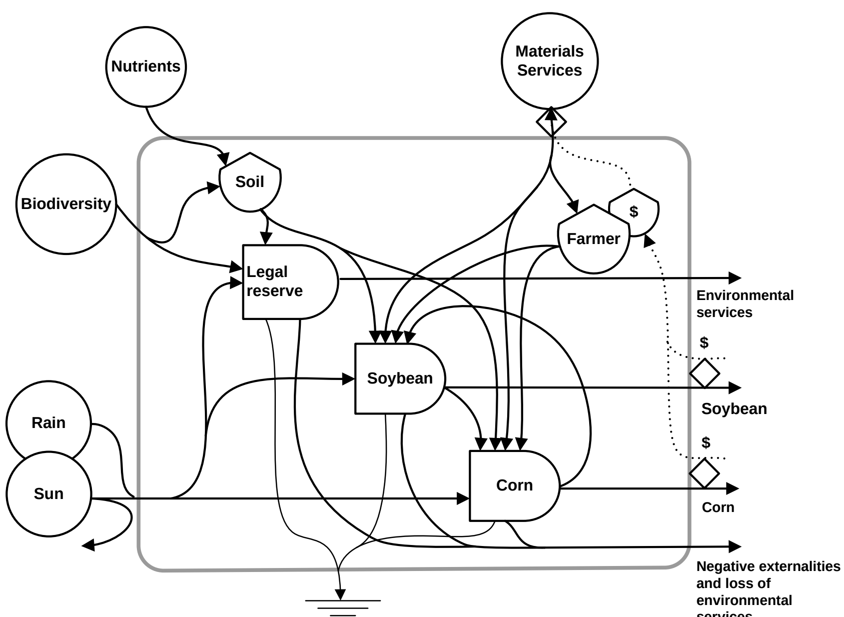

Figure 2*: Energy system diagram of the agricultural soybean production system.*

RESULTS AND DISCUSSION

Table 1 present the emergy flows and emergy indicators results and Figure 3 shows the emergy signature of biodiesel production from the different agricultural systems. In Figure 3 all the inputs were spited in seven different categories: environmental flows, fossil fuels, electricity, machinery, purchased goods from economy, labor & services and negative externalities produced.

The environmental flows for the conventional soybean biodiesel (CSB) are highest due to the higher soil loss in the agricultural production stage. It is important make clear that the soil loss is included as a local non renewable resource (N) in the emergy calculations while the other environmental inputs (rain, deep heat and nitrogen fixation) are accounted for as local renewable resources (R). This system also requires more machinery, purchased goods and labor & services use. It also generates more negative externalities measured as additional service (economical cost) of the production process

Relating the emergy results with productive performance it is possible to show that, although the annual crop yield was lower (24%) in organic and agroecological systems than in conventional one, the transformity of organic soybean biodiesel (OSB) was around 16% lower and agroecological was around 39% lower than CSB. In this respect, it has been shown that almost the OSB, which use less chemical fertilizers and pesticides, saved 36% emergy in comparison with CSB. The emergy savings of the agroecological soybean biodiesel (ASB) in comparison with CSB were 53%. These values are reflected in a relevant difference in the empower densities

Transformity, specific emergy and empower density significantly decrease from CSB to ASB due to the higher emergy flows supporting the agricultural stage indicating a higher demand for resources and therefore a lower large-scale efficiency. Nevertheless, the biodiesel transformities from different soybean production methods are higher than those calculated by Odum (1996) for fossil fuels (coal, 6.70E+04 seJ J^{-1}; natural gas, 8.04E+04 seJ J^{-1}; oil 9.05E+04 seJ J^{-1}; gasoline and diesel, 1.11E+05 seJ

Table 1: Summary of the emergy flows and emergy indicators for biodiesel produced from different agricultural systems.

