EXERGOENVIRONMENTAL ANALYSIS OF THE ANHYDROUS ETHANOL PRODUCTION PROCESS

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Abstract. *According to the Life Cycle Assessment (LCA) methodology, allocation is required for multi-product processes. In the ethanol life cycle this refers to six sub-processes: sugarcane milling, juice treatment, evaporation, fermentation, ethanolrecovering and purification and electricity generation. In these processes an allocation based on the exergy of the main streams was applied.This was done trought an exergoenvironmental evaluation of ethanol production process from sugarcane, considering an autonomous distillery plant with a milling capacity of 1,672,000 t/year using thermoeconomics and life cycle assessment (applying the Eco-Indicator 99 method). The results allowed to determine which stages of ethanol production process present the greatest environmental impacts, and the possibilities to minimize them.*

Keywords: *Anhydrous Ethanol, Autonomous distillery, Exergoenvironmental analysis*

1. INTRODUCTION

According to the Ministry of Agriculture, Livestock and Supply (MAPA), a government agency responsible for the registration of the mills and distilleries installed in Brazil, in the harvest 2007/2008 there were in operation 434 plants crushing 495 million tons of sugarcane per season, 16 being used for sugar production only, 167 for ethanol production and the other half producing both sugar and ethanol (MAPA, 2009). Most of the large plants are located in the state of São Paulo, where almost two-thirds of the Brazilian ethanol is being produced (Goldemberg, 2008).

It is important to remember that environmental impacts associated to the ethanol production differ widely depending on upon how the sugarcane cultivation is made in the agricultural stage (referred to the use of fertilizers, pesticides, diesel fuel spent in sugarcane cultivation, mechanized harvesting and the transportation of sugarcane to the processing mill) and how the steam and electricity needed for the production process is generated. At present, all the Brazilian plants are self-sufficient in the generation of these utilities, and in some cases produced a small surplus of electricity for sale to the grid using sugarcane bagasse as a fuel, instead of fossil fuels, by the cogenerations systems, this allows to obtain a lower overall CO_2 emissions on a life cycle basis.

A commonly used tool for sustainability studies is LCA, which includes evaluation of inputs, products and impacts in all stages of the product life cycle. There has been a substantial development of life cycle methodologies to assess the energetic and environmental performance of product systems from cradle-to-grave. However, due to the methodological scope of LCA, the environmental impact is related to the overall product of the energy conversion process, e.g., to the amount of electric energy generated by a power plant. Due to the lack of thermodynamic assessment, LCA is not capable of allocating the environmental impact of fuel consumption to single components. This problem has not been solved by authors suggesting an exergy analysis over the entire life cycle of a product or process, e.g., by the concept of exergetic life cycle analysis or life cycle exergy analysis, neither by extensions of environmental LCA through exergy-based indicators (Meyer et al., 2009).

The purpose of this work is to develop a better understanding of the environmental impact formation in the anhydrous ethanol production by means of an exergoenvironmental analysis. In this study, the environmentally most relevant system components of this process are identified and information about possibilities to reduce the overall environmental impact is provided.

2. ENVIRONMENTAL ASSESSMENT OF THE SUGARCANE PRODUCTION AND ENERGY

According to the Brazilian Communication to the United Nations Framework Convention on Climate Change (1994 figures), the utilization of sugarcane as energy source had reduced carbon emissions by 13% in the energy sector. In the same way UNICA indicates that for each 100 million tons of sugarcane used for energy, the emission of 12.6 million tons of equivalent CO_2 could be avoided (taking into account ethanol, bagasse and surplus electric power provided to the grid) (BNDES and CGEE, 2008).

The most relevant issues associated with environmental impacts of sugarcane and bioethanol production in Brazil includes emissions with global impacts (greenhouse effect gases), local impacts (especially associated with pre-harvest burning), water use and the disposal of effluents (including stillage), use of agricultural pesticides and fertilizers, erosion and protection of soil fertility and biodiversity. To quantitatively assess the environmental impact of the previously mentioned aspect and to combine them with an exergetic analysis, we need a LCA method that converts the main environmental impacts into a single indicator.

The LCA methodology is standardized and described under the standards of the International Standard Organization, ISO 14040–14043 (ISO 14040; ISO 14041; ISO 14042 and ISO 14043). LCA is used to evaluate the environmental impacts and other potential factors related to the product's life cycle energy balance, including raw materials, production, consumption, and waste utilization. The LCA methodology developed in this study is based on the ISO 14040 Standard, in so far as it deals with the definition of the objective, function, scope and goal of LCA studies including inventory analysis.

