USE OF VEGETABLE OILS IN DIESEL ENGINES: AN ANALYSIS OF SUSTAINABILITY

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Abstract. *Currently when thinks in energy, most of the people thinks about fuels and electricity. These rich forms energy are explored until the current days and they form the base of our civilization. The conventional fuels (petroleum, natural gas, coal and nuclear energy) are the main sources of energy obtention. Actually, the renewable sources of energy are considered as an alternative to conventional sources. However, in the last ten years, with the interest of the global pollution, the use of these was considered as a more positive factor. Though the participation in the world main energy matrix is still not significant (less than* $2,5\%$*). The main objective of this paper is to observe the sustainability analysis for diesel engines using vegetable oils (specifically soy oil) as fuel. The principal reason of the use of vegetable oils as fuel is due that fuel provides a "by pass" related to biodiesel, providing in a certain way, cost reduction. Engines using vegetable oils are already a reality in Germany. A major international corporation, MAN B&W, produces diesel engines with low rotation, using vegetable oils as fuel. The "Qlear I" engine, located in Netherlands, produces* 760 *kW of electric power, recommissioned in October* 2004 *and over* 3000 *hours of operation. In the sustainability analysis, the methodology of life cycle analysis (LCA) and indicators as exergy analysis (ExA) and emergy analysis (EmA) is used. In this paper is proposed an integration among them, allowing an evaluation of environmental analysis and the evaluation of sustainability of a productive system of energy, which counts ecological and economical factors.*

Keywords: *Sustainability, life cycle analysis (LCA), exergy analysis (ExA), emergy analysis (EmA), vegetable oils.*

1. INTRODUCTION

Currently when thinks in energy, most of the people thinks about fuels and electricity. These rich forms energy are explored until the current days and they form the base of our civilization. Nowadays, the conventional fuels (petroleum, natural gas, coal and nuclear energy) are the main sources of energy obtention. The renewable sources of energy are considered as an alternative to conventional sources (Moreira, 2002), but in the last ten years, with the interest of the global pollution, the use of these was considered as a more positive factor.

The sustainability can be measure by indicators. One of the reasons of the use of vegetable oils as fuel is due that fuel provides a "by pass" (shown in the figure 1) related to biodiesel, providing in a certain way, cost reduction. The renewable alternative energies (BiodieselBR, 2006) have the technical potential of assisting great part of the demand incremental of energy of the world, independent of the origin of the demand (electricity, heating or transport). There are three important aspects the to point out: the economical viability, the sustainability of each source and the availability of renewable resources for generation of energy, changes among the different areas of the world. A concrete example is the "Qlear I" engine (Carranca, 2005), located in Netherlands, produces 760 kW of electric power, recommissioned in October 2004 and over 3000 hours of operation.

Brazil has a great potential to produce biodiesel (Passos, 2004) starting from vegetable oils, due to geographical location, agricultural vocation and, also, to the great diversity in terms of oleaginous. The energy use of vegetable oils makes possible the generation of new workstations mainly in the rural area, besides increasing the offer of the proteic fraction of the oleaginous, important input for elaborate foods and ration.

Even like this, the participation in the world main primary energy it is not still significant (less than $2,5\%$). The small participation is based by the frequent lack of competitiveness commercial, demanding a technological improvement further on for to overcome such barrier. Though, several studies showed that now there are technologies for the use of new sources and also renewable. Such sources compete economically with conventional sources. When economical barriers are present, it is necessary to provide incentives. Be for wide use, it is possible to reduce costs.

