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

Environmental Impacts Assessment of Biodiesel Production from Soybean in Brazil

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Abstract

This paper presents the results of the environmental impacts of biodiesel production from soybean in Brazil. For this objective it were used the environmental impact indicators provided by emergy accounting method, the embodied energy analysis and the material flow accounting method. One of the in findings of the study are that energy content in a liter of biodiesel is only 2.3 times greater than the fossil-based energy required to produce it. The transformity of biodiesel (4.59E+05 seJ/J) is higher than those calculated for fossil fuels (coal, 6.70E+04 seJ/J; natural gas, 8.04E+04 seJ/J; oil 9.05E+04 seJ/J; gasoline and diesel, 1.11E+05 seJ/J) and also for other biofuels (Ethanol from sugarcane, 3.15E+05 seJ/J; Biodiesel from sunflower, 2.31E+05 seJ/J) indicating a higher demand for resources. Similarly, the biodiesel emergy yield ratio was only 1.46, while it ranges from 3 to 7 for fossil fuels indicating lower net emergy that is delivered to consumers. When crop production and industrial conversion to fuel are supported by fossil fuels (considered non renewable energy sources) in the form of chemicals, goods, and process energy, the fraction of fuel that is actually renewable is very low (around 25%). In this way, the future of biodiesel production 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 to take advantage of the potential supply of valuable co-products.

Keywords: Emergy accounting, Energy balance, Material flow accounting, Biodiesel; Soybean.

1 Introduction

The use of Biodiesel has been an increasingly important topic on world discussion on energy resources. Usually it is presented as suitable option for energy supply, since, if adequately supported, biodiesel can replace a portion of fossil fuels demand. The main reasons often presented to promote biodiesel production are: (a) It is a clean or “green” energy produced from renewable natural sources and, therefore, could supply a virtually infinite amount of energy for an infinite period of time; (b) It is often stated that biodiesel, by replacing oil products, would allow reducing greenhouse gases emissions. It is supposed that the carbon emitted by biodiesel in the combustion phase is the one absorbed by the plant during its growth through photosynthesis, resulting in a neutral carbon budget; (c) Finally, biodiesel production is divulged though press that constitutes a strategy for rural development.

However, if one takes a closer look at the entire biodiesel production chain, these benefits do not appear so clear. In fact, biodiesel production requires the use of fossil fuel energy, in the form of fertilizers, agrochemicals, fuels, machinery for both agricultural and industrial stages.

In order to obtain this wide overview on the biodiesel production process, including the environmental impact, a comprehensive assessment was carried out. The objective of this study is to discuss the global environmental impacts of biodiesel production from soybean in Brazil. For this objective it were used three environmental assessment methods as proposed by Ulgiati et al. (2006): (a) Emergy accounting, (b) Embodied energy analysis and (c) Material flow accounting.

2 Methods

The Material Flow Accounting method (MFA) (Hinterberger and Stiller, 1998; Bargigli et al., 2004) evaluates the environmental disturbance associated with the withdrawal or divertion of material flows from their natural ecosystemic pathways. In this method, appropriate material intensity factors (kg/unit) are multiplied by each input, respectively, accounting for the total amount of abiotic matter, water, air and biotic matter that is directly or indirectly required in order to provide that very same input to the system. The resulting material intensities (MI) of the individual inputs are then separately summed and assigned to the system's output as a quantitative measure of its cumulative environmental burden.
The Embodied Energy Analysis method (Slesser, 1974; Herendeen, 1998) deals with the gross energy requirement of the analysed system. The method accounts for the amount of commercial energy that is required directly and indirectly by the process of making a good or a service (Herendeen, 1998). As the embodied energy analysis of a product is concerned with the depletion of fossil energy, all the forms of material and energy that do not require the use of fossil resources to make them available are not accounted for. For instance, resources provided for free by the environment such as rain, topsoil, spring water, human labor and economic services are not accounted for by embodied energy analysis. In this method, all the material and energy inputs to the analysed system are multiplied by appropriate oil equivalent factors (kg oil/unit), and the cumulative embodied energy requirement of the system's output is then computed as the sum of the individual oil equivalents of the inputs, which can be converted to energy units by multiplying by the standard calorific value of oil fuel (41860000 J/kg).
The Emergy Accounting method (Odum, 1996; Brown and Ulgiati, 2004) looks at the environmental performance of the system on the global scale, taking into account all the free environmental inputs such as sunlight, wind, rain, as well as the indirect environmental support embodied in human labour and services, which are not usually included in traditional embodied energy analyses. Emergy methodology uses the solar energy embodied in the system's inputs as the measurement base. Emergy is defined as the total amount of solar available energy that was directly or indirectly required to make a given product or to support a given flow, and measured in solar equivalent Joules (seJ). The amount of emergy that was originally required to provide one unit of each input is referred to as its specific emergy (seJ/unit) or transformity (seJ/J). 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 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.