Related to the Life Cycle Impact Assessment, many methodologies applied to human health and environmental risk have been developed. One of these methodologies applied in many LCA works is the Eco-Indicator 99. This method analyzes environmental burden under three impact areas (human health, ecosystem, resources), computing eleven different impact categories like carcinogens, respiratory organics, respiratory inorganic, climate change, radiation, ozone layer, eco-toxicity, acidification, eutrophication, land use, minerals and fossil fuels (Figure 1).

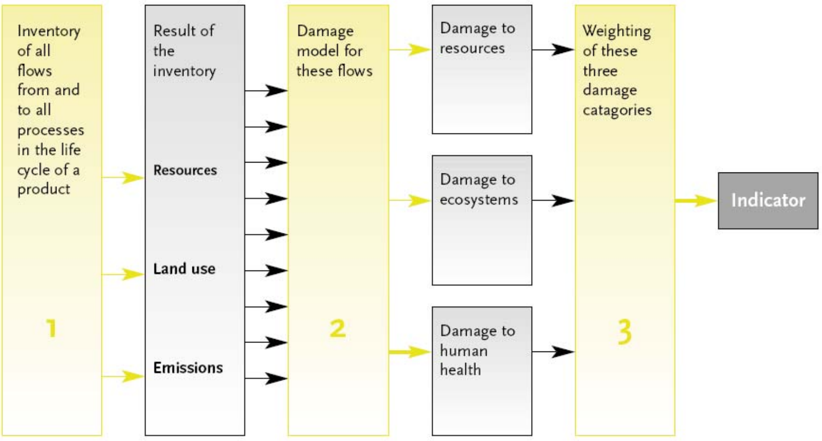

Figure 1. General procedure for the calculation of Eco-indicators. The light coloured boxes refer to procedures, the dark coloured boxes refers to intermediate results (Ministry of Housing Spatial Planning and the Environment, 2000)

Luo et al. (2009) carried out a comparative study of LCA on gasoline and ethanol as fuels. From the LCA results it can be concluded that in terms of abiotic depletion, GHG emissions, ozone layer depletion and photochemical oxidation ethanol fuels are better options than gasoline, while gasoline is a better fuel from the point of view of human toxicity, ecotoxicity, acidification and eutrophication are concerned. When GHG emissions are concerned, however, burning bagasse for electricity generation (base case) is a much better option than converting bagasse to ethanol (future case); while in all the other aspects the results are better for the future case.

Nguyen et al. (2008) had carried out an analysis of energy performance and supply potential performed to evaluate molasses utilization for fuel ethanol. The molasses ethanol even having a potential could improve it if co-products, e.g. stillage, and cane trash are utilized for process energy in place of fossil fuels. Moreover, there are also opportunities by adopting new technologies in ethanol conversion to reduce energy demand as it is the case of raising ethanol productivity. Even more remarkable is the figure of ethanol energy gain from petroleum energy use, 6.12 MJ/MJ.

In this sense Rocha et al. (2010) had carried out a study showing that energy recovery from stillage, before the final disposition, has environmental benefits for the overall of ethanol production. The recovery of the energy value of the stillage could be accomplished before its final disposition. For example, its anaerobic digestion had shown to be quite favourable in three indicators: be used for the fertirrigation of the soil, reduce the emission of GHG as a consequence of the kWh generated without conventional fuel , and also in the use of abiotic resources.

Renouf et al. (2008) shows that sugarcane provides energy, no GHG and potentially acidification benefits by virtue of the fact that bagasse is available as a renewable energy source. Sugarcane obtains some of its comparative advantage through its high yields of saccharide. The analysis has also shown that field emissions, N in particular are important.

Botha and von Blottnitz (2006) had presented a LCA study comparing the production of two alternative energy sources products from surplus bagasse. For the conversion technologies compared in this study, the option of electricity generation resulted the best one referred to carbon balance indicators and also when considered the energy industry associated impacts (acidification and eutrophication), being more ecofriendly liquid fuel option.

3. EXERGOENVIRONMENTAL ANALYSIS

The exergoenvironmental analysis in this work consists mainly, of three steps. First an exergy analysis of the energy conversion process, that consists of an ethanol plant and its cogeneration system to supply the thermal and electrical demand. Second, to computes the environmental impacts by applying the Eco-Indicator 99 Life Cycle Assessment method. As a third step the environmental impact are assigned to the exergy streams in the process, using thermoeconomics tool, which allows the calculation of the exergoenvironmental variables and consequently allow to make the exergoenvironmental evaluation.

In the exergoenvironmental evaluation the approach of thermoeconomic analysis is modified to deal with an evaluation of the ecological impact instead of an economic problem. The thermoeconomic model is a set of equations, describing all the process of cost formation in the plant, which describes the distribution of the resources in the plant through the components, to obtain the final products. To construct the system of equations, the mathematical formalism used by Santos et al., (2006) and Frangopoulos (1994) was used.

