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USE SYSTEMS DYNAMICS TO EVALUATE SCENARIOS OF REUSING COOKING OIL IN BIODIESEL PRODUCTION IN A PUBLIC IES

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Abstract

The article presents the modeling and development of a simulation model to assess the production of biodiesel from the reuse of cooking oil used in university restaurants (UR) of a higher education institution (HEI). For the construction of the model (definition of variables and their interrelationships) used by theoretical basis the bibliographic research and observations of the process of generation of the waste cooking oil economics. Among the issues analyzed is the reduction of environmental impact, due to the reduction of inappropriate disposal of cooking oil, and reducing the generation of CO2 caused by the use of biodiesel. To evaluate the possibilities of generation and reuse of the UK oil in biodiesel production, were generated two scenarios: a scenario based on current situation of waste generation and another, named future scenario with best practices of reuse and recycling of these. The results obtained by the simulation shows that, in addition to the large reduction of the environmental impact, the recycling process brings significant economic gain as a function of cost savings with the purchase of fuel. The simulated time horizon was 10 years and Vensim software was used for the development of the simulation.

Keywords: Cooking oil; recycling; reuse; biodiesel; simulation.

1. INTRODUCTION

Currently, the concern with sustainability, as well as the use of materials from renewable sources are the center of attention, not only by the government but also by enterprises and the population in general. In Brazil, as in all developing countries, the concern about the proper final disposal of solid wastes has been much discussed. This destination is one of the biggest problems of modern society, because the composition of municipal waste has been modified over the past few years and the production has increased significantly (Oliveira *et* Sommerlatte, 2009).

Waste generation occurs in quantities and constitutions that change according to the economic level of the population and of different cultural and social aspects, as well as other local features. In the classification by Pessin *et al.* (2002), the cooking oil fits in the category Miscellaneous among domestic waste. For being an important component in the kitchens, the oil causes a lot of problems to the environment when disposed of improperly, such as deposits in pipes and in water pollution (Oliveira *et* Sommerlatte, 2009).

For being an excellent byproduct, the cooking oil can be used in the production of soap and detergents, animal feed, resin for adhesives, as well as in the production of biodiesel, which is showing an alternative to fossil fuels, in addition to using renewable raw material, strikes less the environment, reducing the emission of greenhouse gases.

Within this context, this article presents a simulation model and a proposal for utilization of waste cooking oil, used in university restaurants (UR) higher education institution (HEI) public. In the specific case, was simulated the possibility of transforming the oil into biodiesel, and its subsequent

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use as fuel for vehicles that carry out the transport of the academic community (intracampus and intercampi).

The article is structured as follows: section 2 presents the theoretical framework about the consequences of incorrect disposal of cooking oil and biodiesel concepts. Section 3 presents the research method applied at work. Section 4 presents the current scenario of waste generation in HEI, proposes a new scenario, modeled through the *Vensim PLE*, and presents the results generated by the model. Finally, section 5 presents the final considerations.

2. TREATMENT PROCESS OF COOKING OIL

On the basis of the difference in density, the cooking oil is lighter than water, so when mixed, tends to emerge, thus forming a film on the mass of water which causes the reduction or blockage of oxygen, resulting in the death of living beings that dwell in it. In addition, because of its viscosity, tends to insulate the soil, besides acting as an aggregator of various element particles which cause problems in pipes causing flooding and damaging (SABESP, 2007).

The rates allowed by the CONAMA (2011) in effluents, to cooking oil to 50 ml per liter, which is in need of 18400 liters of water for each liter of cooking oil thrown inappropriately in the environment. According to Santos (2009), it is estimated that in Brazil are discarded 9 billion liters per year, being that only 2.5% of this amount is recycled. The potential polluter of this amount would be of 161.46 billion liters of water a year. I.e. 2650-year would be needed so that the company could handle all the water potentially contaminated by cooking oil (SABESP, 2007).

2.1. Alternatives for distribution of cooking oil

Before such data can verify that the inappropriate disposal of this oil is a serious problem. Thus, it is imperative that any reuse of the waste strategy, so that it can again be entered in the production chain, minimizing environmental impact and adding economic value to the residue. One of these uses, the most common are processed into biodiesel or soap (SABESP, 2007).

