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LCA OF THE INSERTION OF AN INTEGRATED LIGNOCELLULOSIC ETHANOL PLANT TO A SUGARCANE PLANT.

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Abstract.:

The production of lignocellulosic ethanol by hydrolysis has been increasingly improved and developed due mainly to the fact that it allows an increase in production without the need for greater planting of raw material. Its production techniques are still undergoing refinement, mainly in terms of yields and technical-economic viability. The sugar and alcohol industry has great potential to supply the raw materials for the production of this biofuel, and its integrated production with the production of conventional ethanol would bring great economic benefits and reduce the demand for fossil fuels. In order to compare the impacts to the environment of a biorefinery that produces only 1G ethanol with another that integrates the production of 1G with that of 2G, a life cycle analysis (LCA) was done for both cases. The results show that the 1G + 2G unit has a small advantage or disadvantage in relation to the impact categories used, but for a better evaluation of this result, economic studies and energy yields would be ideal for better planning and decision making.

Keywords: LCA, biorrefineries, biomass, lignocelulosic ethanol.

1. INTRODUCTION

Biorefineries can be defined as industrial installations that integrate different processes and biomass conversion technology for the simultaneous production of added-value products such as, fuel, chemicals, energy and food. Energy crops and forestry, business, industry, and agriculture residues such as, straw, cane bagasse, oil, barks, and wood waste amongst others, are mainly the raw material for biorefineries. According to Pereira, *et al.*, 2014 Second generation of ethanol production was noticed as a complementing possibility to amplify ethanol production at sugarcane biorefineries with equal sugarcane cultivation area. The concept is defined by the utilization of fermentable sugars extracted from the lignocellulosic of the sugarcane plant, like the bagasse or straw. According to Dias, *et al.*, 2012, there are potential benefits in incorporating second generation units with conventional first-generation refineries, such as sharing important operations (syrup concentration, fermentation, distillation, cogeneration), as well as the raw material already available in the production area (bagasse and straw). Sustainability is a characteristic inherent to biorefineries, constituting a potentially better alternative than the conventional conversion methods. Therefore, it is necessary a comparison that is capable of quantify how much more sustainable is a biorefinery against the conventional techniques, besides comparing sustainability in different biorefineries, and also the environmental impact generated by biomass conversion. An objective tool for such analysis is the Lifecycle Analysis (LCA).

1.1 Article Objective

Lifecycle Analysis is a methodology with great potential in supporting various sectors decision making, both products and services alike. Therefore, this article intends to determine both cases LCA. The first case refers to a biorefinery that produces only first generation ethanol, and utilizes all residual bagasse and straw in cogeneration, producing all the necessary energy and steam for functioning. The second case shows the same refinery but integrated with a plant that produces cellulosic ethanol using sugarcane bagasse, the bagasse being used both for 2G ethanol production and cogeneration. It is intended to compare both configurations to determine which one is better in both environmental and sustainability terms.

2. . EXPERIMENTAL PART OR METHODOLOGY

Lifecycle Analysis is a methodology to evaluate various potential environmental impacts of a product or service during its lifecycle, it takes into account all the product lifecycle steps: from natural resources extraction, necessary resources for its production and to its destruction. According to (ISO 14040 and ISO14044 2006), LCA structures are divided into four steps: Objective and Defining Scope, Lifecycle Inventory (LCI), Impacting Evaluation and Interpretation.

- Objective and Defining Scope:

The objective was to compare, the Lifecycle Analysis of both a conventional sugarcane biorefinerie in which there is maximum available biomass (bagasse and straw) usage, meaning that all the produced bagasse is burned to produce steam and electric energy for the distillery and having all the exceeding electricity sold to the energy company and the same refinirie when a parcel of the biomass goes to a cellulosic ethanol plant, which is linked to the distillery.

- Mass and energy balance sheets

The energetic balance is a process that consists in controlling how much energy enters and exit the process, and determining the process energetic needs as a whole. The mass balance were made based in a distillery which processes 500 tons of cane per hour, and 28% of this quantity turns into bagasse after griding (CGEE, 2008). It's also known that the straw content in sugarcane is 15% of the total mass (CGEE, 2008), therefore, the amount that arrives to the mill corresponds to 86% of the cane that was harvested. The quantity of sugarcane available in the field corresponds to 81,4 tons per hour. However, the maximum recommended value for straw removal in the field corresponds to 50% of the total (CGEE, 2008). In this study, it was considered that the maximum quantity of straw to be utilized will be of 40 tons per hour. The amount of straw will be mixed to the bagasse to be used as fuel in a Rankine cogeneration cycle.