3 Results and Discussion

In this assessment it was considered the biodiesel production from soybean. The stages are: soybean agricultural production; transport to industry; crushing process to produce soy oil and soy meal and trans-esterification of soy oil to produce biodiesel. Figure 1 shows the system diagram of the biodiesel process.

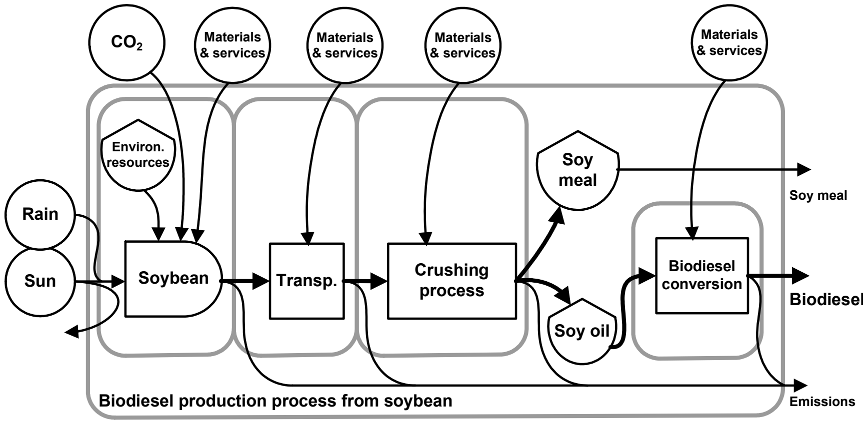

Fig. 1. System diagram of the biodiesel production process from soybean.

Table 1 shows the results of the three analysis of the conversion process of soybean to biodiesel. The available set of indicators offer a way to evaluate the process sequentially (the agricultural step first, and then the industrial step).

Table 1: Matter, fossil energy and emergy indicators in soybean and biodiesel production.

Indicator	Soybean	Biodiesel	Unit[a]
Input			
Soil eroded	5.80	8.57	kg/FU
Oil equivalent demand	0.09	0.29	kg/FU
Gross fertilizers demand	0.13	0.20	kg/FU
Pesticides demand	0.003	0.004	kg/FU
Material intensity, abiotic factor	4.56	7.12	Kg/FU
Material intensity, water factor	5855	8662	kg/FU
Material intensity, air factor	0.04	0.55	kg/FU
Material intensity, biotic factor	0.23	0.45	kg/FU
Total material input (including water)	5859	8670	kg/FU
Labor demand	0.013	0.020	hr/FU
Land demand	3.41	5.04	m^2/FU
Output			
Total product	2932	621	kg/ha yr
Net energy yield	55372	11358	MJ/ha yr
CO_2 released	0.28	0.92	Kg CO_2/FU
Industrial wastewater released	-	1.26	L/FU
Energy Output/Input	6.07	2.34	
Emergy indicators			
Transformity	1.17E+05	4.59E+05	seJ/J
Specific emergy	2.65E+12	1.29E+13	seJ/FU
Renewability = R/Y	29.5	25.1	%
Emergy Yield Ratio = Y/(M+S)	1.58	1.46	
Environmental Loading Ratio = (M+S+N)/(R)	2.39	2.97	
EYR/ELR	0.66	0.49	

[a] The Functional Unit (FU) is 1 kg for soybean and 1 liter for biodiesel.

Analysis from the Material Flow Accounting perspective

Table 1 shows that some material flows are remarkably high. For instance, about 8.6 kg of topsoil eroded, 0.2 kg of fertilizers and 7.12 kg of abiotic materials are necessary per liter of biodiesel produced, also about 0.92 kg of CO_2 are released per liter of biodiesel produced. As expected, higher unit material, energy, land and labor demands are calculated for biodiesel than for soybean, due to further processing stages.

