Energy balance of biodiesel for five sources recommended for Mexico.

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ABSTRACT

This document provides a brief comparison of the energy balances, both physical and caloric, for the five sources of biodiesel recommended for Mexico by two specific studies: Jatropha curcas, Ricinus communis (Higuerilla or Castor), Oil Palm, used cooking oils and algae. This comparison is made taking into account the requirements of production, properties, and yields of each of them. The analysis of the information resulting from the caloric energy balance allows us to determine the rate of energy return (RER) for each source in the whole cycle of generation and use of biodiesel, which shows the competitiveness of crops of Jatropha, Ricinus and Palm oil with positive RER or positive balances, while used cooking oils and algae do not show until now (in the conditions they are produced in Mexico) the desired sustainability and profitability characteristics.

INTRODUCTION

The main motivation for this study is rooted on the importance of the fossil diesel as one of the main sources of energy supply for transportation and electricity generation, and the following facts: a) petrodiesel prices are going up; b) it is obtained from petroleum, a natural resource that is being depleted; c) when burned as a fuel, it emits pollutants into the atmosphere, known as Greenhouse Gases (GHG), and its sulfur contain makes this pollution even worse; e) biodiesel prices are decreasing as a result of improved technologies and development of new sources; f) Mexico has a huge unexploited potential to produce biofuels through several endemic vegetal varieties that do not compete with food production [1, 2]. The development of biofuels is a solution promoted by international agencies, mainly by the Protocol of Kyoto, as an alternative energy source either for improving the characteristics of fossil diesel (blends of biodiesel with fossil diesel) or as a substitute of petrodiesel by biodiesel (B100).

On the other hand, petroleum production in Mexico is declining (in 2013 is about 26 % less than in 2004) and the deep sea oil reserves require huge investments and complex technologies that the country cannot afford in the short term [3, 4].

According to Silitonga et al. [5], there are more than 350 crops oilseeds identified for the production of biodiesel, some of them producing non-edible oils that do not compete with food crops, such as Jatropha, Karanja, and Neem.

Within this context our study will focus on the comparison and analysis of the performance, requirements, sustainable properties, co-products and disadvantages of each of the five selected sources: Jatropha, Ricinus o Higuerilla, Oil Palm, used cooking oils and Algae for the generation of biodiesel in Mexico. The research will be limited to report the (still insufficient) scientific knowledge on the subject of the life cycle of energy crops for biodiesel, taking case studies made for specific regions like Indonesia, India, China and Malaysia. These studies can orient similar works for Mexico, given the fact that this kind of studies are still in an initial phase in our country. The object of this work is to reveal the competitiveness, sustainability and impacts of the sources recommended for biodiesel production in Mexico.

METHODOLOGY

This work has as theoretical basis the concepts presented by the Latin American Energy Organization [6], on the subject of Energy Balance (EB), which defines it as the accounting of all energy flows, which go in and out during the entire structure of the productive chain of biodiesel, from its origin to its final use; so EB may occur in two ways:

a) Physical Energy Balance (PEB), also called balance of products that accounted for physical measurements (volume) units.
b) Caloric Energy Balance (CEB), which takes into account the energy inputs and outputs during all steps of the production and burning process (complete life cycle).

We use the EB in this study to compare the sustainability, that is, competitiveness and environmental impact, of the different sources for the production of biodiesel in Mexico. We develop a comparable energy matrix of the five sources mentioned above, using the data of references [1, 2] complemented with additional information for algae.

RESULTS & DISCUSSION

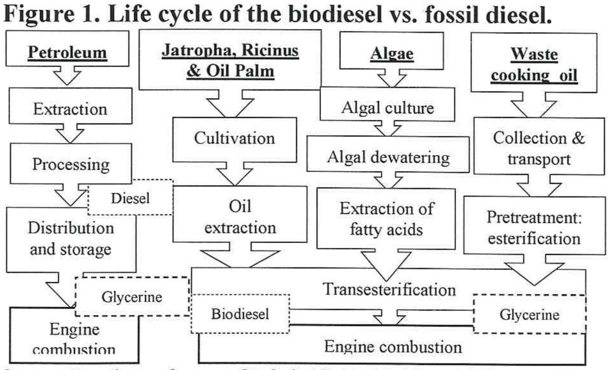
Energy balance of Biodiesel

As previously mentioned, in what follows we present the PEB and CEB for Jatropha curcas, Ricinus communis (Higuerilla or Castor), Oil Palm, used oils and Algae. It must be pointed out that the information presented in power grids (Tables 1 and 2), is a compilation that compares the differences between the requirements, yields and properties of biodiesel production from the five selected sources, taking into account that due to the nature and properties of sources, their level of performance in fruit content, processes for oil extraction and properties of biodiesel production, the results vary from one type of crop and plant to another, as well as from a country or region to another, depending on the conditions of growth of the crop in different ecosystems; that makes the quality and quantity of oil extraction to fluctuate. It is important to highlight that the information presented in the energy matrix (PEB and CEB), intends to reduce the asymmetry of information in the case of the uncertainty of biodiesel in Mexico´s bioenergy crops, in relation to the life cycle of energy crops for biodiesel in specific regions (case studies from Indonesia, India, China and Malaysia).