In order to verify the plants energy demand, simulations were made utilizing the GateCycle software.

- Inventory Analysis:

Inventory analysis is the data gathering and inputs and outputs process-relevant fluxes quantification calculus phase. Elaborating flowcharts helps in the processes that are taken in account. In the lifecycle inventory of the agricultural phase was taken from the SimaPro software. This inventory takes in consideration, both the inputs and outputs for sugarcane in Brazil.

- Impact Assessment:

According to Carneiro, *et al.*, 2017 The Lifecycle Impact Assessment (LCIA) aims to evaluate the magnitude and significance of the potential environmental impacts of a product/service. Issues such as choosing, modeling and evaluating the impact categories can add subjectivity to the study. That is why transparency is a critical factor in this ACL step to ensure that the premises are clearly described. In the impact assessment inventory, streams are associated with potential environmental impact categories. The main categories used are the exhaustion of non-renewable resources, global warming, ozone layer reduction, human toxicity, eco-toxicity, acidification, photochemical oxidants and nutrition.

- Interpretation:

The interpretation phase according to Carneiro, *et al.*, 2017 is the final phase of LCA's methodology. It considers both inventory and impact assessment and verifies that the results are consistent with the objective and defining scope. Figure 01 - flowchart of the methodology presented for the study of this article.

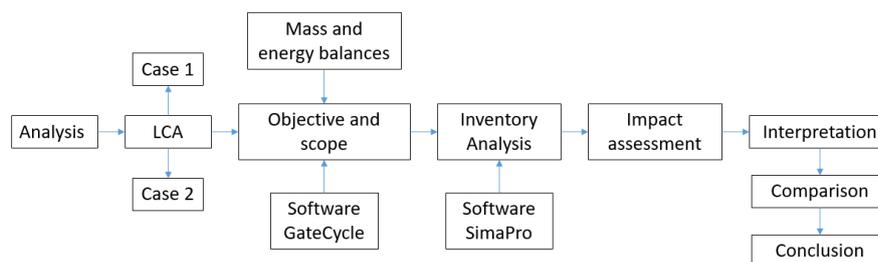


Figure 01: Study Methodology

3. RESULTS AND DISCUSSIONS

3.1 Definition of objective and scope

For this case, it is considered that 60% of bagasse is destined for the production of second-generation ethanol, and the remaining 40% are intended for generating electric power and steam.

The systems studied will consider from the production of the raw material, which in the case is the sugarcane, until its processing for the production of ethanol. The boundaries plotted for each system can be viewed in section 3.1.2. Due to the fact that most of the data found for the sugar-ethanol sector are supplied per ton of sugarcane, it will be adopted as a functional unit of the study.

3.1.1 Mass and energy balances

The case studies refers to the production of ethanol in a conventional distillery, and in one where cellulosic ethanol is also produced, in which both all the available amount of bagasse and straw was used.

The two case studies discussed in this paper differ in the use of bagasse, and in the first case, all the 140 tons per hour of bagasse, together with the straw, are burned in a cogeneration boiler, and in the second case study, 80 tons per

hour of bagasse will be destined for a cellulosic ethanol plant, and the other 60 tons will be used together with straw as fuel of the Rankine cycle. Figure 02 show the schematics of the simulated cases:

In order to verify the energy demand of the plant, simulations were made using GateCycle software. The simulations of the Rankine cycle of cogeneration were carried out in such a way that their operation takes place according to the characteristics of each study, taking into account their respective consumption of electricity and steam, besides the energy produced by the amount of biomass available in each case. For the simulation, the parameters presented in Table 1 were used:

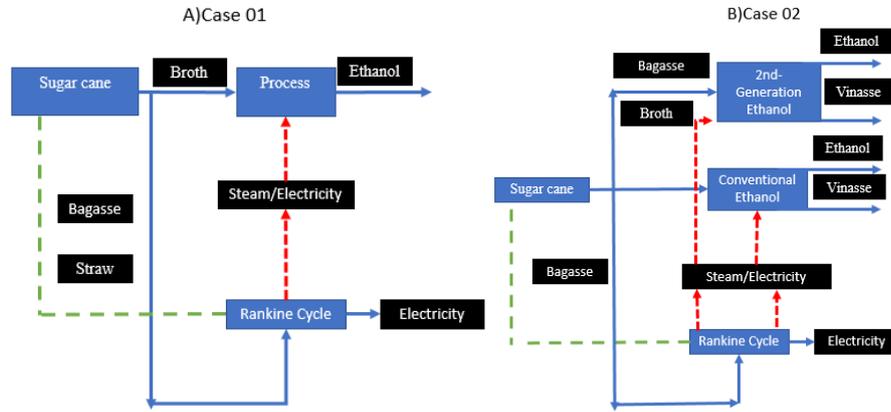


Figure 02: A) Case study 01; B) Case study 02.

Table 1 – Simulation data in the Gatecycle software.

PARAMETERS	VALUES	UNITS	REFERENCES
Moisture content of Bagasse	50	%	Hassuani, <i>et al.</i> , 2005
Bagasse PCI (50%)	7650	kJ/kg	Hassuani, <i>et al.</i> , 2005
Quantity of straw (15%)	40	ton/h	Hassuani, <i>et al.</i> , 2005
Straw PCI (15%)	14900	kJ/kg	Hassuani, <i>et al.</i> , 2005
Boiler efficiency	85	%	Reno, <i>et al.</i> , 2011
Pump isentropic efficiency	80	%	Renó, <i>et al.</i> , 2011
Turbines isentropic efficiency	82	%	Renó, <i>et al.</i> , 2011

Case 01 - Biorefinery ethanol

In the first case, it was considered an ethanol distillery that will process sugarcane, producing 140 tons of bagasse per hour. Assuming that the moisture content of the bagasse is 50% (PCI 7650 kJ / kg), it will be mixed with the straw (15% moisture content and 14900 kJ / kg PCI) at the end of the milling process, forming a fuel with a PCI of 9260 kJ / kg. Through the simulation in the GateCycle software, it was determined the burning of this fuel, according to a Rankine cycle, which produced, in addition to the steam and the electricity demanded in the process, a surplus of 100.6 MW. The parameters adopted in the simulation, as well as results, are presented in Table 2.

Case 02 - Biorefinery ethanol coupled to a cellulosic ethanol plant

As in the first case study, after distilling sugarcane, the distillery will supply 140 tons of bagasse per hour, of which 80 tons per hour will be used to produce cellulosic ethanol. Thus, the remaining 60 tons per hour of bagasse together with the 40 tons of straw will form the fuel for the cogeneration cycle. The calorific value of this fuel corresponds to 10550 kJ / kg.

Besides the conventional process that demands 380 kg of steam per ton of sugarcane (Hassuani, *et al.*, 2005), there is also the consumption of the cellulosic ethanol process. This consumption corresponds to 352 kg of steam per ton of bagasse in the pre-treatment stage (OJEDA, *et al.*, 2011), which must be saturated and have a pressure of 23 bar. There is also steam consumption in the distillation stage, which demands 340 kg for each ton of bagasse, and this steam must be saturated and have a pressure of 2.5 bar (OJEDA, *et al.*, 2011).

In addition to the consumption of steam, there is also electricity consumption of the second generation process, corresponding to 187.8 kWh for each ton of bagasse (OJEDA, *et al.*, 2011) corresponding to a total consumption of 15.02 MWh. This amount added to the amount of energy spent in the conventional process (14 MWh) corresponds to 29.02 MWh. The simulation of this case using GateCycle resulted in an electricity output of 54.5 MWh, resulting in a surplus of 25.48 MWh. The results of the simulation are presented in Table 3.