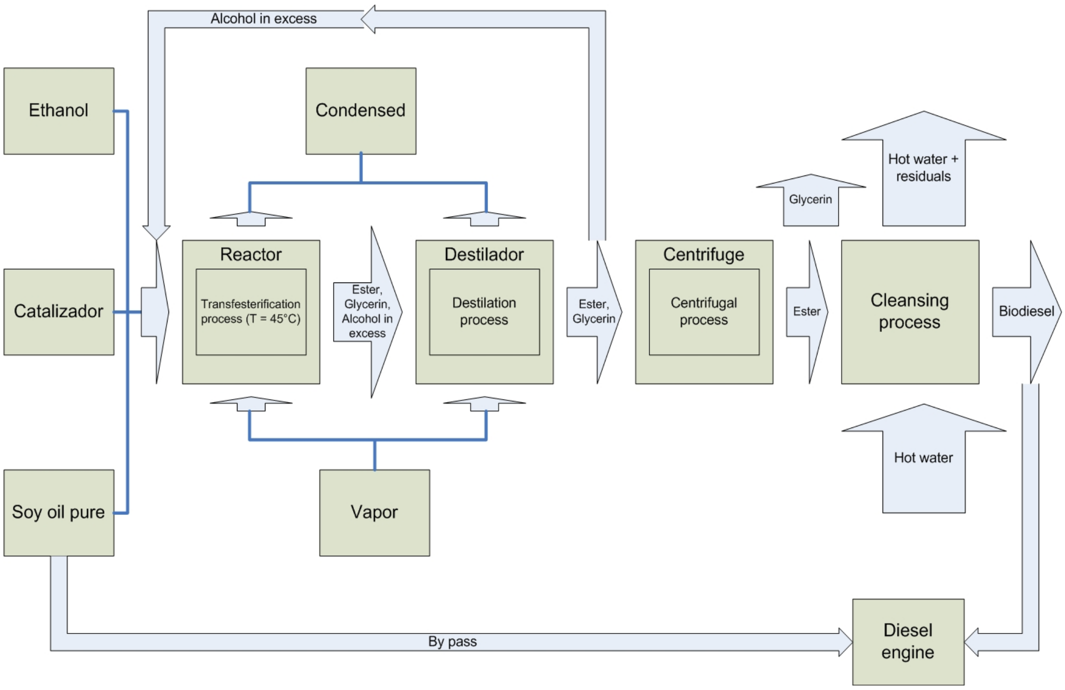


Figure 1. Vegetable oils and Biodiesel production: final destination as fuel

In spite of the fact that the biomass to produce electricity has the larger benefits in the subject of emission of greenhouse gases and that the warm biomass is cheaper, the biofuels for transport has the largest intensity in the job generation. It provides a renewable alternative for existent vehicles. At least even 2010, there won't be some competition for raw material: The biofuels depend, mainly, of agricultural crops while electricity and heaters depend only the burn of wood and residues.

2. METHODOLOGY

A methodology of evaluation the systems should appreciate the ecological and environmental elements. So, the evaluation of the biofuels should include the concept of the term "*Cradle to Grave*". In other words, from the cultivation of the raw material, going by the production phases and use to final provision.

According to Passos (2004), actually the new theories of evaluation of systems search to incorporate environmental considerations in their analysis. However, these theories don't consider, in general, all of the relevant interactions among the ecological and economical systems. In some way, they limit their analysis the some specific environmental aspects. With the objective of showing in general, the methodologies of life cycle analysis, exergetic analysis and a emergetic analysis are presented. Also are presented in this paper their reaches, the limitations of each other and the complemental characteristics of these analysis.

2.1 Life cycle analysis – LCA

The life cycle analysis is one of the tools more used in the evaluation of environmental impacts. With that analysis, they can be identified the most of the environmental impacts caused by products or for processes during all of the phases of the life cycle–production, use, maintenance and final destiny.

The main advantage of the life cycle analysis is to provide a structure of application of the study in subject and for the evaluation of the environmental impacts provoked by the economic activities. The absence of a common base is a restriction factor of this methodology. In general, they are taken into account just the impacts of the environmental associates to the residues discharged in the nature, to the energy consumption and the use of non-renewable resources.