One of the results from exergoenvironmental analysis is the named specific environmental impact bj. This represents environmental impact associated with the production of the j stream per exergy unit (mPts/kJ) (Meyer et al., 2009). Similarly, it computes the environmental impact rate $\dot{B}_j$ (mPts/s) of j stream. This impact is the product of its exergy rate $\dot{E}_j$ and the specific environmental impact b_j, as shown in Eq. (1):

$$\dot{B}_j = b_j.\dot{E}_j \tag{1}$$

Another important variable that is calculated is the Environmental Impact of Exergy Destruction. As previous work (Buchgeister et al., 2009), it is assumed that exergy destruction is compensated by a higher consumption of fuel to obtain a given amount of product. So, in this case the exergy destruction ($\dot{E}_{D,k}$) is multiplied by the specific environmental impact $b_{F,k.}$ associated with the fuel of component. The result is the environmental impact of exergy destruction (Eq. (2)).

$$\dot{B}_{D,K} = b_{F,K}\dot{E}_{D,K} , \tag{2}$$

So, computing the specific environmental impact of all internal flows of exergy (j) through the environmental impact balance of each equipment or sub-system k from thermal system, as it is in Eq. (3).

$$\sum(b_j\dot{E}_j) = \dot{Y}_K , \tag{3}$$

Where $\dot{Y}_k$ is the environmental impacts that occur during the life cycle phases of equipment or sub-system k, like: construction (including manufacturing, transport and installation), operation and maintenance. These environmental impacts use the Eco-Indicator 99 method for calculation, after it divides the results by lifespan of equipment. In this study assumed lifespan of all equipments is 100,000 hours.

4. PLANT DESCRIPTION

During ethanol production from sugarcane in an autonomous distillery (i.e., not annexed to a sugar mill), the feedstock is cleaned, crushed and milled to extract the sugarcane juice and in doing so a co-product is generated (bagasse). The sugarcane juice is transformed into ethanol according to the following stages: juice treatment, concentration and sterilization; fermentation; distillation and dehydration. The sugarcane bagasse (50% humidity) is burn in a boilers generating steam that is fed to a turbogenerator for electricity, in such a way that all the thermal and electricity demands are satisfied (Fig. 2).

In this study, the cogeneration plant is based on a condensing/extraction steam turbine (CEST). The mills are driven by simple stage steam turbines, the evaporation system is a four effects one, and the plant also has continuous fermentation, atmospheric distillation and dehydration system based on cyclohexane. The steam is generated in two boilers at steam parameters of 6.5 MPa and 490 °C.