Table 2 – Simulation of Case 01

PARAMETERS	VALUES	UNITS	REFERENCES
Quantity of fuel-bagasse	140	tc	-
Moisture content of Bagasse	50	%	Hassuani, <i>et al.</i> , 2005
Bagasse PCI (50%)	7650	kJ/kg	Hassuani, <i>et al.</i> , 2005
Quantity of straw (15%)	40	ton	Hassuani, <i>et al.</i> , 2005
Straw PCI (15%)	14900	kJ/kg	Hassuani, <i>et al.</i> , 2005
Quantity of fuel	180	ton/h	-
Mixing PCI	9260	kJ/kg	Calculated
Demand for steam in the process	380	kg/tc	Hassuani <i>et al.</i> , 2005
Electricity production	114,6	MWh	Calculated
Energy consumed in distillery	14	MWh	Hassuani, <i>et al.</i> , 2005
Electricity surplus	100,6	MWh	Calculated
Boiler efficiency	85	%	-
Pump isentropic efficiency	80	%	Hassuani, <i>et al.</i> , 2005
Turbines isentropic efficiency	82	%	Hassuani, <i>et al.</i> , 2005

Table 3 – Simulation of Case 02.

PARAMETERS	VALUES	UNITS	REFERENCES
Quantity of fuel-bagasse	60	tc	-
Moisture content of Bagasse	50	%	Hassuani, <i>et al.</i> , 2005
Bagasse PCI (50%)	7650	kJ/kg	Hassuani, <i>et al.</i> , 2005
Quantity of straw (15%)	40	Ton/hs	-
Straw PCI (15%)	14900	kJ/kg	Hassuani, <i>et al.</i> , 2005
Quantity of fuel	100	Ton/h	Calculated
Mixing PCI	10550	kJ/kg	Calculated
Demand for steam in the conventional ethanol process	380	kg/tc	Hassuani, <i>et al.</i> , 2005
Energy consumed in distillery	14	MWh	Hassuani, <i>et al.</i> , 2005
Demand for steam in the second-generation process (pre-treatment at 23 bar)	352	kg/tb	Ojeda, <i>et al.</i> , 2011
Demand for steam in the second generation process (distillation to 2.5 bar)	340	kg/tb	Ojeda, <i>et al.</i> , 2011
Electrical energy consumed in the second-generation process	15,02	MWh	Ojeda, <i>et al.</i> , 2011

Table 4 and 5 shows the simulation of the Cases 01 and 02 Rankine cycle:

Table 4 – Case 01 cogeneration cycle

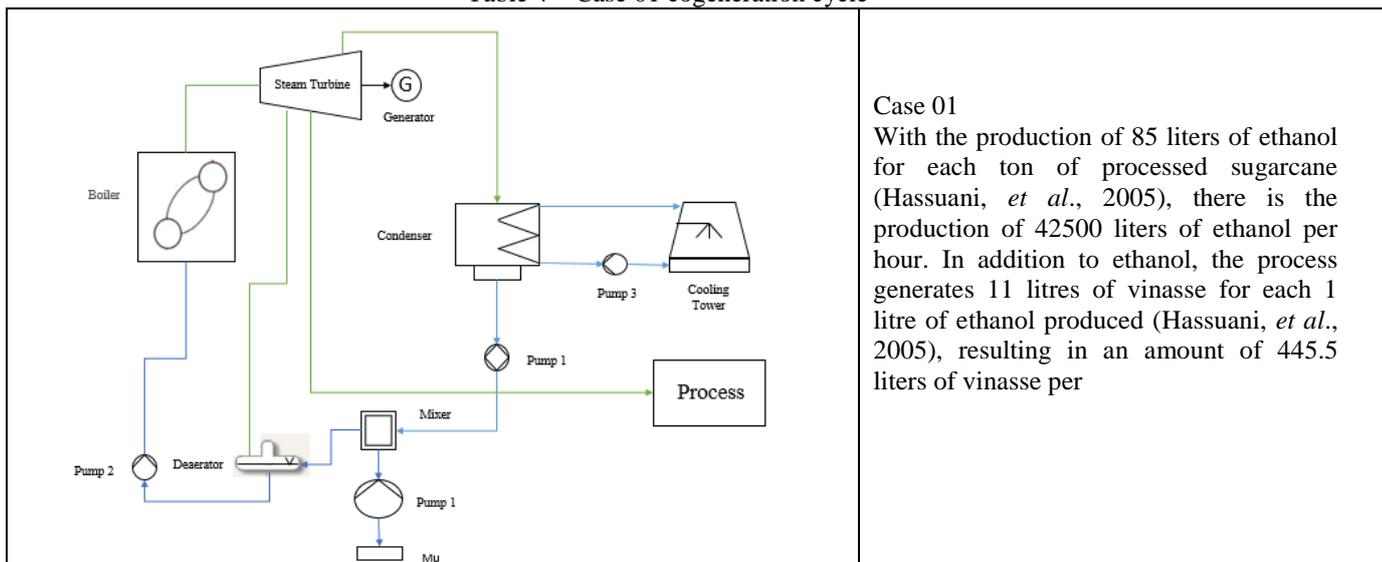
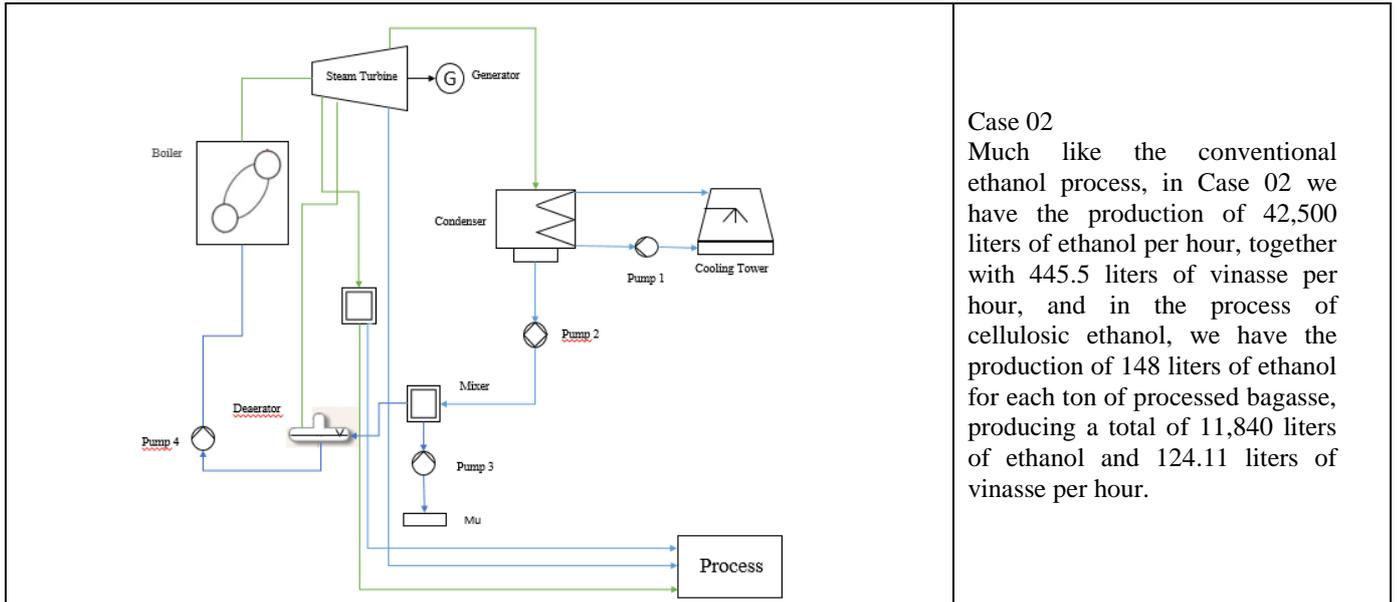


Table 5 – Case 02 cogeneration cycle



Case 02

Much like the conventional ethanol process, in Case 02 we have the production of 42,500 liters of ethanol per hour, together with 445.5 liters of vinasse per hour, and in the process of cellulosic ethanol, we have the production of 148 liters of ethanol for each ton of processed bagasse, producing a total of 11,840 liters of ethanol and 124.11 liters of vinasse per hour.

3.1.2 Description of the production chain of the studied cases

Case 01 – Biorefinery of ethanol

The productive stages considered within the borders of the system are described below:

- **Agricultural stage**

For sugarcane cultivation it is ideal to first prepare the soil, usually through liming. The cane is then planted manually or mechanically, and in Brazil, is most common to plant it manually. It is important to emphasize that in the country it is common to recycle waste from the industrial phase of ethanol production, vinasse. It is applied to crops with excellent results, enabling the reduction of chemicals fertilizer application. The stage of the current harvest is carried out in a mechanized manner, without prior burning, so that the sugarcane can be integrally utilized (straw, bagasse and colms) (Renó, 2014).