2.2 Exergy analysis – ExA

The exergetic analysis uses, in a certain way, the exergic concept in the evaluation of industrial systems. The exergy definition is the maximum amount of useful energy that theoretically it could be produced by a system when interacting with the environment reference, reaching the balance. Therefore, the total exergic of a system depends on the thermodynamic state in that this is and being calculated by the equation 1 in agreement with Moran and Shapiro (2002):

$$Ex = S(T - T_0) - V(p - p_0) + \sum_i n_i(\mu_i - \mu_0) \tag{1}$$

Where:

- S it is the entropy of the substance;
- T it is the temperature;
- V it is the volume;
- p it is the pressure;
- n_i it is the amount of substance in mols;
- μ_i it is the chemical potential of the substance *i*

The balance of exergy for the control volume can be expressed of the follow way according to Moran and Shapiro (2002):

$$\frac{dEx}{dt} = \sum_i Q\left(1 - \frac{T_o}{T_{boundary,i}}\right) - \left[W - p_0\frac{dV}{dt}\right] + \sum_{inlet} m_{inlet}ex_{b,inlet} - \sum_{outlet} m_{outlet}ex_{b,outlet} - I\left[\frac{kJ}{s}\right] \quad (2)$$

The potential of impact of a certain industrial system on the environment it can be measured through the destruction and of the losses of exergy in this system. The destruction of exergy (I – irreversibility ratio) it doesn't provoke direct environmental impact Rosen and Dincer (2001). However, when it has been elevating exergic destruction in a system, the tendency is that destruction is compensated by the increase of the consumption of exergetic inputs, promoting, like this, the degradation of natural resources.

On the other hand, the impact of the exergic losses on the environment is direct, because the exergic losses are related to the residual flows spilled by the system in the nature. These industrial residues can harm the environment, promoting the degradation of the ecosystems which are thrown. The damage potential to the environment of these residues it can be measured through the exergic of the substances that they constitute.

2.3 Emergetic analysis – EmA

The emergetic analysis has been used in the evaluations of systems in several areas. Be ecological, agricultural or industrial, the emergetic theory converts all of the resources (monetary contributions, flows of energy and of mass, information, human work) necessary to the operation of a system, in terms of a type of energy.

In the emergetic analysis, the systems and processes are represented through diagrams of emergy. Therefore, all of the flows, expressed in units of solar energy *solar emjoule* $[sej]$ (Ukidwe, 2002). All the flows related to the system are counted, classified and converted in units of emergy. The classification of the flows proceeds in the following way:

- Natural resources, originating from of local ecosystems, classified in renewable (R) and non-renewable (N)
- Economic resources (F–Feedback), coming of external economic systems. They are material, fuels, capital goods, services and work hand that are part of the productive system.

Through these entrance flows, obtains the output stream of the system (Y–Yield), the manufactured product. All of the described flows are schematized accordingly to the figure 2:

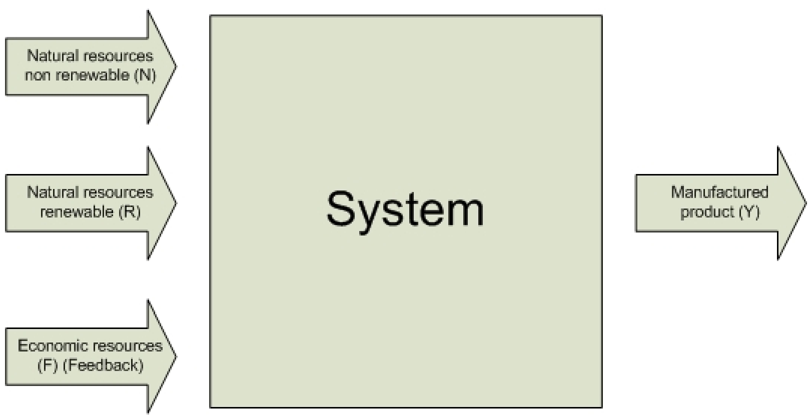


Figure 2. Representation of the flows of the system for the analysis of emergy

The systems can, then, to be appraised, in relation to economical and ecological aspects, through indicators below. Those indicators are:

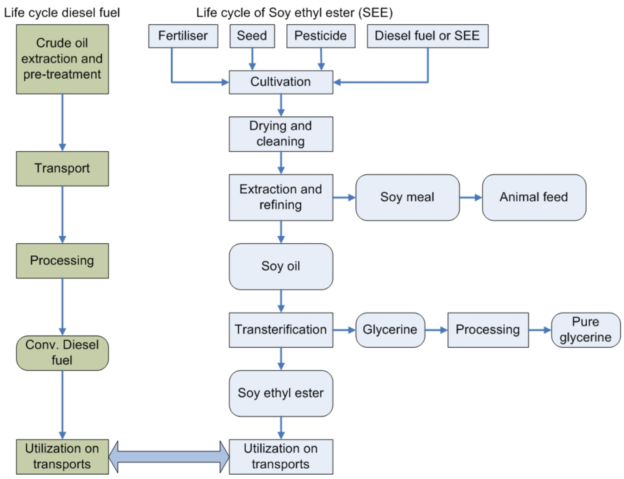
- Transformity – τ: The transformity of a certain product depends on the processes involved in the execution. Also the transformity can be used to confront systems. Formed by different production processes, that manufacture a same product, aiding in the choice of the most appropriate alternative. The transformity can be calculate in the following way: $\tau = \dfrac{\text{Emergy}}{\text{Energy}} \left[\dfrac{sej}{J} \right]$
- Emergy Yield Ratio – EYR: It represents the return of the applied economical investment in the system. It is obtained dividing the emergy of products for the emergy invested by the economy. As larger EYR, larger the return of the economical investment. Can be calculated using this formula: $\text{EYR} = \dfrac{\text{Y}}{\text{F}}$
- Emergy Investment Ratio – EIR: It measures the relationship between the investment of the economy and the investment of the nature in a certain system. As larger the value of EIR, larger the dependence of the resources of the economy. The EIR can be calculate in the following way: $\text{EIR} = \dfrac{\text{F}}{\text{R+N}}$
- Environmental Loading Ratio – ELR: The reason of environmental shipment, measures the impact of the system in the environment. A high value for ELR indicates a great consumption of non renewable resources (local and/or external). Can be calculated using this formula: $\text{ELR} = \dfrac{\text{F}+\text{N}}{\text{R}}$

3. RESULTS AND DISCUSSIONS

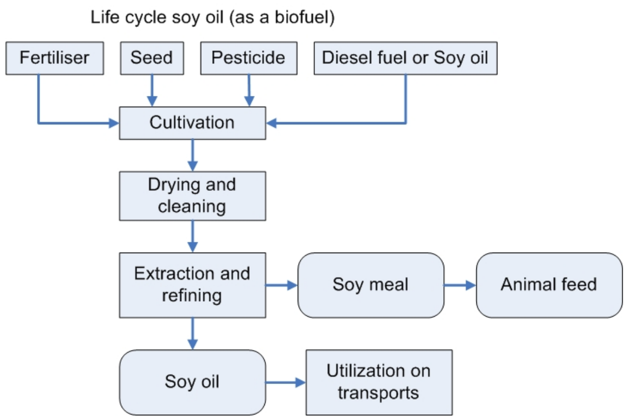
3.1 Life cycle analysis – LCA

The LCA was elaborated with the aid of a tool computacional, the program *GaBi*©. *GaBi*© is an software of analysis and optimization for environmental products, using evaluations of life cycle of those products. The general categories of environmental impacts can be considered, including the use of resources, the human health and the ecological consequences (Caldeira-Pires et al., 2006).

The function of the products biodiesel and soy oil is to serve as fuel for combustion in motor vehicles. The main goal of this LCA study was the assessment of the environmental impact (in terms of energy) of biodiesel made from used vegetable oil (SEE) and the soy oil as fuel compared to fossil diesel (Fig. 3).



(a) Basic scenario: Diesel and Biodiesel



(b) Basic scenario: Soy oil

Figure 3. Basic scenario for life cycle assessment of Diesel, SEE and Soy oil (as fuel)

In the table 1, shows the energy balance of the soy oil and of the biodiesel. In the way that they are introduced, it is observed that the soy oil possesses a superavit of energy of approximately of 17.318 MJ while the biodiesel possesses a deficit of approximately of 21435 MJ.