The process of reverse logistics for getting this oil used is quite complex (Zucatto *et al.*., 2013). Some specific initiatives are coming from companies that offer financial incentives for restaurants and condominiums provide used cooking oil for recycling. After collected, so you can undergo any transformation process is necessary for the removal of solid wastes, usually food scraps, as well as removing the moisture present in the oil. The first is done through the filter, the second is performed by the process of decanting, since the oil and water are heterogeneous mixtures and therefore easily separable, only after this separation is possible using the oil in any recycling process.

2.2 Biodiesel

Biodiesel is a fuel made from vegetable or animal raw materials. Vegetable raw materials are derived from vegetable oils, animal, in turn, can be obtained from pigment, beef tallow and poultry (Parente, 2003). The stages of the process of production of biodiesel can be viewed in Figure 1.

Biodiesel composes, along with ethanol, important offer to the fuel segment. Both are named for biofuels derived from biomass and for being less polluting and renewable. The pure biodiesel is called biodiesel, which is also called B100. Mixtures of biodiesel with mineral diesel are named for "BXX", where "XX" refers to the amount of biodiesel in the blend, for example, B10 is a mixture of 10% biodiesel in 90% of mineral diesel. Figure 1 presents the flowchart of biodiesel production.

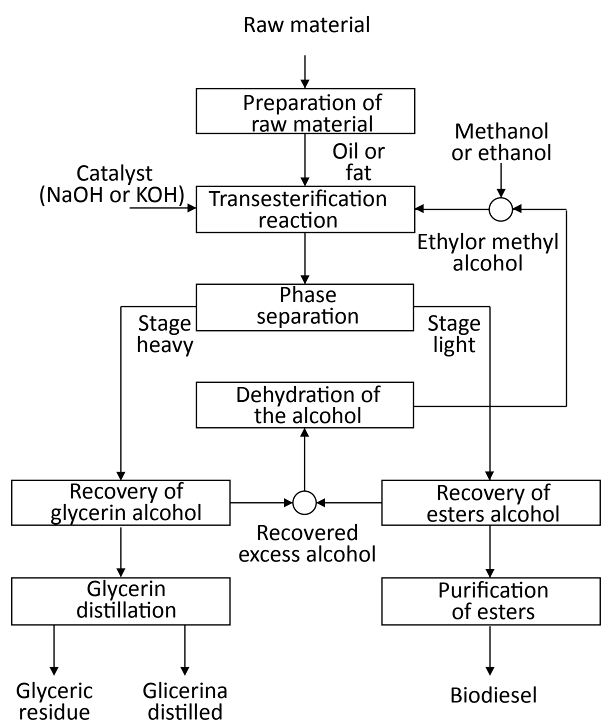

Figure 1 - Flowchart of the biodiesel production process
Source: Parente (2003)

3. RESEARCH METHOD

In this work, the research method adopted for the development of computational model was based on the me-

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thodology by Law *et* Kelton (1991), which is made up of the following steps: (1) exploratory studies in scientific articles, reports and interviews with the managers of the simulated environment, in case an UR, through these data the problem was specified and structured, as it was formulated the dynamic hypothesis presented in Section 3.1; (2) development of the solution, the construction of formal models able to represent the problem; (3) computer implementation of the solution, using the *Vensim* Simulator in the area of *system dynamics*; (4) validation of the solution, through laboratory testing and analysis of the historical behavior, to verify that the results obtained represent the observed reality, as well as through the simulation of an experiment using two scenarios. Were also interviewed managers of areas involved to ensure maximum reliability to the study.

3.1. Formulation of Dynamic Hypothesis

For Silva (2006), the dynamic hypothesis aims to work the problem theoretically, analyzing their behavior and observing which variables are part of the system. In this article, incorporated four basic variables: change in the use of cooking oil per meal, CO2 emissions, biodiesel and diesel fuel economy. The goal of this step is to formulate a hypothesis to explain the dynamics as a result of the internal structure of the system through the interaction between the variables and the agents represented in the model. Thus, the dynamic hypothesis of *systems dynamics* model of this work is defined as the following: the variation of the amount of meals served by the UK associated with the amount of cooking oil used has direct influence on the total quantity of waste generated, as well as oil, recycling and environmental and financial benefits generated by this (recycling).