- **Transportation stage**

At this stage the harvested cane is transported to the processing plant through diesel-powered trucks.

- **Industrial processing stage**

When the sugarcane arrives at the industrial unit it is sent to the mill, where it first passes through a washing process, followed by its disintegration, with the intention of facilitating the extraction of its juice. The result of the grinding phase is to obtain sugarcane juice and bagasse, which will be used for ethanol production and the cogeneration process, respectively (Renó, 2014). The fermentation product is wine, which possesses a concentration of 7% to 10% of alcohol. In distillation, ethanol is recovered from the distillation columns, where wine passes through the following processes: proper distillation, rectification and dehydration (Seabra, 2008).

- **Cogeneration Stage**

According to (Renó 2014) The Brazilian sugar-ethanol sector has been applying cogeneration systems with bagasse since the 70s, in order to meet the steam demand of its industrial processes and attain electrical self-sufficiency. The simulated arrangement in this study was based on the Rankine cycle, one of the most used in Brazil, where fuel, in the case of bagasse and straw, are burnt in a boiler for steam production, which triggers a turbine to generate potency.

Case 02 – Biorefinery of ethanol linked to a cellulosic ethanol plant.

•For the second case study, the conventional ethanol production process through sugarcane juice is the same as presented in the first case study. However, 57% of bagasse is used in the cellulosic ethanol process, which operates integrated with the distillery, and the remainder is used in the cogeneration stage. It is considered that the bagasse limit that can be sent to the lignocellulosic ethanol process corresponds to 57% of the bagasse available, and for higher values, the energy consumption of the E2G plant can't be met by the steam cogeneration cycle. Thus, the processes of the production of first-generation ethanol and cogeneration are the same as described in the previous case. The following shall be described only the complementary steps considered within the borders of the system that incorporates the 2G ethanol:

- **Agricultural and transport step:** both stages are similar to those described in Case 01.

- **Industrial processing Step**

- Preparation or mechanical treatment: primarily a mechanical treatment is conducted, where biomass passes through a process of cleaning and grinding, facilitating its response to subsequent chemical and biological treatments (CGEE, 2008; Neto, 2009). In the specific case of sugarcane bagasse, this step would be the grinding of the cane for extracting juice, not requiring additional reduction of the particle size (Seabra, 2008).

• **Pre-treatment:** At this stage of the process takes place the separation of the components of the raw material, being part or all of the hemicellulose converted into sugars, and the cellulose and lignins sent to the next process. During the process, a small portion of cellulose may end up being converted into glucose. The product of the process must be filtered and pressed, the solids (cellulose + lignin) are sent to the cellulose hydrolysis and the liquids (sugars) sent directly to fermentation (Seabra, 2008). In this study, the pre-treatment technique chosen was the steam explosion, which according to the (Seabra, 2008), is the most widely used. Basically, the biomass is placed in a tank where it is injected high temperature saturated steam (160 °-260 °c) and pressure followed by rapid decompression and cooling.

• **Hydrolysis:** In this stage cellulose is converted to glucose, the reaction catalyzed by diluted acid, concentrated acid or enzymes. In this study, the applied technique was the enzymatic hydrolysis, process that has been largely studied for presenting great potential for evolution and cost reduction. This hydrolysis is a process that uses enzymes as a catalyst and therefore should be carried out under mild conditions (4.8 pH and temperature of 45-50 °c), causing the reaction time to be longer. However, it presents less degradation of sugars than acid hydrolysis. Enzymes can be produced in the industrial plant itself (reactor destined for this purpose) or come from a supplier. The main advantages of enzymatic hydrolysis are that in addition to presenting high yields it utilizes cheaper materials, presents less operational cost and does not generate residues (Seabra, 2008).

• **Fermentation and Distillation:** both processes follow the same principles of first-generation ethanol production. However, it is important to note that in the case of hydrolysis, in addition to the hexoses, pentoses, sugar that cannot be fermented by conventional yeast lineage, are produced, so currently, in most cases, this fraction of sugars is discarded or fermentation is done in two steps, which makes the process more expensive (CCGE, 2008; Seabra, 2008). According to Neto (2009), in recent studies it is noted the tendency of the attempt to create a fermentation procedure that is able to process both sugars in a same reactor, reducing the costs of the technique.