Analysis from the embodied fossil energy perspective

The energy efficiencies are calculated on the global scale and offer an interesting overall energy cost evaluation of the biodiesel production. About 0.09 kg of crude oil equivalent is needed to produce 1 kg of soybean, which translates into an energy return of about 6.07 Joule of soybean per Joule of fossil fuel invested. Instead, 0.29 kg of oil equivalent are globally required per liter of biodiesel produced, equal to an energy return of 2.34 Joule of biodiesel per Joule of fossil fuel invested. This value is higher than those calculated by Venturi and Venturi (2003) (0.7 - 1.6) and by Pimentel and Patzek (2005) (0.79) for biodiesel from soybean; by Janulis (2004) (1.04 - 1.59) for biodiesel from rapeseed; and by Giampietro and Ulgiati (2005) (0.98 – 1.21) for biodiesel from sunflower. On the other side the value obtained is a little lower than that calculated by Sheehan et al. (1998) (3.2) for biodiesel from soybean. Fossil fuels presents much better energy return, between 10 - 15 and, also, wind energy, with energy return around 8 (Ulgiati, 2001). The biodiesel energy return calculated using energy allocation (2.34) yield the net-to-gross ratio of 0.54. This means that it is necessary to produce 1.75 liters of biodiesel to deliver one liter of biodiesel to the society if we foresee a biodiesel production process that is independent for fossil fuels inputs. This would make resources demand 75% larger than those calculated in Table 1.

Analysis from the emergy perspective

The transformity of 1.17E+05 seJ/J is calculated for soybean in the field. Instead, the biodiesel is produced in the industrial phase, with transformity of 4.59E+05 seJ/J. Transformities and specific emergies significantly increase from soybean to biodiesel due to the flows of emergy supporting the industrial steps. Emergy indicators show a higher environmental loading of the whole process compared to the agricultural step alone.

Transformity can be used to compare different production systems producing same product, helping to choose the better alternative. The transformity of biodiesel from soybean is higher than those calculated by Odum (1996) for fossil fuels (coal, 6.70E+04 seJ/J; natural gas, 8.04E+04 seJ/J; oil 9.05E+04 seJ/J; gasoline and diesel, 1.11E+05 seJ/J; however, is important to notice that these tranformities can be underestimated because were calculated using old baseline transformities) and close to those values obtained by Giampietro and Ulgiati (2005) for other biofuels (Ethanol from sugarcane, 3.15E+05 seJ/J; Biodiesel from sunflower, 2.31E+05 seJ/J) indicating a higher demand for resources and therefore a lower large-scale efficiency.

The emergy yield ratio (EYR) is a measure of the ability of the product to contribute to the economic system by amplifying the investment. Biodiesel EYR is only 1.46, while it ranges from 3 to 7 for fossil fuels (Odum, 1996). Therefore, based on emergy accounting results, the investigated case of biodiesel from soybean does not compete with nonrenewable energy resources, even when its energy efficiencies are higher than 1.

The biodiesel EYR can be increased by reducing the use of non renewable resources by the system, mainly on the agricultural stage, which use the major part of resources. The usual soybean agricultural production methods in Brazil are characterized by intensive use of herbicides, fertilizers, agrochemicals, and agricultural machinery. The high dependency on economy resources (F) can be noticed by the environmental impact indicators calculated by biodiesel production processes. Therefore, the agricultural stage has expressive influence in these results.

4 Conclusion

In the last century, the use of industrial resources in soybean crops increase sharply. Agriculture become strongly dependent on chemical inputs and high technology to ensure crops yields. Most of these resources is directly or indirectly dependent on the global availability of the fossil fuels and, also, some minerals, both non renewable resources. 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 as quantitatively showed by the indicators calculated in this study.

Results showed that biodiesel production from soybean as proposed until now is not a viable alternative taking into consideration materials, energy, emergy and CO_2 emission assessment performed in this study. In fact, direct pollution (industrial wastewater, agrochemicals, pesticides) and other environmental damages (soil loss, deforestation, biodiversity loss) related to the net energy delivered to society as biodiesel indicate that large scale production produce a high pressure on the environment. The sustainability of the biodiesel production 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 25%).

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 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, 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 energy source to society.

Acknowledgment

The authors wish to acknowledge the financial support of Capes. We are also grateful to Consuelo Pereira for the many ideas offered during the preparation of this paper.

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