3.2. System Dynamics

The methodology *system dynamics* (SD) allows the study of the behavior of systems over time, allowing the assessment of the consequences of our decisions. For this reason and the need to study the impacts of recycling of waste at a future time horizon decided to use it on modeling and computer simulation. An SD model can be defined as the structure resulting from the interaction of policies. This structure is comprised of two main components, which are stocks and flows. Ford (2009) defines SD as a combination of stocks and flows that use a computational framework to be simulated.

4. SYSTEM MODELING

Recycling, pursuant to law, is the process of transformation of waste involving the modification of their physical properties, physico-chemical or biological weapons, aiming at transforming these into new products or inputs (ABRELPE, 2014).

Currently, the growing solid waste generation by population, so demanding that viable alternatives to the better use of waste is created and executed. In this respect, the recycling and the reuse of the residues appear as viable alternatives, since at the time the material is recycled or salvaged it does not pollute the environment and does not use natural resources in excess in its transformation. In this section will be presented the variables and the model developed, simulated scenarios in the same and, finally, the results and to validate the template.

4.1. Model development and component variables

On the basis of the importance of the cases cited for the preservation of the environment and the environmental gains caused by these, this work sought to develop a simulation model, which allowed both the managers of waste area assess recycling policies/reuse of cooking oil of the UK a public HEI, where they assessed the environmental gains, aiming at sustainable development, generated by this, as well as the economic benefits of the process.

In the model, the environmental gains assessed were the reduction of water pollution and CO2 emissions and, with regard to financial gains, cost-cutting was evaluated with the purchase of diesel for buses that make the inner path on campus, as well as, intercampus transportation.

The decisions, from the analyses generated by the model, may involve the pursuit of total recycling of waste cooking oil, search by reducing the use of oil consumption at meals, incentives to increased “green consumption” (Mansvelt, 2010), as well as other reviews and notices of interest to environmental managers and/or academic, since they are enforceable in the simulation model. The model was developed aiming to simplify user-computer interaction, so that analyses of the type “what if?”, common in simulation models, are fast and simple implementation.

For the definition of the variables of the simulation model presented in Figure 2 were used in academic papers and Government waste area, BNDES (2004), CONAMA (2011), Oliveira *et* Orrico Filho (2014) and Zucatto *et al.* (2013). Selected variables, as well as their interrelationships with other variables, which influence on the values of reuse of the total cooking oil in biodiesel production, are:

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- The ***OleoParaReciclar*** variable from the variables ***OleoPorRefeicao*** and ***QuantRefeicao***, that is, the amount of oil available for recycling is the product of the quantity of residual oil per meal by the number of meals served. The described variables are represented in equation (1) of the model equations in Figure 3;

- The variable ***BiodieselGerado*** is the product of the variable ***OleoParaReciclar*** by the ***TaxaAprovOleo***, which represents how much takes advantage of the residual oil when recycling. The described variables are represented in equation (2) of the model equations;

- The ***ReducaoPoluicaoAgua*** variable is obtained through the product amount of residual oil by potential polluter of each liter dumped inappropriately, i.e. 18400 liters of water per liter of oil. The variable is described in equation (3) of the model equations shown in Figure 3;

- The variable ***ReducaoCO2*** is the product of the quantity of biodiesel produced by the amount of CO2 emissions per liter of diesel (2.66 kg/CO2) by the estimated reduction of biodiesel (15%). The equation (4) of the model equations describes the variable;

- The ***ConsumoMedioBiodiesel*** variable is obtained by the product of the ***ConsumoMedioDiesel*** (average consumption of traditional diesel) by the estimated consumption increase between 5% and 10% of biodiesel. The equation (5) equation model represents the variable described;

- The variable ***Economy*** represents the financial gains of the reuse of cooking oil and is obtained using the variables ***ConsumoMedioBiodiesel***, **BiodieselGerado**, ***ValorDiesel*** and ***CustoProducao*** (which represents the estimated cost per liter of biodiesel produced). The variable is described in equation (6) model of equations shown in Figure 3;

- The ***GeracaoGlicerina*** variable represents the total generated by the production of Glycerin biodiesel from recycled cooking oil. The generation rate is 10% of the total of biodiesel produced. It is noteworthy that this variable was not the main object of this study, but from the Glycerin can be produced other products. This fact demonstrates the importance of recycling of oil, not only for environmental gains, but also by the financial. The variable is described in equation (7) model of equations shown in Figure 3.