Below the flowcharts representing the steps considered in the LCA and the main inputs and outputs of the system and their processes for Case 01 and 02 in Figure 03:

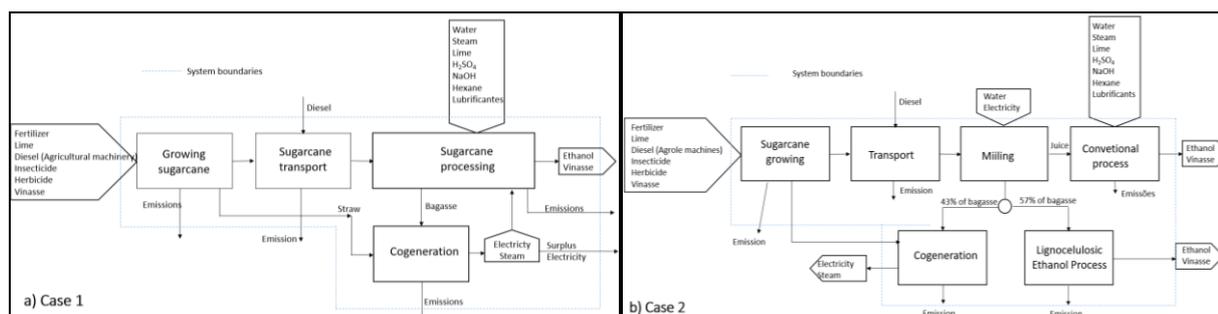


Figure 03 - Delimitation of the boundaries a) Case 1; b) Case 2.

3.2 Inventory analysis

The lifecycle inventory consists of collecting the quantities of inputs that have been used in all the productive stages of ethanol production. The study considers the resources and inputs demanded for the production of 1 ton of sugarcane (functional unit).

Inventory

Case 01 – Biorefinery of ethanol

As mentioned earlier the ethanol production chain is divided into stages, each step has an inventory of the lifecycle, which is nothing more than a weighing of the inputs and outputs. For each productive step, the following inventories are:

• **Agricultural stage:** The inventory of the life cycle of the agricultural stage was taken from the database of the SimaPro software. This inventory takes into consideration both the inputs and the outputs for sugarcane in Brazil. The main entries that should be considered are: fertilizers, lime, diesel used by agricultural machinery, insecticides, herbicides and vinasse. The output is the emissions to the atmosphere, soil and water.

• **Transport stage:** After the agricultural stage, the transport stage occurs, in which the already minced cane is placed on trucks, which will make the transport of this raw material to the distiller. According to (Rocha, *et al.*, 2005. 2014), it is admitted that the average distance of the transport carried out is 40 km and each transport vehicle has the capability to offset 45 tons of sugarcane.

As well as in the agricultural stage, the inventory data was collected from the SimaPro software database, considering, however, that instead of 45 tons, the capacity of transport vehicles corresponds to 40 tons. We basically have diesel as an input and the outputs are gas emissions due to fuel burning by transportation vehicles.

•**Industrial processing stage:** Having been received in the distillery, the cane is sent to the industrial processing step, in which the processes of washing and grinding, responsible for cleaning and removing impurities and earth, in addition to the extraction of sugarcane juice. Then the juice is sent to the processes of treatment of juice, fermentation and distillation, thus having as the final product, ethanol and vinasse.

As inputs besides sugarcane, it has water, which is used for cleaning and soaking, chemicals (NaOH, H₂SO₄, hexane, limestone and lubricants), necessary for juice treatment and maintenance of the equipment. Finally, the electricity supplied to the milling and the other equipment of the distiller. The outputs of the industrial processing stage correspond to bagasse (which has distinct destinations for each of the case studies), the emissions of biogenic carbon dioxide and ethanol (in distillation).

•**Cogeneration stage:** In the cogeneration stage, both bagasse and straw, are used to fuel Rankine cycle. After burning, it produces steam, which is used to meet the thermal demand of the process, and the generation of electricity. Of the total quantity of electricity produced, a portion is used to supply the productive process, and the remainder is sold to the energy company.

The inventory of the life cycle of the cogeneration stage in the same way as in the agricultural and transport stages, was taken from the SimaPro database. It is important to emphasize that in the case that they contemplate second-generation processes, both the thermal (steam) demand, and the electrical demand, will be supplied by the cogeneration system.

