Assessing the sustainability of Brazilian oleaginous crops – possible raw material to produce biodiesel

Fábio Takahashi*, Enrique Ortega

FEA (College of Food Engineering) – Unicamp, CP 6121, CEP 13083-862 Campinas, SP, Brazil

ARTICLE INFO

Article history:
Received 24 June 2009
Accepted 16 December 2009
Available online 18 January 2010

Keywords:
Biodiesel
Sustainability
Emergy synthesis

ABSTRACT

The aim of this paper is to make an emergy assessment of oleaginous crops cultivated in Brazil, available to produce biodiesel, in order to determine which crop is the most sustainable. This study evaluates conventional agro-chemical farms that produce rapeseed (canola), oil palm, soybean, sunflower and cotton. Rapeseed (canola) crop uses 40.41% of renewable energy and it is the most sustainable conventional oil crop; on the other hand, it is not widely produced in Brazil, probably due to climate restrictions or low market demand. The oil palm emergy indicators are contradictory: its emergy exchange ratio (EER) value is the lower, showing the possibility of fair exchange, and the low transformity value indicates high efficiency; however, it also has low renewability (28.31%), indicating a high dependency on agro-chemicals (basically fertilizers). Oil palm is a potential energy source due to its high agricultural productivity, but appropriate management is necessary to increase its sustainability and reduce the use of non-renewable resources.

1. Introduction

This paper reports part of a vast work on assessing the sustainability of Brazilian agricultural systems using the emergy methodology (Ortega et al., 2005; Takahashi et al., 2008). The subsystem studied in this paper is “Oleaginous crops”, and was chosen mainly to contribute to the discussions about the sustainability of biofuels.

World-wide oil production from crops is estimated to be 144.8 million tonnes and Brazil is responsible for 8% of this amount (FAO, 2009). Only six oil crops are responsible for 90% of the vegetable oil used in the world: oil palm, soybean, rapeseed, sunflowers, peanuts and cotton in order of volume of oil production. Oil plants and the chemical products derived from them are an alternative to petroleum stocks (Carlsson, 2009). There are many debates about the consequences of the use of biofuels in particular regarding the impacts on climate, the emission of CO₂ and NOₓ (Reijnders, 2006). The analysis of exhaust emission from the combustion of rapeseed biodiesel when compared with diesel showed that he use of biodiesel reduces emissions of CO₂ emissions but also increase of NOₓ emissions (Krahl et al., 2009).

The projected rise of biofuels demand for transportation is expected to cause a significant increase in vegetable oils production. In Brazil, this increase in demand is projected to be of 260% by 2030, and worldwide it is of 900% in the same time span (Escobar et al., 2009).

Brazil is already a potential producer of biofuels, especially ethanol and biodiesel. The National Program for Production and Use of Biodiesel (PNPB) was launched in December 2004. Besides the economic objective of fostering biodiesel production, a major social objective was the regional development via promotion of small family agricultural units. The PNPB provided research incentives for projects associated with biodiesel and stimulated the market demand for biodiesel in the Brazilian energy matrix. Biodiesel is defined by PNPB as a “biofuel derived from renewable biomass for use in engines of internal combustion with ignition by compression or for generation of another type of energy that can partially or totally substitute fossil fuels” (Pousa et al., 2007).

Are oilseed crops for biodiesel renewable? In order to answer this question and verify the environmental impact caused by biodiesel production, various methodologies and indicators have been used, such as ecological footprint (Stoeglehner and Narodoslawsky, 2007), exergy analysis (Talens et al., 2007), carbon footprint (Holzman, 2008), energy analysis (Ortega et al., 2005; Cavalett and Ortega, 2009; Comar et al., 2004) and life cycle assessment (LCA) (Yee et al., 2009).

LCA in agriculture focuses primarily on the environmental impact of emissions and non-renewable energy inputs in the product’s life cycle, from the extraction of the natural resource to the use and disposal of the product. LCA does not include ecosystem services and products, and the final results of this analysis depend on subjective evaluation. For this reasons, Ulgiati...
et al. (2007) proposed the integration among methods that may be potentially complementary like LCA and energy evaluation (Pizzigallo et al., 2008).

Emergy methodology is able to evaluate environmental and economic products and services in a common basis called “solar emergy” (Scienceman, 1987) and it has already been applied to several agricultural systems to compare management and scale (see for example Martin et al., 2006; La Rosa et al., 2008; Bastianoni and Marchetti, 1996).