4.2. Simulated scenarios in the model

The transformation ratio of the cooking oil into biodiesel, through the insertion of the methanol is in the order of 80% (Santos, 2009), although other references present differences in value (Zucatto *et al.*, 2013). As a by-product in the process there is also the generation of Glycerin, corresponding to approximately 10% (Yang *et al.,*2012)

It is noteworthy that diesel engines, without adaptation, will work with biodiesel with maximum 20% mixture. That is, the biodiesel produced should be mixed with common diesel so it can be used. In Brazil, since the year 2013, the legislation provides that the common diesel must have this 5% biodiesel, what characterizes the B5 diesel. Therefore, from this mixture, you can add the generated form the B20 biodiesel that can be used as fuel. Thus, for each liter of diesel B5 must be added 190 ml of biodiesel produced.

In addition to the reduction of the environmental impact resulting from inappropriate disposal, other additional advantages may be obtained from the use of biodiesel. Among them, reducing the carbon dioxide emitted into the atmosphere through the burning of the fuel, because biodiesel generates a smaller quantity of this pollutant. There is also economic impact, by reducing the purchase of diesel for use in these vehicles.

According to the data of the CONAMA resolution (2011), is admitted to the presence of up to 50 mg/l of vegetable oils and animal fats in effluents. The recommended density by ANVISA for the cooking oil is 0.920. From these data, we can calculate the environmental impact caused by liter of oil improperly disposed of in the environment.

This relationship has been that each liter of oil needs 18400 liters of water to scatter. This value is lower than the values indicated on Oliveira *et* Sommerlatte (2009) and Zucatto *et al.* (2013), however, did not identify himself to support the values alleged in such references.

The modeling developed, the variable causing the greatest impact, the sensitivity of the model is the amount of meals served. This is directly affected by variations in the numbers of students and servers present in the institution. Based on internal reports provided by HEI, the growth in the number of meals was estimated at around 5000 meals/year.

The amount of oil used currently remains constant, around 0.00411 liters per meal served. Figure 2 graphically presents the modeling developed, that is, the components of the system, as well as their interrelationships.

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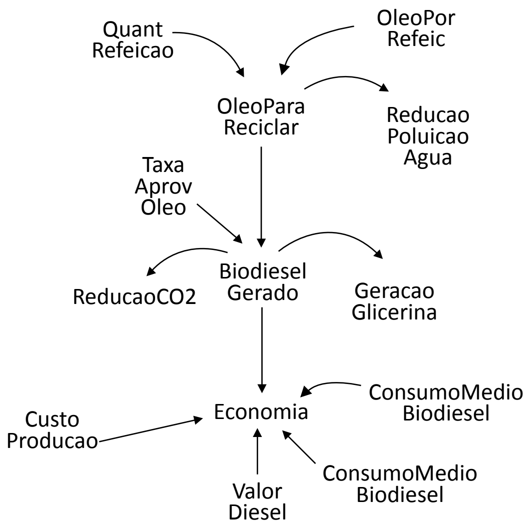

Figure 2 - Simulation model developed

Source: Authors, 2015

The cost of biodiesel production is strongly influenced by the cost of the raw material used in this case, is free. The costs involved for the process and other products required the chemical reaction is estimated around R$ 0.30 per liter of oil, i.e. approximately R$ 1.05 per liter of biofuel B100.