	Conventional	Organic	Agroecological	Unit
Emergy flows considering partial renewability				
Local renewable inputs (R)	2.42E+15	2.35E+15	2.32E+15	seJ ha^{-1}
Locally non renewable inputs (N)	5.72E+14	2.86E+14	3.36E+13	seJ ha^{-1}
Purchased inputs without services (F)	3.42E+15	1.80E+15	1.48E+15	seJ ha^{-1}
Labor and services (S)	3.63E+15	2.01E+15	8.56E+14	seJ ha^{-1}
Total emergy inputs (Y)	1.00E+16	6.45E+15	4.69E+15	seJ ha^{-1}
Emergy flows without considering partial renew.				
Local renewable inputs (R)	2.29E+15	2.21E+15	2.21E+15	seJ ha^{-1}
Locally non renewable inputs (N)	5.72E+14	2.86E+14	3.36E+13	seJ ha^{-1}
Purchased inputs without services (F)	3.53E+15	1.91E+15	1.59E+15	seJ ha^{-1}
Labor and services (S)	3.64E+15	2.05E+15	8.56E+14	seJ ha^{-1}
Total emergy inputs (Y)	1.00E+16	6.45E+15	4.69E+15	seJ ha^{-1}
Emergy indicators				
Transformity	5.05E+05	4.25E+05	3.09E+05	seJ J^{-1}
Specific Emergy	1.62E+13	1.36E+13	9.90E+12	seJ kg^{-1}
Emergy Yield Ratio	1.40	1.63	1.92	
Environmental Loading Ratio*	3.15	1.74	1.02	
Renewability*	24.1	36.4	49.5	%
Empower Density	1.00E+12	6.45E+11	4.69E+11	Sej m^{-2}
Investment Ratio	2.50	1.58	1.09	
Emergy Exchange Ratio	6.65	6.83	7.31	
Emergy Sustainability Index*	0.44	0.94	1.88	

*Emergy indicators calculated with emergy flows considering partial renewability.

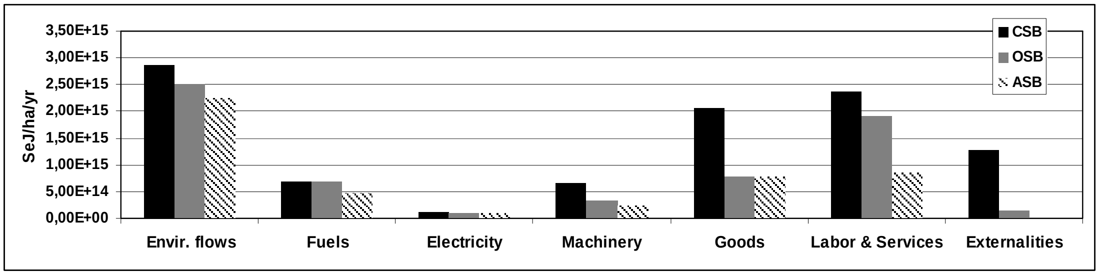

Figure 3: *Emergy signature of biodiesel production from different agricultural systems.*

J^{-1} and close to those values obtained by Giampietro and Ulgiati (2005) for other biofuels (Ethanol from corn. 3.15E+05 seJ J^{-1}; Biodiesel from sunflower. 2.31E+05 seJ J^{-1}).

The emergy yield ratio (EYR) is a measure of the ability of the product to contribute to the economic system by amplifying the investment. EYR values range from 1.40 to 1.92 for case studies of soybean biodiesel. while it ranges from 3 to 7 for fossil fuels (Odum. 1996). Emergy indicators showed in Table 1 show that ASB emergy yield ratio is higher than CSB. indicating a relatively less relevant use of external inputs. which is a higher level of dependence on local ones in the ASB production system. The ASB can provide 35% more net emergy contribution to society than CSB. The conventional soybean agricultural production methods in Brazil are characterized by intensive use of herbicides. fertilizers. agrochemicals. and agricultural machinery. Biodiesel EYR can be increased by reducing the use of non renewable resources by the system such as in the organic and agroecological systems.