Table 1. Energetic balance of products

(a) Soy oil

SOY OIL	Energy input $[MJ]$	Energy output $[MJ]$
agricultural issues	3356,76	0
diesel	3454,56	0
biomass	245300	235024
eletric energy	3087,86734	0
Soy oil	0	37493,503
TOTAL	17318,31567 MJ	

(b) Biodiesel

BIODIESEL	Energy input $[MJ]$	Energy output $[MJ]$
agricultural issues	3190,8365	0
diesel	4193,99348	0
biomass	233035	223406,844
eletric energy	42254,3009	0
biodiesel	0	37832,6996
TOTAL	-21434,58712 MJ	

With these results, it is observed that the soy oil possesses a superior advantage in relation to biodiesel in energetic terms. In environmental terms, according to the life cycle analysis, it can be said soy oil possesses a smaller environmental damage than biodiesel.

Energy fluxes are important because they involve materials (e.g., fuels, combustion products). According to the figure 4, shows a inventory in terms of energy. In this figure, is observed that the soy oil is more advantageous than the biodiesel due to inexistence of energy spending in the transterification and an electric power economy.

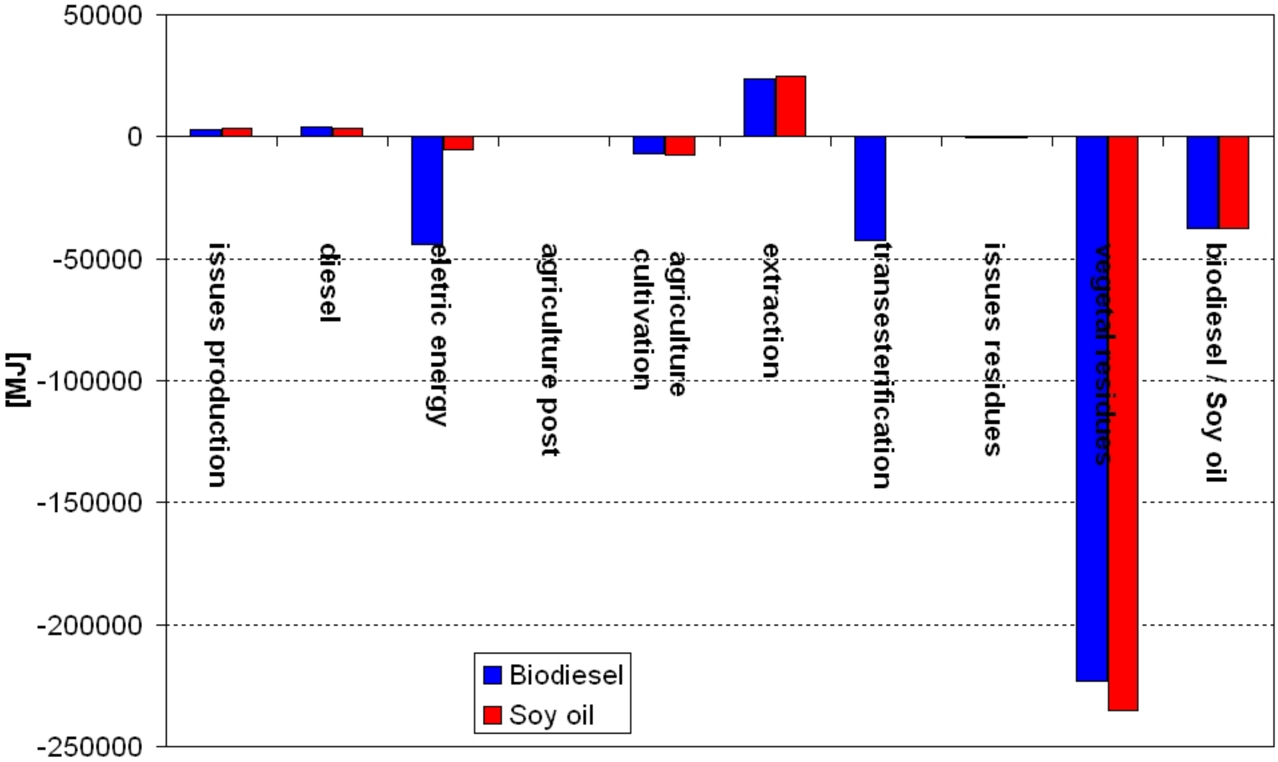


Figure 4. Energetic balance of biodiesel and soy oil on each process

However, in the LCA analysis, the following aspects are not computed:

- The environmental work involved in the production and in the replacement of the renewable ones;
- The environmental work spent in the assimilation;
- Dispersion of pollutant substances for the environment.