The aim of this paper is to evaluate the main oleaginous crops cultivated in Brazil using the emergy methodology to verify the sustainability of the possible raw materials used to produce biodiesel and thus determine which crop is the most sustainable for biofuel production. This is a very important task since raw materials contribute a major portion to the cost of biodiesel production (Sharma and Singh, 2009), and the choice of raw materials and the agricultural practices used have a great influence on the ecological impacts (Stoeglehner and Narodowsky, 2009).

1.1. Characterization of the oleaginous crops evaluated

Oleaginous plants are vegetable oil-producing plants, which have a wide range of chemical compositions. The crops evaluated in this study are cotton seed, soybean, canola, sunflower and oil palm. Among this group, cottonseed oil is the only non-edible oil. It is important to distinguish these types of oils because edible oils intended for food cannot be processed in the same industrial processing facilities as non-edible oils. Table 1 shows the main characteristics of the oleaginous plants assessed in this study.

The palm oil is the most produced oil in the world. Oil palm (Elaeis guineensis) is believed to be indigenous to West Africa, but today more than 80% comes from Southeast Asia, mainly Indonesia and Malaysia. Soybean oil is the second most produced oil in the world and Brazil is the second largest soybean producer (27%), just behind the US (33%) (FAO, 2009).

Rapeseed (Brassica napus) is the third largest oil crop with 12% of the world’s plant oil market; more than 60% is produced by Europe and China. The most popular type of rapeseed cultivated today is Canola. Sunflower oil accounts for approximately 9% of the world’s vegetable oil production; the main producers are Russia (20%) and Europe (19%) (Carlsson, 2009). Cotton (Gossypium hirsutum) produces non-edible oil, and the main producers are China (27%) and Australia (17%) (FAO, 2009). Table 2 shows the production of vegetable oil in Brazil.

1.2. Biodiesel

Biodiesel is a biofuel produced from vegetable oils, animal fats and even recycled cooking oil and is defined by PNPB as a “biofuel derived from renewable biomass for use in engines of internal combustion with ignition by compression or for generation of another type of energy that can partially or totally substitute fossil fuels” (Pousa et al., 2007).

PNPB stimulated the market demand for biodiesel in the Brazilian energy matrix encouraging the optional use of B2 (a diesel fuel with 2% biodiesel) until the beginning of 2008. Between 2008 and 2013, blends with up to 5% biodiesel can be used, and after this period, B5 will be mandatory. Since July 2008, Brazil has adopted blend B3, and it is forecasted to switch to the blend B4 by mid-2009 (ANP, 2009).

The world-wide production of biodiesel increased by 200% from 1995 to 2006, and the European Union was responsible for 75% of the global production of biodiesel in 2006 (Demirbas et al., 2009). The major producers of biodiesel and its main raw materials are shown in Table 3.

Brazil has a total of 65 industrial units of biodiesel producers with an annual capacity of 3.8 billion liters (ANP, 2009). The production of biodiesel in Brazil has grown rapidly in recent years, as shown in Fig. 1.

From 2004 to 2008, Brazilian biodiesel production increased from 404 million liters to 1.16 billion liters. In 2008, Brazilian diesel consumption amounted 44.6 billion liters, which represented a demand of 1.13 billion liters of biodiesel for the production of blend B2 (mandatory until June) and B3 (mandatory in July) (ANP, 2009). It is expected that the Brazilian government will make blend B4 mandatory by mid-2009 (Nacheluk and Freitas, 2009).

2. Materials and method

2.1. Emergy synthesis

The fundamentals of emergy synthesis can be found in the book Environmental Accounting (Odum, 1996). Emergy is defined as the sum of all inputs of energy directly or indirectly required in the process of producing a given product and is expressed in solar equivalent joules (seJ) (Odum, 1988; Scienceman, 1987). Emergy analysis considers inputs from nature (e.g., sun, rain, wind, soil nutrients) and from the economy (e.g., goods, services, machinery, fossil fuels). It is a powerful tool that can measure the real wealth of the work of nature and society and assess public policies aimed at sustainability and fair trade (Odum, 1996; Brandt-Williams, 2002; Ulgiati and Brown, 1998). Many published works related to agriculture and emergy analysis use this methodology to compare systems for different types of agricultural production and management and thus evaluate which is the most sustainable

Table 1 Characteristics of the oleaginous plants assessed in this study (Lora and Andrade, 2009).