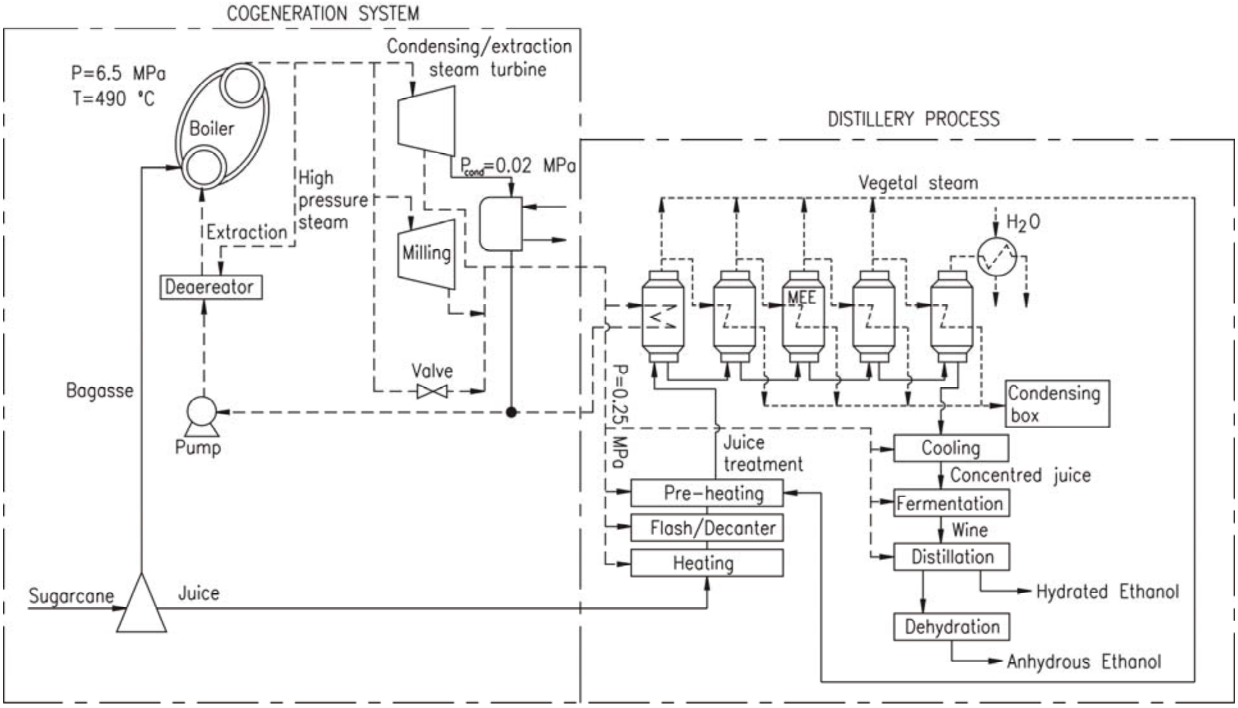

Fig.2 - Physical structure of autonomous distillery (Adapted from Higa, 2003)

Table 1 - Parameters adopted for the process simulation

Parameter	**Value**	**Units**
Cogeneration plant		
Atmospheric air temperature	25	°C
Atmospheric air pressure	101.3	kPa
Steam pressure	6.5	MPa
Steam temperature	490	°C
Condensing pressure	20	kPa
Bagasse moisture content	50	%
Sugarcane fiber content	14	%
Bagasse - Low Heating Value (LHV)	7560	kJ/kg bagasse
Boiler thermal efficiency	82*	%
Steam turbines isentropic efficiency	80	%
Pump isentropic efficiency	85	%
Electric generator efficiency	96	%
Process electric power consumption	12	kWh/tc
Cogeneration plant auxiliary equipment power consumption	**	
Mills		
Mills capacity	380	tc/h
Inlet steam pressure	2.2	MPa
Process steam pressure	250	kPa
Mechanical power demand of cane preparation and juice extraction	16	kWh/t of cane
Steam turbines isentropic efficiency	70	%
Process steam demand		

Process steam pressure	250	kPa
Process steam temperature	124.7	°C
Process steam consumption	388	kg/tc
Hydrated ethanol production	365	m^3/d
Anhydrous ethanol production	364	m^3/d

*Based on LHV of mill wet bagasse

** Calculated for each case using the modeling software Gate-Cycle.

5. EXERGOENVIRONMENTAL MODEL

Figure 3 represents one of the options to define the productive structure of the plant, which graphically depicts its cost formation process. The external resource is the sugarcane (C) and the main products are the net electrical power (PNP), hydrated (AEH) and Anhydrous Ethanol (AA) volumetric flows.