It is known that the common diesel emits KgCO2 2669 per liter of fuel burned, the B5 diesel, i.e. the standard diesel available in Brazil today, presents a pollution reduction, compared to diesel, 3.75%. Already the B20 diesel, reaches an index of pollution reduction of 15.28%. In this way it is possible to measure the reduction of CO2, one of the main greenhouse gases, according to the reduction in the use of common diesel oil. However, it is worth mentioning that the B20 diesel, although reducing pollution levels features a reduction in yield, consuming 6% more compared to diesel fuel (which is taken into account in the formulation of the model).

Based on these information, projected two scenarios: a current scenario, where it is called represented only the increase in the number of meals served; and future scenario, in which, in addition to the increase in the number of meals served, varies the amount of oil used for meal and also the rate of utilization. The proposal is to minimize the environmental impact caused by the waste generated, this can be achieved through more efficient processes of transformation or through the reduction of generation of these wastes, which is represented in this scenario. In table 1 the values of the variables used in both scenarios.

Table 1 - Setting of the variables used in the scenarios

Variable	Current Scenario	Future Scenario
Number of meals	1,449 million meals / year	Adding 5,000 meals / year
Oil per meal	0,00411mL	Reducing 5% by year 4, 2% from year 5 to year 8, 0.5% from year 9 to year 10
Utilization rate in the recycling process	80%	80% incremented linearly until it reaches 90% in the year 10
Production cost	R$ 1,05	R$ 1,05
Diesel oil value (B5)	R$ 2,65	R$ 2,65
Biodiesel Yield (B20)	94%	94%
Diesel oil consumption	3,03 Km/l	3,03 Km/l
Glycerine generation	10%	10%
CO2 pollution	2,669 KgCO2	2,669 KgCO2
Biodiesel Reduction (B20)	15,38%	15,38%
Potential pollutant per liter of oil disposed of improperly	18.400 l of water	18.400 l of water

Source: Authors (2015)

4.3. Results and possibilities of use of biodiesel generated in HEI

Given the seriousness of the scenario, where the cooking oil is thrown in the environment, and incipient initiatives of recycling of this waste was created a proposal to reuse it as raw material for the manufacture of biodiesel. For the analysis of the results generated by the simulation model, took into consideration the possibility

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(1) OleoParaReciclar (t) = OleoPorRefeicao (t) *QuantRefeicao (t)
(2) BiodieselGerado (t) = OleoParaReciclar (t) *TaxaAprovOleo
(3) ReducaoPoluicaoAgua (t) = 18400*OleoParaReciclar (t)
(4) ReducaoCO2 (t) = (2.669*0.85)*BiodieselGerado (t)
(5) ConsumoMedioBiodiesel (t) = ConsumoMedioDiesel (t)*[0.9..0.95]
(6) Economia (t) = ((ConsumoMedioBiodiesel (t)*BiodieselGerado (t)) *ValorDiesel (t
)/ConsumoMedioDiesel (t)) - CustoProducao (t)
(7) GeracaoGlicerina (t) = BiodieselGerado (t)*0.1
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Figure 3 - Simulation equations model developed.

Source: Authors (2015)

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of fuel produced to be used on buses that carry out internal transportation on campus, as well as the intercampi transport of public HEI.

Buses (transport of HEI) make up a total of about 800 km/month on intracampus shuttle and 12000 km/month in intercampus transportation. Considering an average of consumption obtained through the study of Oliveira *et* Orrico Filho (2014), to take a bus, 0.330 l/km or 3.03 Km/l.

In the scenarios modeled it was considered that the recycling of cooking oil, while reducing the environmental impact in terms of inappropriate disposal, have other positive impacts, such as obtaining a less pollutant fuel that traditionally obtained through fossil fuels. Thus, the following are presented the results obtained by the simulation model in *Vensim PLE*.

Figure 4 presents the results related to the variation in the production of oil for the current scenario and future scenario. Note a reduction in the production of waste in the future, even with the gradual increase in the number of meals, the reduction in the amount of product used in the preparation of meals contributes significantly to reduce their generation.