<table>
<thead>
<tr>
<th>Species</th>
<th>Origin of the oil</th>
<th>Content of oil (%)</th>
<th>Maximum efficiency cycle</th>
<th>Harvesting months</th>
<th>Oil yield (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil palm or “Dendé” (Elaeis guineensis)</td>
<td>Nut</td>
<td>20</td>
<td>8 years</td>
<td>12</td>
<td>3000–6000</td>
</tr>
<tr>
<td>Sunflower (Helianthus annus)</td>
<td>Seed</td>
<td>38–48</td>
<td>Annual</td>
<td>3</td>
<td>500–1900</td>
</tr>
<tr>
<td>Canola (Brassica campestris)</td>
<td>Seed</td>
<td>40–48</td>
<td>Annual</td>
<td>3</td>
<td>500–900</td>
</tr>
<tr>
<td>Soy bean ( Glycine max)</td>
<td>Seed</td>
<td>17</td>
<td>Annual</td>
<td>3</td>
<td>200–400</td>
</tr>
<tr>
<td>Cotton (Gossypium hirsutum)</td>
<td>Seed</td>
<td>15</td>
<td>Annual</td>
<td>3</td>
<td>100–200</td>
</tr>
</tbody>
</table>

Table 2 Vegetable oil production in Brazil in 2007 (FAO, 2009).

<table>
<thead>
<tr>
<th>Vegetable oil</th>
<th>Production (tonnes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soybean oil</td>
<td>5,430,000</td>
</tr>
<tr>
<td>Cottonseed oil</td>
<td>242,000</td>
</tr>
<tr>
<td>Palm oil</td>
<td>190,000</td>
</tr>
<tr>
<td>Maize oil</td>
<td>75,000</td>
</tr>
<tr>
<td>Palm kernel oil</td>
<td>75,000</td>
</tr>
<tr>
<td>Sunflower oil</td>
<td>33,700</td>
</tr>
<tr>
<td>Rapeseed oil</td>
<td>30,000</td>
</tr>
</tbody>
</table>
The first step in an emergy diagnosis is to construct the diagrams that identify all inputs, outputs, components and their relationships. Fig. 2 shows a general diagram of the agricultural systems studied in this paper.

The next step is to evaluate the inputs and outputs of the system. Every energy inputs must be multiplied by a conversion factor (transformity) so that they can be expressed in solar equivalent joules. Transformity is defined as the emergy input per unit of available energy (exergy) output. For example, if 4000 seJ are required to generate a joule of wood, then the solar transformity of that wood is 4000 seJ per joule (or seJ/J) (Brown and Ulgiati, 2004b). The flows of emergy can then be aggregated according to their origin, as shown in Table 4, by considering the renewability fraction of each material and service (Ortega et al., 2005, 2002; Ulgiati et al., 1994; Agostinho et al., 2008).

The renewability fraction is very important to be considered because a fraction of the energy from some materials and services can be considered as renewable, such as seedlings, seeds and labor. The final stage includes a calculation of the emergy indices, as shown in Table 5.

2.2. Data collection for the emergy analysis

The data for emergy evaluation were obtained from AGRIANUAL (Agrianual, 2006), which is an important publication that provides data of the productivity and profitability of agricultural products in Brazil. Each crop has a different data set for each region, management strategies and productivity levels. The emergy evaluation shown in this study considered the average of inputs for each crop. For canola, the average inputs of 3 canola systems were considered and for palm oil, soybean sunflowers and cotton, 1, 26, 4 and 15 systems, respectively, were considered.

3. Results and discussion

Tables 6–10 show the emergy table for cotton, soybean, canola, sunflower and oil palm, respectively.

<table>
<thead>
<tr>
<th>Country</th>
<th>Production (billion liters)</th>
<th>Share of total production (%)</th>
<th>Raw material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Germany</td>
<td>2.80</td>
<td>46.70</td>
<td>Rapeseed</td>
</tr>
<tr>
<td>USA</td>
<td>0.85</td>
<td>14.20</td>
<td>Rapeseed</td>
</tr>
<tr>
<td>France</td>
<td>0.63</td>
<td>10.50</td>
<td>Soybean</td>
</tr>
<tr>
<td>Italy</td>
<td>0.57</td>
<td>9.50</td>
<td>Rapeseed</td>
</tr>
<tr>
<td>Brazil</td>
<td>0.07</td>
<td>1.17</td>
<td>Soybean</td>
</tr>
</tbody>
</table>

Fig. 1. Biodiesel production of Brazil (ANP, 2009).

Fig. 2. General emergy diagram of an agricultural system (Based on Odum, 1996)
Table 6 shows the emergy table for cotton and the non-renewable resources that most impact the system are the limestone (11.81%) and soil loss (19.95%). These two non-renewable resources also have the most impact to the soybean system as shown in Table 7.