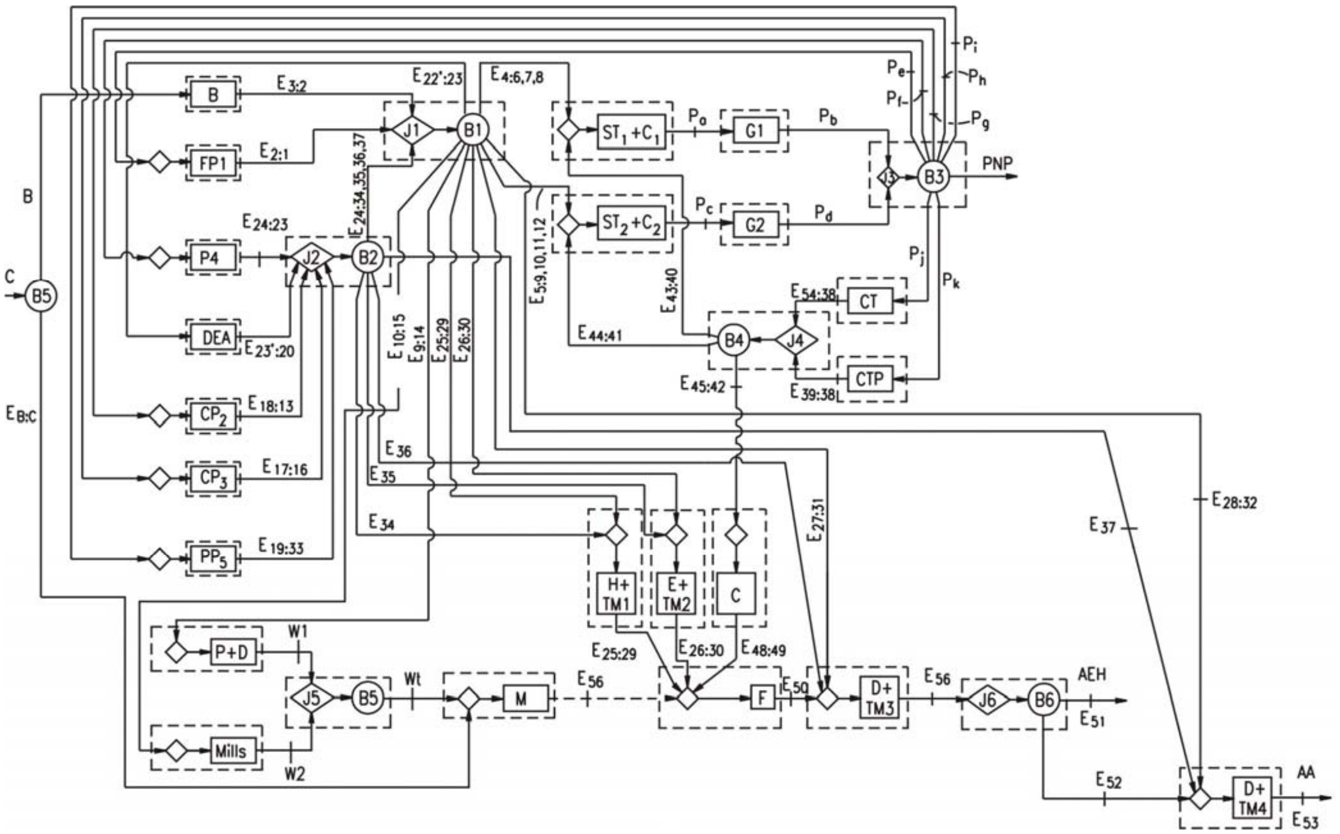

Figure 3. Productive structure for the evaluated distillery

Table 2. Exergoenvironmental model

Unit	Equation
B5	$b_B.E_B + b_{B:C}.E_{B:C} - b_c.E_c = \dot{Y}_c$ (4)
B	$b_{3:2}.E_{3:2} - b_B.E_B = \dot{Y}_B$ (5)
FP1	$b_{2:1}.E_{2:1} - b_P.E_{Pe} = \dot{Y}_{FP1}$ (6)
P4	$b_{24:23}.E_{24:23} - b_P.E_{Pf} = \dot{Y}_{P4}$ (7)
DEA	$b_{23':20}.E_{23':20} - b_{22':23}.E_{22':23} = \dot{Y}_{DEA}$ (8)
CP2	$b_{18:13}.E_{18:13} - b_P.E_{Pg} = \dot{Y}_{CP2}$ (9)
CP3	$b_{17:16}.E_{17:16} - b_P.E_{Ph} = \dot{Y}_{CP3}$ (10)