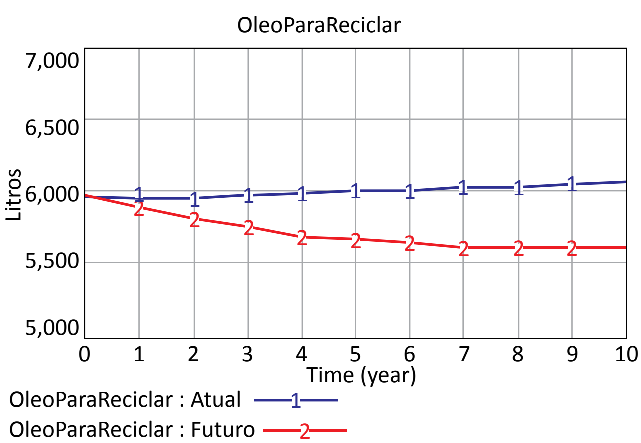

Figure 4 - Variation in the generation of oil (residue)
Source: Authors (2015)

The potential polluter to the waste cooking oil generated by the current scenario and future scenario can be seen in Figure 5. Keeping the current scenario, the horizon of 10 years, the total amount of oil residue generated during this period will be of 65949.07 liters, whose potential polluter is more than 1.2 billion liters of water. Note that the current scenario has a potential polluter greater depending on the largest waste generation.

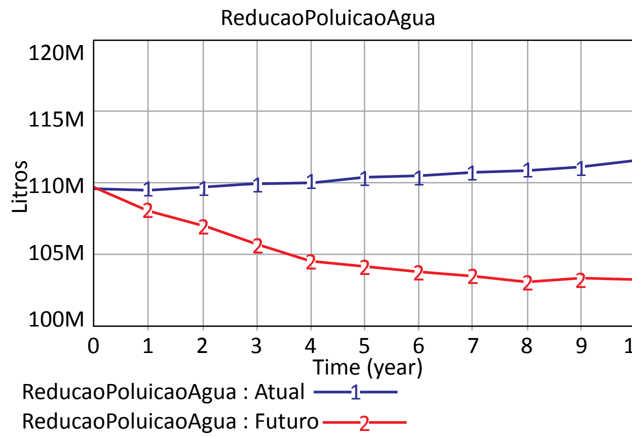

Figure 5 - Variation of potential polluter
Source: Authors (2015)

The potential for generating biodiesel, through recycling, is presented in Figure 6, your variation is directly proportional to the amount of waste produced and the rate of utilization of the recycling process. In the future, depending on the rate of growth in the transformation process, presents a result approximately 5% over the current scenario of production (if generated).

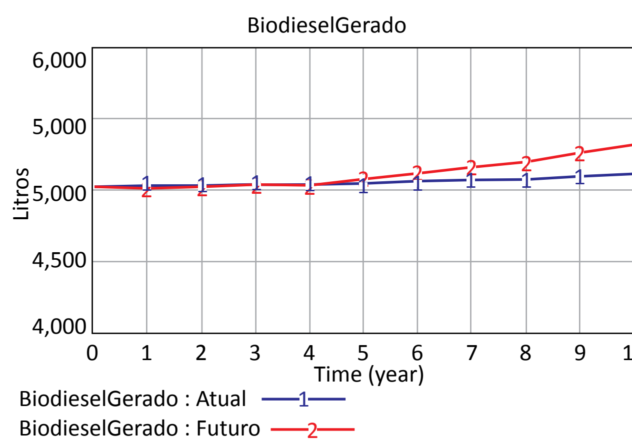

Figure 6 - Generation of Biodiesel
Source: Authors (2015)

In the simulated period, if you keep the current scenario of using common diesel would be reduced almost 11000 kg of CO2 per year, with the manufacturing of biodiesel, the reduction potential is presented in Figure 7. The future scenario, despite highlighting the increased reduction in 464 kgCO2 in 10th grade simulated, can be considered a good result, because in this scenario is considered a relative increase in the UK. Soon, increases considerably the biodiesel produced, thereby reducing emissions.

In addition to the reduction of environmental impact, through the reuse of this waste has been a savings of over $

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120,000.00 R$ over 10 years, I subtracted the costs involved in the production of biodiesel. Figure 8 presents the financial impact of the reuse of cooking oil over the ten years mock exams.