Table 8 shows the emergy table for canola and the non-renewable resources that most impact the system are the NPK fertilizer (15.30%) and soil loss (23.39%). The non-renewable resource that most impact the oil palm system is NPK fertilizer, which represents more than 39% of non-renewable emergy used by the system as shown in Table 9.

Table 10 shows the emergy table for sunflower and the non-renewable resources that most impact the system are the NPK fertilizer (12.60%) and soil loss (34.54%).

3.1. Emergy analysis results for the crops investigated

The aggregated emergy flow and output data are shown in Table 11.

Fig. 3 shows the proportion of aggregated emergy used in each crop. It is notable that the emergy from materials increase with the productivity of the crop. In other words, the use of more emergy from materials (especially fertilizer) makes the productivity of crops increase but the proportion of renewable resources used decrease.

Oil palm is a special case due to the low net topsoil loss but the use of emergy from economy and services are high when compared with canola, sunflower and soybean. Fig. 4 shows the proportion of emergy from fertilizers compared with the total material emergy. Oil palm and cotton had worse emergy indices mainly due to the high use of chemicals.

The emergy indices of studied systems are shown in Table 12. The transformity measures the efficiency of the system, in other words, how much of the emergy used is converted into net energy. The most efficient crops from high to low efficiency are oil palm, canola, sunflower, soybean and cotton. The high efficiency of oil palm was expected due to its high productivity (16800 kg/ha year).

Transformities references: R1, by definition; R3, Odum, 1996; N1, M23, Odum and Odum, 1983; M1, M2, Ortega et al., 2002; M6, Brandt-Williams, 2002; M35, M36, M37, M38, Brown and Ugliani, 2004a; M50, Coelho et al., 2003; M58, M60, M61 and S4-S15, Ortega, 1998. Renewability fraction references:

* Ortega et al., 2005.
The renewability ratio (R%) is the percentage of renewable energy used by the system. Canola has the highest renewability, followed by sunflower, soybean, oil palm, and cotton. As shown in Fig. 3, the renewable energy from nature is practically constant among the crops, and the variation on this index refers to the use of non-renewable materials and services from economy. Thus, the canola crop is less dependent on non-renewable energy.

The emergy yield ratio (EYR) is the ratio between the total emergy and the emergy value of economy purchased inputs. This ratio measures the ability of a process to exploit and make local use of non-renewable emergy.
resources available by investing in outside resources, in other words, the measure of use of local resources. All the crops show small EYR values, indicating a high dependency on non-renewable resources for production. Energy intensive agricultural systems have EYR values lower than two (Odum, 1996; Ulgiati et al., 1994; Ortega et al., 2002; Panzieri et al., 2000). Sunflower crops have the highest EYR value (2.92), followed by canola (2.76), soybean (2.50), cotton (1.58) and oil palm (1.42). These results indicate that cotton and oil palm have a high dependence on non-renewable resources and sunflower, canola and soybean crops have better performances when compared with another intensive agricultural system. The EYR index may give the wrong impression that sunflower crops are better than the others crops since they use more natural resources \((R+N)\) compared with the economic resources \((F)\) required. Therefore, the high EYR value for sunflower is due to the extensive use of non-renewable resources from nature \((N)\), specifically soil loss. Thus, crops that use more local and renewable resources from nature are canola (1.04), sunflower (0.91), soybean (0.48), oil palm (0.34) and cotton (0.24). This index clearly shows that canola crops use 4% more renewable emergy from nature than from economy resources.

The energy investment ratio (EIR) measures the intensity of use of economic resources in agriculture. The calculation of this ratio allows the choice of a model for agriculture compatible with the economic and environmental concerns. Accordingly, this index is a good indicator to assist the development of a sustainable agricultural policy. The low value for the sunflower index is a good indicator to assist the development of a sustainable agricultural policy. The low value for the sunflower index is due to the extensive use of non-renewable resources from nature. Therefore, the high EYR value for sunflower is due to the extensive use of non-renewable resources from nature, specifically soil loss. Thus, crops that use more local and renewable resources from nature are canola (1.04), sunflower (0.91), soybean (0.48), oil palm (0.34) and cotton (0.24). This index clearly shows that canola crops use 4% more renewable emergy from nature than from economy resources.