Structure of the productive chain of biodiesel

For a better understanding of the results for EB, in Fig. 1, we compare generically all five systems (Jatropha, Ricinus or Castor, Palm oil, used cooking oils and Algae) production facilities for the production of biodiesel process, taking as a reference the production process of fossil diesel. Fig. 1 shows that the main difference between the life cycle of the production process of biodiesel from Jatropha, Ricinus and Palm oil, with respect to the Algae, is due to the stage of cultivation of the plants and the process of extracting the oil from these sources; the process of used cooking oil only requires the collection of oil for processing.

Figure 1. Life cycle of the biodiesel vs. fossil diesel.



Source: Based on references [7, 8, 9, 10, 11, 12, 13, and 14].

Physical energy balance of energy crops for biodiesel.

Within the context above, Table 1 shows the matrix for the PEB corresponding to energy crops for the production of biodiesel from the four different sources (Jatropha, Castor, Palm oil and Algae), which is discriminated against the source of used cooking oils, since this does not require a prior cultivation, but only its collection. It should be noted at this point that agricultural yields can vary depending on farm management and plantation age.

Table 1. PEB of crops for the production of biodiesel: requirements and performance.

Parameters	Jatropha	Ricinus	Oil Palm	Algae
Crop water requirements	l/day or per every 15 days[1]	118059000 l to produce 0.2 t of biodiesel	NA	NA
Production life of crops	After 1 year	NA	After 3 years	After 6-9 days[2]
Content of the raw oil	28-40%	48%	17-22-36%	30-50-70%[3]
Percentage retrieved from the oil extraction.	75-96%[2] of the kernel of the seed	NA	93.4% of the flesh or mesocarp	98% of pure fatty acids
Crude oil (l/ha).	741-2500	1307	5366	58700-97800-136900[3]
Biodiesel (l/ha).	2709-570720	1103980	4357746	44501439-74143355-103786128[3]

NA = Not Available

1. 600 mm of rain per year (at least) for thrives and also supports 3 years of severe drought.
2. In this case of the Microalgae Thalassiosira double their biomass in a period of 3.5 h., but his level of ripening for growth depends on its environment and plant nutrients.
3. Microalgae oil content: low, medium and high.

Source: Based on references [12, 14, 15, 16, 17, and 18].

Fluctuations between different bioenergy crops observed in Table 1 are due to the different characteristics of each variety. Jatropha farming requires less water than any other of crop, since it resists up to 3 years of drought [5]; this makes poor lands in Mexico suitable for these crops. On the other hand, the microalgae cultures begin his productive life in less time than other crops, even less than Jatropha that produces after 1 year planted; algae productive life starts from the sixth or ninth day, depending on its environment and plant nutrients. Palm oil has the longest maturity time: the first harvest comes after 3 years. Algae also produce a higher volume of crude oil and biodiesel than any of the 3 energy crops presented.

Caloric energy balance of Biodiesel

To complete the previous PEB, Table 2 presents the array of CEB which contains the parameters of the energy life cycle and cycle of pollutant emissions of biodiesel from the five different sources studied for Mexico.

Table 2. CEB of biodiesel: energy comparison.

Parameters	Biodiesel				
	Jatropha	Ricinus	Oil Palm	Waste oils	Algae
Cycle of pollutant emissions	400000 t of CO_{2-eq}	500000 t of CO_{2-eq}	6729639 t of CO_{2-eq}	6000 t of CO_{2-eq}	2650000 t of CO_{2-eq}
Reduction of pollutant emissions	600,000 t of CO_{2-eq}	2,000,000 t of CO_{2-eq}	10028931 t of CO_{2-eq}	NA	800000 t of CO_{2-eq}
Energy used in the production cycle	5000 TJ	8000 TJ	0.03438 TJ	8000 TJ	41000 TJ
Energy value of biodiesel	8000 TJ	8500 TJ	0.078408 TJ	8000 TJ	8000 TJ

NA = Not Available
(The data for oil palm were normalized with respect to the rest of the units of values given in studies done for 2 tons of biodiesel).
Source: Based on articles [10, 17].