Therefore, the work accomplished by the environment to maintain and to regenerate the ecological systems that supports the economic activities is not known.

3.2 Exergetic analysis – ExA

According to Passos (2004), the total flows of exergy for biodiesel (soy ethyl ester) and soy oil for each ton of biodiesel are shown in tab. 2:

Table 2. Exergic massic flows of the system for each ton of biodiesel (Passos, 2004)

Flow	Ex_{total} [kJ/ton]
Soy oil	$3,85 \times 10^7$
Ethyl ester of soy	$4,00 \times 10^7$

The irreversibility ratio of both systems is $I_{system} = 1,83 \times 10^6 \dfrac{kJ}{\text{ton}}$ and exergic losses of both system is $Ex_{losses} = 4,30 \times 10^5 \dfrac{kJ}{\text{ton}}$ (Passos, 2004). So, the irreversibility ratio and the exergetic losses by the total consumption of exergy are shown in tab. 3:

Table 3. Irreversibility ratio and the exergetic losses by the total exergy (in percent)

	I	Ex_{losses}	I+Ex_{losses}
Biodiesel (ethyl ester)	4,60%	1,13%	5,73%
Soy oil	4,73%	1,11%	5,84%

In both cases (Biodiesel and soy oil) the percentage of impacts (Irreversibility and exergetic losses) are small (around 6% of the exergy of the system). It is possible to affirm that industrial system of production of the ester ethyl of soy and soy oil possesses a low potential damage to the environment. In virtue of the analysis not to count the work accomplished by the natural systems, it is not possible to affirm that the ecosystems will support the pressure imposed by this industrial system.

One of the flaws of the exergia analysis is in considering only the systems. In other words, the evaluations take into account the causes of environmental impact. The exergic analysis and, as well, the life cycle analysis, they only allow to evaluate which system is less harmful to the environment, not allowing a determination if ecological systems will support the foreseen environmental impact (Seager and Theis, 2002).

3.3 Emergetic analysis – EmA

The system of oil of soy pure also understands two stages, the agricultural and the agroindustrial. The complete productive cycle of the oil of soy pure is based in the following stages:

- **Agricultural stage** – Where the inputs are Renewable resources, Non renewable resources and Economics resources. The outputs are the subproducts or residues, in this case is soy bean as the product, and the straw as a subproduct. In the middle of the stage, happens the fase agricultural in fact. They are the preparation of soil, planting and the gathering of seeds of soy.

- **Agroindustrial stage** – Like the stage before, the inputs are the same. In the middle of stage occurs the following processes: the cleaning, drying and storage of the seeds; The conditioning of these seeds; The extraction of the oil and finally removal of the rude oil the composed of phosphorus, proteins and colloidal substances. Already, the outputs are the subproducts or residues, which are: Peel, Bran of soy, solvent (by the way can be recovered) and gums.

For this system, the calculated indicators were:

Table 4. Calculation of the indicators for production of soy oil (Passos, 2004)

Indicators	Systems	
	System production of soy (Agricultural stage)	System production of soy oil (Agroindustrial stage)
Transformity $\left[\frac{sej}{J}\right]$	$2,1 \times 10^5$	$5,98 \times 10^5$
Emergy Yield Ratio – EYR	1,30	1,29
Emergy Investment Ratio – EIR	3,38	3,43
Environmental Loading Ratio – ELR	10,30	10,42
Sustainability – EYR/ELR	12,62%	12,38%

For biodiesel, only the stage of agroindustrial is considered. And like the stage before, the inputs are the same, adding the process of transterification, becoming at table below:

Table 5. Calculation of the indicators for production of Biodiesel (Passos, 2004)

Indicators	
Transformity $\left[\frac{sej}{J}\right]$	$5,85 \times 10^5$
Emergy Yield Ratio – EYR	1,29
Emergy Investment Ratio – EIR	3,44
Environmental Loading Ratio – ELR	10,47
Sustainability – EYR/ELR	12,32%

Through the application of this methodology to the production system of the soy ethyl ester and soy oil, it was possible to determine the origin, the nature and the amount of energy spent in the production of those biofuels. As well identify the pressure exercised by the system on the environment. For both cases (soy oil and biodiesel), the sustainability obtained are around 12%, resulting a moderate number. This result shows how much is the environment impact.