The high dependency on economy resources (F) also can be noticed by the highest environmental impact indicator (ELR) calculated by CSB. The ELR values show that the non-renewable part of the emergy is 3.15. 1.74 and 1.02 times higher than the renewable part for CSB. OSB and ASB production. respectively. meaning that the imbalance in favor of the non-renewable is less than one third for the ASB with respect to the CSB.

The %R values indicate that soybean biodiesel is not a fully renewable source of energy. When it is produced by the conventional production system the renewability is only 24.1%. This means that production processes uses 76% of external to a high degree of non renewable origin. Nevertheless. it is still better than fossil fuels that are non renewable resources. Fossil fuels are considered to be a non renewable resource since the use exceeds the rate that this resource is generated. However biodiesel can be produced from more sustainable soybean cropping systems. increasing it's %R to 36.4% for organic soybean and to 49.5% for agroecological soybean.

The EIR value of CSB is the highest when compared to other biodiesel production systems. This indicates an intensive use of purchased resources from economy in comparison with the "free" resources from nature. jeopardizing CSB competitiveness in the long run.

The EER values obtained for biodiesel were between 6.65 and 7.31. Therefore. it is possible to notice that the system are delivering around seven times more emergy with the soybean sold than the emergy they are receiving with the money paid for it. on an average. This means that production system exports much more emergy in the biodiesel delivered than the emergy it receives through the money received in exchange. The CSB showed lowest EER value indicating that this system is losing less emergy in the exchange with the external market when compared to the biodiesel produced in the organic and agroecological systems. It occurs due to higher crop yield in the soybean conventional system. Usually. agricultural systems transfer emergy to urban systems. Odum (1996) reports EER values between 5 and 10 for agricultural and other primary processed products. The EER calculated showed that there are great benefits for the purchasers of soybean biodiesel because they receive much more emergy with the products than the emergy they are paying in the form of money.

The ESI values showed that CSB is the system that produces less net emergy per unit of stress on the environment. On the other hand. the ASB is the system that showed better net benefit to the society.

The incorporation of the negative externalities and loss of environmental services are an very important issue to address more properly the real environmental performance of complex agricultural production systems. The negative externalities and loss of environmental services represented 12.7% of the CSB transformity. For OSB this value was lower: 2.2%.

Comparison of the organic and agroecological soybean production systems with a conventional one from the viewpoint of sustainability showed that all the emergy-based indicators are in favor of the OSB and ASB production systems with a higher efficiency in transforming the available inputs in the final product. a higher level of renewable inputs. a higher level of local inputs and a lower density of energy and matter flows. The study also showed that the other indexes are consistent in indicating the organic and agroecological systems with better environmental performance (see Table 1). These results indicate that biodiesel from organic or agroecological soybean are better alternatives for biodiesel production because they are able to decrease the system's dependence on non renewable resources by the maximization of local resources and internal recycling.

The organic and agroecological production systems are important strategies heading in the direction of sustainability. using less external non renewable resources. avoiding the use of some chemical compounds. limiting the intensity of production and providing controls along the entire biodiesel production chain. However. the biofuel production policy implemented in Brazil supports the conventional energy intensive systems and. as result. the large scale monoculture farms are stimulated to reproduce and substitute traditional food production farming. Therefore. it is possible to notice that Brazilian biodiesel production policy mainly seeking maximizing the economic profit. in spite of their original objective that was clustering biodiesel production with more sustainable systems of bioenergy production. The more sustainable biodiesel production can only be achieved by more ecological production practices. small scale and local consumption.

CONCLUSION

The comparison of more sustainable soybean production systems with the conventional one from the viewpoint of sustainability showed that all the emergy-based indicators are in favor of the biodiesel from organic and agroecological farming systems. In particular there is: higher efficiency in transforming the available inputs in final product; higher level of renewable inputs; higher level of local inputs; lower density of energy and matter flows.

The conventional biodiesel production chain is strongly dependent on the use of non renewable resources in the agricultural production. transport and industrial processing stages. When crop production and industrial conversion to fuel are supported by fossil fuels in the form of chemicals. goods. and process energy. the fraction of fuel that is actually renewable is very low (around 24%).