According to Table 2, biodiesel from Castor or Higuerilla oil has the largest emission reduction capacity of 400%, followed by Jatropha oil with 150%. Algae have the minimum capacity for emissions reduction. In terms of energy efficiency, the best crop is Jatropha and the worst case corresponds to algae.

Biodiesel Rate of Energy Return (RER)

Based on the data in table above, Fig. 2 shows the RER. The rate of energy return is defined as:

$$RER = Ep/Ei$$

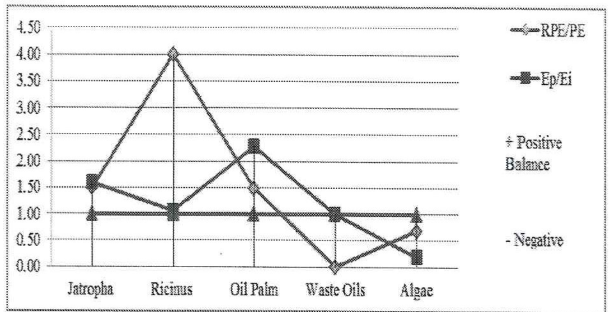
(Where: Ep = useful energy content of biodiesel and Ei = energy used in the whole production cycle).

And the emissions balance is:

$$EB = RPE/PE$$

(Where: RPE = Reduction of Pollutant Emissions, and PE = Pollutant Emissions)
A value of RER < 1 will correspond to a negative balance or loss of energy in the whole cycle; if RER = 1 the energy gain is zero; otherwise we have a positive balance: the energy produced is larger than the energy inverted and the overall cycle could comply with a cost-effective and sustainable process. The same conditions hold for the emissions balance.

Figure 2. RER, CO_2 emissions and energy used in biodiesel production and burning processes.



Source: This work.

From Fig. 2 it can be concluded that the highest reduction of CO_2 corresponds to Ricinus biodiesel followed by Jatropha and Oil Palm; biodiesel from algae comes in the last place. The zero emissions of waste oils in the figure simply means that no information about RPE is available for this case. On the other hand, from the point of view of energy return the best case is Oil Palm, followed by Jatropha, then Ricinus and waste oils with RER = 0, and in the last place the cultivated Algae. Combining both emissions and energy efficiency, it can be concluded that the best case is the Oil Palm and in the second place the Jatropha. If we take into account the type of land needed for each crop and other inputs, Mexico's best choice would be the Jatropha biodiesel. This result is reinforced by considering the co-products of each crop in addition to the biodiesel production.

Sustainable properties and co-products of biodiesel bioenergy crops and their disadvantages.

Jatropha curcas
Sustainable properties and co-products of Jatropha described by Sudhakar, et al [17] and Silitonga, et al. [5], are:

- Its production does not compete with food crops because the seed contains some chemicals that are poisonous, which makes the oil not suitable for human consumption.
- It can survive and thrive in infertile land, in sandy soils, gravel, salt and poorest stony ground.
- It requires little water, it needs less than 600 mm. of rain a year to prosper; however, it can survive three years of drought.
- It acts as a fertilizer, enriching the soil, and avoiding soil erosion and the movement of sand dunes.

- It is a plant of hot climate (it grows in the tropics and subtropics), but also supports low temperatures (can withstand a light frost).
- It can be intercropped with many food crops such as coffee, sugar, fruits and vegetables, since it offers both protection against livestock and fertilizers (it provides nitrogen, phosphorus and potassium).
- The residue of the seed (the flattened cake) can be used as biomass feeding material to electric power plants power.
- The transesterification catalyzed by vegetable oils proceeds faster than the reaction catalyzed by acid and biodiesel, a renewable energy source, cheap and inexhaustible; it can be a good substitute, ligament or diesel fuel mixture (oxygenating).
- The biodiesel flash point (after transesterification) and combustion point are higher than those of fossil diesel, two important factors of safety for their transport, storage and handling.
- Co-products of Jatropha: Jatropha bark produces a bluish dye useful for fabrics, nets, etc. The bark is also used as anti-inflammatory in medicine.