PP5	$b_{19:33}.E_{19:33} - b_P.E_{Pi} = \dot{Y}_{PP5}$ (11)
J1-B1	$b_{10:15}.E_{10:15} + b_{9:14}.E_{9:14} + b_{25:29}.E_{25:29} + b_{26:30}.E_{26:30} + b_{27:21}.E_{27:31} + b_{5:9,10,11,12}.E_{5:9,10,11,12} +$ $b_{4:6,7,8}.E_{4:6,7,8} + b_{22':23}.E_{22':23} - b_{3:2}.E_{3:2} - b_{2:1}.E_{2:1} - b_{24:34,35,36,37}.E_{24:34,35,36,37} = 0$ (12)
J2-B2	$b_{34}.E_{34} + b_{35}.E_{35} + b_{36}.E_{36} + b_{37}.E_{37} - b_{24:23}.E_{24:23} - b_{23':20}.E_{23':20} - b_{18:13}.E_{18:13} -$ $-b_{17:16}.E_{17:16} - b_{19:33}.E_{19:33} = 0$ (13)
P+D	$b_{W1}.E_{W1} - b_{9:14}.E_{9:14} = \dot{Y}_{P+D}$ (14)
Mills	$b_{W2}.E_{W2} - b_{10:15}.E_{10:15} = \dot{Y}_{Mills}$ (15)
M	$b_{56}.E_{56} - b_{B:C}.E_{B:C} - b_{Wt}.E_{Wt} = 0$ (16)
J4-B4	$b_{43:40}.E_{43:40} + b_{44:41}.E_{44:41} + b_{45:42}.E_{45:42} - b_{54:38}.E_{54:38} - b_{39:38}.E_{39:38} = 0$ (17)
CT	$b_{54:38}.E_{54:38} - b_P.E_{Pj} = \dot{Y}_{CT}$ (18)
CTP	$b_{39:38}.E_{39:38} - b_P.E_{Pk} = \dot{Y}_{CTP}$ (19)
ST1+C1	$b_{Pa}.E_{Pa} - b_{4:6,7,8}.E_{4:6,7,8} - b_{43:40}.E_{43:40} = \dot{Y}_{ST_1+C_1}$ (20)
ST2+C2	$b_{Pc}.E_{Pc} - b_{5:9,10,11,12}.E_{5:9,10,11,12} - b_{44:41}.E_{44:10} = \dot{Y}_{ST_2+C_2}$ (21)
G1	$b_{Pb}.E_{Pb} - b_{Pa}.E_{Pa} = \dot{Y}_{G1}$ (22)
G2	$b_{Pd}.E_{Pd} - b_{Pc}.E_{Pc} = \dot{Y}_{G2}$ (23)
H+TM1	$b_{25:29}.E_{25:29} - b_{34}.E_{34} - b_{25:29}.E_{25:29} = \dot{Y}_{H+TM1}$ (24)
E+TM2	$b_{26:30}.E_{26:30} - b_{35}.E_{35} - b_{26:30}.E_{26:30} = \dot{Y}_{E+TM2}$ (25)
C	$b_{48:49}.E_{48:49} - b_{45:42}.E_{45:42} = \dot{Y}_C$ (26)
F	$b_{50}.E_{50} - b_{56}.E_{56} - b_{25:29}.E_{25:29} - b_{26:30}.E_{26:30} - b_{48:49}.E_{48:49} = \dot{Y}_F$ (27)
D+TM3	$b_{56}.E_{56} - b_{36}.E_{36} - b_{27:31}.E_{27:31} = \dot{Y}_{D+TM3}$ (28)
J5-B5	$b_{Wt}.E_{Wt} - b_{W1}.E_{W1} - b_{W2}.E_{W2} = 0$ (29)
J3-B3	$b_P.(E_{Pe} + E_{Pf} + E_{Pg} + E_{Ph} + E_{Pi} + E_{Pj} + E_{Pk}) - b_{Pb}.E_{Pb} - b_{Pc}.E_{Pc} = 0$ (30)
J6-B6	$b_{51}.E_{51(AEH)} - b_{52}.E_{52} = 0$ (31)
D+TM4	$b_{53(AA)}.E_{53(AA)} - b_{52}.E_{52} - b_{37}.E_{37} - b_{28:32}.E_{28:32} = \dot{Y}_{D+TM4}$ (32)

5.1 LIMITATIONS AND ADVANTAGES OF EXERGOENVIRONMENTAL ANALYSIS

The restriction of exergoenvironmental analysis is referred to the LCA method that presents the following typical limitations (González et al., 2003; Renó et al., 2010):

- The nature of choices and assumptions made in LCA (e.g. system boundary setting, selection of data sources and impact categories) may be subjective;
- Models used for inventory analysis or the assess environmental impacts are limited by their assumptions, and it may not be available for all potential impacts or applications;
- The results of LCA studies based on global and regional issues, so for local applications it might not be adequately represented;
- The accuracy of LCA studies is limited by accessibility or availability of relevant data, or by quality of data;
- The lack of spatial and temporal dimensions in the inventory data used for impact assessment introduces uncertainty in the value of the impact results.

According to the International Standard on LCA the allocation should be avoided where possible by sub-division or system boundary expansion (Malça and Freire, 2006). However, when the allocation is unavoidable, the ISO 14041 recommends that the allocation should reflect the physical relationships between the environmental loads and the functions. Thus, allocation can consider the physical properties of the products, such as mass, volume, energy, because data on the properties are generally available and easily interpreted. The choice and justification of allocation procedures is a major issue for life cycle assessment, especially since it can have a significant influence on subsequent results.

In this way the exergoenvironmental analysis allows to allocate the main environmental loads, taking into account the quality of the different kinds of energy.

6. RESULTS

6.1 Life Cycle Assessment

The life cycle analysis of Anhydrous Ethanol starts at the stage of agricultural production of the sugarcane and ends with Anhydrous Ethanol production. In this study, the Anhydrous Ethanol supply stage to the clients, like distribution companies, fuel stations and consumers was not considered. Then with base in the functional unit selected in this work (1 m^3 anhydrous ethanol), the Life Cycle Inventory (LCI) of the sugarcane, steam and electricity production- that are the main energy inputs of this study- were computed. Also, the LCI of construction, operation and maintenance of the equipments (boilers, cooling system, pumps, steam turbines) were computed, as well as, the LCI of the ethanol plant., After that, the environmental impacts of all system- applying the Eco-Indicator 99 Life Cycle Assessment method- is computed . The results are shown in Figure 3.