Results showed that biodiesel production from conventional soybean is not the best alternative taking into consideration the emergy assessment performed in this study. In the last century. the use of industrial resources in conventional soybean crops increase sharply. Conventional soybean agriculture is strongly dependent on chemical inputs and high technology to ensure crops yields. The excessive and inadequate use of these resources. in ensure the crop yield short time perspective. also increase soybean production costs and produce high pressure on the environment. However. soybean biodiesel can be produced in more sustainable systems (organic and agroecological) as quantitatively showed by the emergy indicators of this study. In spite of the more sustainable systems still produce less biodiesel per unit of area; they use less external non renewable inputs for this production than the conventional production system. According to the maximum empower principle. the biodiesel production system should be designed in order to feedback part of the production for the production processes and provide only the surplus as output to the local market to achieve a better degree of sustainability.

The future of biofuels is very likely to be linked to the ability of clustering biofuels production with other agro industrial activities at an appropriate scale and mode of production (organic or agroecological) to take advantage of the potential supply of valuable co-products. If the biofuels production systems are not carefully designed into the diversified small scale perspective with ecological principles. the intensive exploration of land and fossil fuel use for biofuels production is more likely to result many environmental and social damages than to become a renewable source of energy to society.

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APPENDIX 1: Data used in the emergy evaluation for the different soybean production systems.

Inputs	Conventional	Organic	Agroecological	Unit
Sun	5000	5000	5000	$Wh/m^2/yr$
Rain. average precipitation	1715	1627	1627	mm/yr
Evpotranspiration	62	62	62	%
Deep heat	3000000	3000000	3000000	$J/m^2/yr$
Nitrogen fixed from atm.	60	60	60	kg/ha/yr
Soil loss	17000	8500	1000	kg/ha/yr
Limestone	375	0	0	kg/ha/yr
Herbicides	4.8	0	0	kg/ha/yr
Pesticides	3.2	0	0	kg/ha/yr
Seeds	69	67	80	kg/ha/yr
Fertilizer. NPK (0-20-20)	394	68	50	kg/ha/yr
Fuels (includes diesel. gasoline. lubricants)	65	86.3	38	L/ha/yr
Electricity	34	34	34	kWh/ha/yr
Machinery (Steel)	55	27.5	18.3	kg/ha/yr
Farm buildings	531	531	531	USD/ha
Organic fertilizer	0	69	69	kg/ha/yr
Other organic inputs	0	12	12	kg/ha/yr
Local labor	25	6.8	32	h/ha/yr
Extra labor	13	43.8	0.4	h/ha/yr
Externalities	0	39	0	USD/ha/yr
Services (total cost)	498	305	153	USD/ha/yr
Output				
Average soybean yield	2932	2240	2240	kg/ha/yr

APPENDIX 2: Data used in the emergy evaluation for the biodiesel industrial phases.

Inputs	Amount	Unit
Soybean transport		
Steel	2.05	kg/ha/yr
Fuel	4.40	kg/ha/yr
Labor and services	22.9	USD/ha/yr
Crushing process		
Steel	0.294	kg/ha/yr
Cement	0.286	kg/ha/yr
Iron	0.011	kg/ha/yr
Fuel	52.5	kg/ha/yr
Electricity	87.7	kWh/ha/yr
Water	2109	kg/ha/yr
Hexane	3.5	kg/ha/yr
Labor	0.591	h/ha/yr
Services	48.2	USD/ha/yr
Biodiesel production		
Steel	1.283	kg/ha/yr
Cement	0.351	kg/ha/yr
Iron	0.007	kg/ha/yr
Fuel	28.3	kg/ha/yr
Methanol	78.0	kg/ha/yr
Catalyst	5.6	kg/ha/yr
Electricity	0.465	kWh/ha/yr
Water	270	kg/ha/yr
Labor	0.36	h/ha/yr
Services	27.9	USD/ha/yr