There are, however, some disadvantages according to Silitonga, et. al. [5]:

- The toxicity of the Jatropha can present potential environmental and public health problems since the curcanoleic acid can cause skin irritation or skin cancer to agricultural workers.
- Jatropha biodiesel has a higher NOx emission index than fossil diesel.
- Jatropha biodiesel has a high corroding potential for copper and brass.
- Its high viscosity (about 11-17 times greater than that of fossil diesel) causes problems in pumping, combustion and atomization in the systems of a conventional diesel engine long-term injectors. For long periods of inactivity engines can be gummed, produce deposits in the nozzles, clogging of filters, lines and injectors.

Ricinus communis

Little information is found regarding the sustainable co-products of the Ricinus, but the study of Liang et al. [19] shows some benefits:

- Waste extraction seed cake is used as fertilizer.
- The glycerol from biodiesel production has been used in the cosmetics industry.
- It has a good performance in the RPE proofs.
- Disadvantages:
- The lack of studies on the properties, sustainable co-products, and environmental impacts of Ricinus make it unattractive for purposes of industrial processes.

Oil Palm

The oil palm according to Stichnothe & Schuchardt [14], can take advantage of the following co-products and sustainable properties:

- Crude palm oil and oil palm seeds are energy carriers, which can be used as food or as raw material for chemical products (cosmetic or detergents) or biodiesel.
- Dried fruit shells are used and sold as fuel.
- Waste fibers and shells are by-products consumed for the generation of electricity and steam.
- Waste effluent oil, palm plants and empty fruit bunches can be used as compost.

Disadvantages:

- It requires large plantation areas of good soil and strongly contributes to the large scale destruction on rainforests in underdeveloped countries.

Algae

According to Mata, et al. [2] sustainable properties and co-products of the microalgae Thalassiosira are:

- Microalgae are adaptable to a diverse range of environmental conditions. There are about 50,000 species, but only a limited number, of around 30,000, have been studied and analyzed.
- Microalgae are present in all ecosystems (aquatic and terrestrial).
- Its rate of growth and productivity is much higher in comparison with conventional forestry, agricultural crops, and other aquatic plants.
- They do not compete for the arable soil, in particular for human consumption.
- They are a source of raw materials for several different types of renewable fuels (biodiesel, methane, hydrogen, ethanol, among others).
- They eliminates NH_4, NO_3, PO_4, and waste water by making use of these contaminants as nutrients. So they do not require the use of fresh water.
- After extraction of the oil, resulting algal biomass can be processed into ethanol, methane; livestock feed, compost or burn for the cogeneration of electricity and heat.
- They can grow in the most adverse conditions: areas not suitable for agriculture, regardless of seasonal climate changes.
- Depending on the species of microalgae, some compounds can be extracted for chemical products such as fats, polyunsaturated fatty acids, oil, natural dyes, sugars, pigments, antioxidants, compounds bioactive of great value, etc.

Disadvantages:
As previously mentioned in the CEB and the RER, the main disadvantages encountered in the production of biodiesel from algae are:

- Their capacity of reducing polluting emissions is negative.
- The amount of energy delivered is lower than the amount invested.

CONCLUSIONS

A simple consideration of energy return rates and CO_2 emissions for the five sources of biodiesel recommended for Mexico, leads to the conclusion that Oil Palm is the best election. However, when considering other conditions already mentioned for Oil Palm in connection with the displacement of qualified lands for food production, the risks put on the environment derived from the need to open new cultivated areas at expense of rainforests, the nature and characteristics of the crop itself requiring long maturing times for starting production in monocultivated lands, one is led to conclude that a better choice is the Jatropha curcas. Jatropha offers more sustainability and competitiveness in the case of Mexico, since it is a plant that grows in warm climates and in adverse ecosystem; it does not impact on land use change, endangering the food security of the country, it is compatible with the planting of commercial food crops in the same lands. Industrialization of Jatropha can give rise to other industries on cosmetics, chemistry, medicine, etc. One of the most important factor to consider is that the plant is endemic in the country. Of course, more research is needed to overcome the disadvantages already mentioned like toxicity, corroding potential, high viscosity, in order to make it more profitable.

On the other hand, Ricinus oil shows a low energy return rate but a high potential for reduction of emissions, surpassing by a factor of 4 the amount it emits. Oil palm also shows positive balances and desirable characteristics for the production of biodiesel and contains high amounts of oil, but its use as edible oil makes it unattractive (it competes with food). With the information available at the moment we cannot ruled out the use of waste oils and algae for biodiesel, but it is relevant for this analysis to point out that in order to leave the windows open for these sources we need more research and development on these grounds.

Finally, it is important to remember that bioenergy crops should not be monopolized; there must be a mix of different sources to integrate a generation of truly sustainable biodiesel systems. In connection to this we need a comprehensive and efficient legal frame.

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