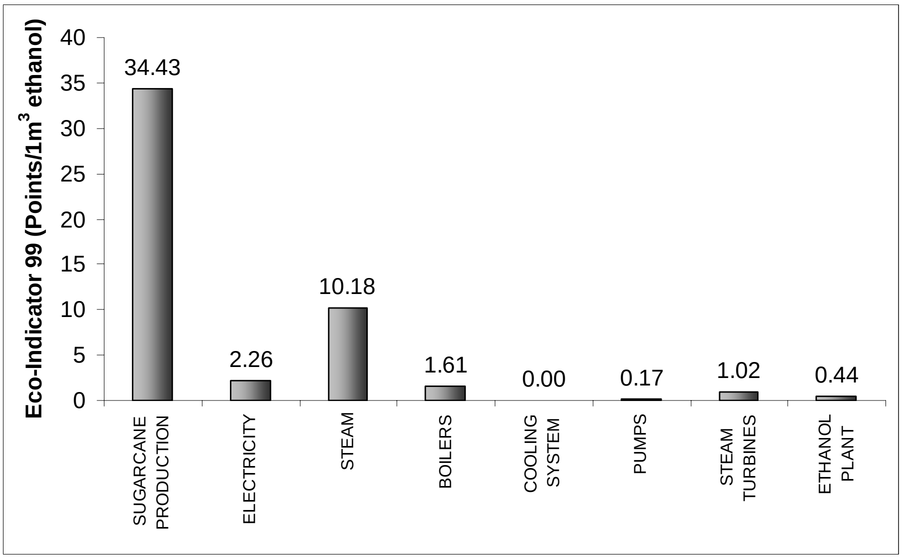

Figure 3. Total environmental impacts of the system

Figure 4 presents the environmental impacts divided by impact categories (carcinogens, ecotoxicity, land use, climate change, and others).

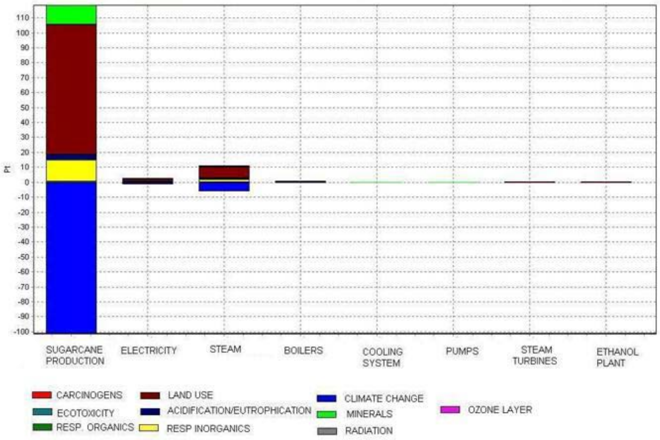

Figure 4. Environmental impacts of all system by impact categories

The Figure 4 also shows that the sugarcane production presents a favorable impact referred to climate change mitigation; this is due to the carbon dioxide absorption by the sugarcane during its growth. Along the life-cycle of the ethanol produced from sugarcane the consumption of non-renewable energy sources is mainly influenced by diesel consumption, principally in agricultural machines such as: harvesting and cultivation machines and trucks. The energy consumption is also impacted by fertilizers herbicides and pesticides used, each one with an energy requirement for their production.

6.2 Exergy Evaluation

For the overall energy conversion system (cogeneration - ethanol production process), the global exergetic efficiency is calculated by the Eq. 33:

$$\eta_g = \frac{E_{HE} + E_{AE} + E_{el.ex}}{E_c} = 37\% \tag{33}$$

Where:

E_{HE} = Exergy content of hydrated ethanol (kW)
E_{AE}= Exergy content of Anhydrous ethanol (kW)
$E_{el.ex}$= Electricity surplus (kW)
Ec = Sugarcane exergy (kW)

The sugarcane exergy content is calculated by the Eq. 34

$$E_C = E_B + E_{B:C} \tag{34}$$

Where:

E_B = Bagasse exergy content (kW)
$E_{B:C}$ = Sugarcane juice exergy content (kW)

In the same way as in the energy content of sugarcane, the exergy content is essentially comprised in bagasse, juice and crop residues (straw). Therefore its important to make a distinction between “clean cane”, which is that the cane that is traditionally transported from field and processed in a mill into juice and bagasse, and “whole cane” that includes crop residues. For this study was considered “clean cane”.

A schematic representation about the sugarcane exergy conversion is shown in the Figure 5.