Note that the future scenario presents a considerable improvement in the economy of approximately 4%. It's worth pointing out that the future represents a reduction of oil used for meal, however, due to the increased efficiency of the transformation process allows you to generate the greatest amount of biodiesel by the remaining residue, contributing significantly to greater economy. Table 2 summarizes the results for both scenarios.

The validation of these scenarios was conducted by examining the historical behavior of the values of variables, using the comparison of values obtained for each of the variables of the scenario, with those observed previously in the UK. Still, in the case of validation of the model developed, managers were interviewed in the area of nutrition and environmental area (with regard to real possibilities of biodiesel production).

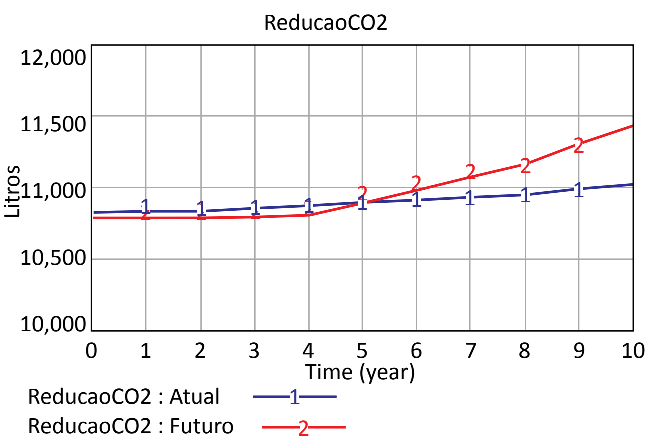

Figure 7 - Reduction of CO2 emission
Source: Authors (2015)

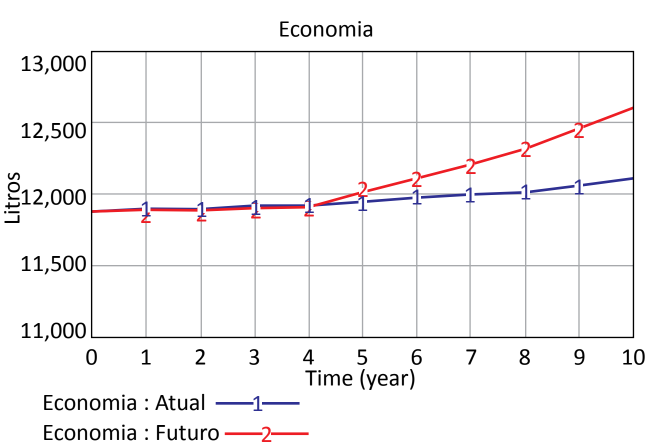

Figure 8 - Economy caused by cooking oil recycling
Source: Authors (2015)

Table 2 - Results summarized in the scenarios analyzed

Variable	Current (Year 10)	Future (Year 10)
Fuel purchase	R$ 99.866,80	R$ 99.357,70
Economy by year	R$ 12.079,80	R$ 12.588,90
Reduction of CO2 Emissions	11.002 kgCO2	11.466 kgCO2
Reduction of water pollution	111.545.000 l	103.330.000 l

Source: Authors (2015)

5. FINAL CONSIDERATIONS

This work presented a proposal for a model for the use of cooking oil used in the UK a public HEI. The results presented were obtained through simulation using *Vensim*software. However, it is possible to say that, in addition to reducing the environmental impact and the economy generated for a scenario of 10 years justify the application of the results generated by the model.

Among the main results caused by cooking oil recycling UR has generated savings of over $ 120,000.00 R$, in the acquisition of diesel, over 10 years, I subtracted the costs involved in the production of biodiesel. On the reduction of environmental impacts, also object of research study, it was found that with the UK oil recycling and, with its later use in transport vehicles of the IES, the emission of CO2 into the environment would be reduced to 11 tons per year. Another important environmental factor evidenced in research is the potential for residual oil polluter, but IES concerned such fact in does not occur.

As possible further work is the expansion of the model to cover the scenario of other educational institutions of the federal sphere, and municipal and State might, in addition to the search for partners for the production of biodiesel and other products for which the cooking oil can be an excellent raw material.

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