The transformity of a certain product depends on the processes involved in the execution, could shifting a lot in agreement with the technologies and used processes in the production of these products. Like this, the transformity can be used to confront different production system that manufacture a same product, aiding in the choice of the more appropriate alternative.

The flaw in the emergy analysis is the emission of pollutant is not considered, turning incomplete for the industrial and agricultural systems analysis. This lack of information could supplied using the life cycle analysis, analyzing the mass flow.

4. CONCLUSIONS

It was presented in this paper the analysis that evaluate the environmental impacts in general, looking for to evaluate the sustainability of the soy oil in comparison with the biodiesel, both liquid fuels of origin of the cycle agroindustrial produced starting from some renewable resources. Also their flaws and their performances were presented in the environmental field, allowing a reasonable general analysis. In all of the analysis were appraised with a referencial for ton of biodiesel. Concluding in a general context, the use of vegetable oil is recommended, showing that vegetable oil fuel has good potential as a substitute for diesel fuel and biodiesel fuel.

When biomass from the cropping system studied here (Soy) is utilized for biofuel production (biodiesel), the cropping system studied have negative environmental impacts (credits) in terms of non-renewable energy consumption and global warming impact. Thus utilizing biomass for biofuels would save non-renewable energy and reduce greenhouse gases.

In the LCA, shows, in terms of energy, the damage of the greenhouse effect will be smaller. According López Sastre et al. (2003), the emission of CO_2 with fossil origin is noticeably lower for the mixtures containing vegetable oil. For example, emission of CO_2 with fossil origin is reduced by 50% when mixtures containing 50% of vegetable oil are used. However, these approaches assess potential ecological loadings the screening approach and thus does not reflect realistic situations (Herrchen et al., 1997). So, a study of dispersion of pollutants gases is essential to integrate the life cycle analysis.

In the exergy analysis it was applied in the evaluation of the industrial system of production of the two fuels. Therefore, it was allowed to estimate the potential of those impact of the systems industrial, through the exergy destroyed in the process and of the losses of exergy of the systems (about 6%) in the form of residues. Then, the high exergetic efficiencies take to have faith that, in the systems, there is a low potential damage of environmental in these two industrial systems. However, the exergic analysis is unable to determine if the involved ecosystems are capable to support the load exercised by these industrial systems.

The emergetic analysis considers in evaluation the phases agricultural and industrial of the systems of soy oil and of biodiesel. The emergetic analysis, of both biodiesel and soy oil, are only limited in evaluating the interactions with the environment, considering only the function of supplying from resources to the environment for the productive systems. The obtained transformities of the biodiesel and of soy oil systems they indicate, respectively, 585 thousand and 598 thousand joules of solar energy for each joule of biodiesel. According with the values obtained by the indicators EYR, EIR and ELR both systems present high dependencies in relation to the economic resources. These resources depend, in their majority, the availability of the non-renewable resources.

Maybe, these elevated dependencies of the economic resources are due of the use excessive or inadequate of the production costs. Therefore, it causes intense damage, exercising a high load on the environment. As a consequence of those dependencies, the sustainability indicators obtained were quite modest (12% each), that in according with the literature is a quite moderate value. A form of reducing the percentage of the sustainability indicator is to minimize the use of herbicides in the agricultural stage or even obtaining the soy bean in an organic way.

If all those results, other aspects should be observed. The increased utilization of biomass for biofuels would increase acidification and eutrophication particularly because of nitrogen (and phosphorus) related burdens from the soil during cultivation. Thus other approaches to reduce these burdens in the agricultural process (e.g., use of buffer strips, etc.) are necessary to achieve better profiles for acidification and eutrophication associated with the cropping systems (Kim and Dale, 2005).

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