The energy investment ratio (EIR) measures the intensity of use of economic resources in agriculture. The calculation of this ratio allows the choice of a model for agriculture compatible with the economic and environmental concerns. Accordingly, this index is a good indicator to assist the development of a sustainable agricultural policy. The low value for the sunflower crop (0.52) and canola crop (0.57) is advantageous, as it reflects a low use of emergy from economic resources. Sunflower (1.08), soybean (0.85) and cotton (1.71) have a moderate use of emergy
from the economy, while oil palm (2.37) uses the largest proportion of emergy from the economy, which reflects the highest EIR value.

The emergy exchange ratio (EER) would have a value of 1 to represent that all emergy spent to produce the product is returned to the producer by the money received. Generally for intensive commercial systems this value is greater than 1, i.e., the producer receives less emergy in the form of money than invested. The values of this indicator for vegetable oil crops from high to low are: sunflower (3.76), soybean (4.00), canola (2.97), cotton (1.87) and oil palm (1.35). Oil palm has the lower EER value among the crops, and this can be explained by the high productivity of oil palm (16,800 kg/ha year), which is 10.9 times higher than that of canola, 9.9 times higher than sunflower, 6.2 times higher than soybean and 4.9 times higher than cotton.

The emergy loading ratio (ELR) is an indicator of the pressure of agricultural systems on the environment and may be considered a signal of possible ecosystem stress. Canola crops have the best value (1.47) indicating a lower pressure when compared with the other systems.

The results from this study largely agree with the results from past studies. The renewability calculated for the sunflower crop in this work (31.6%) is close to the value reported for Italian systems (28.6%) (Bastianoni et al., 2008). The results for soybean crops are similar to those found in the literature (Ortega et al., 2005; Cavalett and Ortega, 2009).

Yee et al. (2009) used the LCA methodology of palm biodiesel and compared with rapeseed biodiesel. They conclude that palm biodiesel produced in Malaysia is more efficient than rapeseed biodiesel. The crop studied in Malaysia only uses 281 kg/ha year of fertilizer. In Brazil, the average use of fertilizer during 25 years of oil palm production is 735 kg/ha year and this reflects in a worse result for Brazilian oil palm crop.

The emergy indices show that canola crops are the most sustainable raw material for the production of biodiesel. Oil palm proves to be a potential source of energy due to its high productivity, low transformity and low EER value; however, it has a high EIR value. In order to increase the sustainability, the use of non-renewable materials should be reduced through the use of appropriate management techniques to reduce the amount of chemical fertilizer, which currently represents over 39% of the total emergy used.
A study of soybean farming and industrialization showed that the industrial portion of production contributes a very small amount of non-renewable energy when compared with the total energy used for farming the crop (Cavalett and Ortega, 2009). High renewable (approximately 80%) can be achieved in agroecological soybean farms that use more renewable resources and less chemicals derived from petroleum (Ortega et al., 2002).

4. Conclusion

The energy assessment of oleaginous crops indicates that the biodiesel produced by vegetable oil with conventional farming methods cannot yet be considered sustainable, as defined by the PNB.

The main oil used in Brazil for biodiesel production is soybean oil. To produce pure biodiesel (B100), the renewable energy used is smaller than 30% (in the case the soybean oil) as showed in the last section; this renewability index tends to fall during the processing chain with the incorporation of new non-renewable energy resources, and when the biodiesel (B100) is blended with diesel (petro fuel), this renewability falls further.

The crop with the best energy indices is canola, a variety of rapeseed that is the main raw material used to produce biodiesel in Europe and North-America. Canola is not widely produced in Brazil, probably due to climate restrictions or low market demand.

The cultivation of oil palm must be researched due to its high productivity and oil yield. Palm oil is the third most produced vegetable oil in Brazil, and appropriate agroecological management can be used to reduce the dependency on non-renewable resources for its production. So that oil palm could be an important source of renewable energy. Thus, the Brazilian government should encourage the production of oil palm and support research aimed at reducing the use of chemical fertilizers.

This study did not consider natural renewable resources such as solubilized minerals, nutrients from the soil, environmental services and negative externalities. These materials should be evaluated and included in a future analysis to obtain more accurate energy indices. However, these flows are difficult to account for, and there is still much debate about how to quantify environmental services and negative externalities.

The use of the LCA methodology integrated with the energy methodology is a good suggestion proposed by Ulgiati et al., 2007 and it is recommended for future works. The results of such a study could contribute to the discussion of conventional oleaginous crops sustainability in Brazil.

Acknowledgements

The authors are grateful to CNPq and Capes for the financial support.

Appendix A. Supplementary materials

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.enpol.2009.12.038.

References