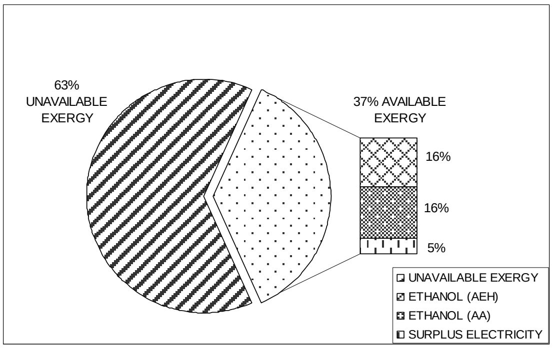

Figure 5. Available and unavailable exergy of sugarcane for the ethanol distillery

Figure 5 shows that only 37% of the exergy contained in the sugarcane is converted to surplus electricity and ethanol, being the remaining 63% is lost. Increased exergy efficiency benefits the environment by avoiding energy use and the corresponding resource consumption and pollution generation. In this sense, the implementation of biorefineries in the sugar and alcohol industry can increase the sugarcane exergy utilization incorporating plants configuration that allows to obtain surplus electricity and ethanol from the lignocelullosic residues through a hydrolysis process from bagasse and trash, and the production of biofuels using Biomass to Liquid (BTL) technologies.

Lignocellulosic biomass such as crop residues and sugarcane bagasse have a real potential to meet the future demand for ethanol feedstocks. Thus, the biorefinery is a means of resolving environmental problems, at the same time that provides effective solutions to the better utilization of the sugarcane energy with also positive economic impacts.

6.3 Exergoenvironmental Analysis

Table 3 shows the main results of exergoenvironmental analysis and allows to identify the process components that should be considered first to improve the global process of ethanol production (cogeneration system and ethanol process). For the calculation of the environmental impact of exergy destruction and system components was considered that the ethanol plant is composed by the following stages: heating, evaporation, cooling, fermentation, distillation and dehydration, this was made because the environmental impacts that of these stages including construction (including manufacturing, transport and installation), operation and maintenance was found for the whole production process and not for each stage for separate. For the cogeneration system was possible to make this separation of components in boilers, pump system, cooling system, steam turbines and condensers (ST+C) due to the availability of information.

Table 3. Environmental impact of exergy destruction and from system components

Equipment	$\dot{Y}_K$ (mPts/s)	$\dot{B}_{D,K}$ (mPts/s)
Boilers	4.48×10^{-9}	1.13×10^{-7}
Pump system	4.77×10^{-10}	5.34×10^{-11}
Cooling system	1.46×10^{-12}	3.75×10^{-10}
ST1 + C1	1.41×10^{-9}	1.01×10^{-8}
ST2 + C2	1.41×10^{-9}	2.54×10^{-9}
Ethanol plant	1.22×10^{-9}	3.85×10^{-8}

The results obtained in the exergoenvironmental analysis shows that the environmental impact caused by exergy destruction ($\dot{B}_{D,K}$) is the main source of environmental impacts in the autonomous distillery when compared with the component-related environmental impact of the system ($\dot{Y}_k$) that were very low.

The values of the environmental impacts due to exergy destruction show that major environmental impacts associated with exergy destruction occur in cogeneration plant components followed by the ethanol plant. Technological alternatives for reduce the exergy destruction in the cogeneration plant are: (i) Increase the steam parameters from 6,0 up to 12,0 MPa. However, in spite of, the steam parameters of 12,0 MPa can reduce the exergy destruction in the cogeneration system, actually these steam parameters not represent the best economic attractiveness when compared with cogeneration plants operating with steam parameters of 8,0 MPa (Escobar et al., 2010).

In the ethanol plant the environmental impacts due to exergy destruction can by reduced by the adequate control of the fermentation process together with a multi-pressure distillation for hydrated ethanol production and molecular sieves for dehydration and incorporating diffusers or electrical drives in the mills (Escobar et al., 2009).

It is important to consider that, in spite that the obtained results for the environmental impacts due to exergy destruction were in accordance to the exergy destruction hierarchy, this value also depends on the value of the average specific environmental impact $b_{F,k}$, which in turn depends on the relative position of the kth component within the overall system. Therefore the relative position of a component in the system has an influence on the environmental impact of exergy destruction $B_{D,k}$.

7. CONCLUSIONS

In this paper, an autonomous distillery plant was evaluated using an exergoenvironmental analysis. The results shows that the environmental impact of the exergy destruction within all components of the autonomous distillery plant is higher than the component-related environmental impact. This means that the overall environmental impact can be reduced by reducing the exergy destruction within components, even if this would require efficient modern equipment items in the whole plant such as: diffuser or electrical drives in the mills, multi pressure distillation and molecular sieves in the dehydration system.

Through the incorporation of new configurations of sugar and alcohol plants (biorefineries) it’s possible the diversification of the main products obtained in the plants (surplus electricity and liquid fuels trough lignocelullosic residues) that allows obtain a better sugarcane exergy this will help in long-term sustainability of the Brazilian sugar and alcohol industry.

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10. RESPONSIBILITY NOTICE

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