In table 6 is presented the inventory of all stages of conventional ethanol industrial processing.

Table 6 – Industrial Processing inventory – Case 01

	Inputs	Values	Units	References
Inputs	Sugarcane	500	ton/h	
	Total water consumption	1500	m ³ /tc	Galdos , <i>et al.</i> , 2013
	Electricity consumption in grinding	16	kWh/tc	CGEE, 2009
	NaOH	0,27.	g/Letanol	Rocha, <i>et al.</i> , 2014
	H ₂ SO ₄	9,05	g/Letanol	Rocha, <i>et al.</i> , 2014
	Hexane (C ₆ H ₁₂)	0,60	g/Letanol	Rocha, <i>et al.</i> , 2014
	Lubricants	0,16	g/Letanol	Rocha , <i>et al.</i> , 2014
	Limestone	10,5	g/Letanol	Rocha, <i>et al.</i> , 2014
	Inorganic chemicals	7,9	g/tc	Galdos , <i>et al.</i> , 2013
	Steam (2.5 bar)	380	kg/tc	Hassuani, <i>et al.</i> , 2005
	Distillation electricity consumption	12	kWh/tc	Hassuani, , <i>et al.</i> , 2005
Outputs	Ashes	6	kg/tc	Galdo, <i>et al.</i> , 2013
	Filter cake	26,5	kg/tc	Galdos, <i>et al.</i> , 2013
	Vinasse	891	kg/tc	Galdos, <i>et al.</i> , 2013
	Quantity of ethanol produced	85	litros/tc	Hassuani <i>et al.</i> , 2005
	Emission of ethanol in distillation	0,135	g/tc	Galdos, <i>et al.</i> , 2013
	BIOGM CO ₂ Emissions	66	g/tc	Galdos, <i>et al.</i> , 2013
	Particulate Material	0,032	kg/tc	Galdos, <i>et al.</i> , 2013

Case 02 – Biorefinery ethanol coupled to a cellulosic ethanol plant.

In the second case study, the agricultural stage, the transport, and the industrial processing of conventional ethanol are the same, therefore, in this stage will be used the same inventory of case study 1. The difference occurs in the cogeneration stage, and in this case the production stage of ethanol cellulosic is added.

•**Cogeneration step:** Like in the first case, bagasse and straw are used as fuel for the production of electricity and steam. However, in this case, the amount of bagasse destined to supply the energy demand is inferior, corresponding to 60 tons, being complemented with 40 tons of straw coming from the plantation field. The elaboration of the inventory for these conditions was made with the database of SimaPro. It is important to emphasize that the cogeneration stage is able to supply the energy demands both of the conventional process and the second-generation process.

•**Second generation ethanol processing step:** they are destined to 80 tons of bagasse per hour to the cellulosic ethanol process, which has a production of 148 liters of ethanol for each ton of bagasse (Ojeda *et al.*, 2011). Table 7 shows the inventory of cellulosic ethanol production.

Table 7 Production inventory of ethane 2g Case 02

	Inputs	Values	Units	References
Inputs	Bagasse	80	ton/tc	
	H2SO4 (0.42%)	28	kg/tc	Ojeda , <i>et al.</i> , 2011
	Water	0,3528	m ³ /tc	Ojeda , <i>et al.</i> , 2011
	Steam (saturated 23 bar)	352	kg/tb	Ojeda , <i>et al.</i> , 2011
	Steam (saturated 2.5 bar)	340	kg/tb	Ojeda , <i>et al.</i> , 2011
	Electricity consumption	187,8	kWh/t	Ojeda , <i>et al.</i> , 2011
Outputs	Ethanol	148	l/tb	Ojeda , <i>et al.</i> , 2011
	Vinasse	1263,3 2	kg/tb	Ojeda , <i>et al.</i> , 2011
	CO2 (Green)	227,3	kg/tc	Botha and Blottnitz (2006)
	NOx as NO2	975,3	g/tc	Botha and Blottnitz (2006)
	Particulate Material	123,6	g/tc	Botha and Blottnitz (2006)
	SOx	154	g/tc	Botha and Blottnitz (2006)
	Nitrates	0,4	g/tc	Botha and Blottnitz (2006)

3.3 Impact assessment and interpretation of results

As a result of LCA, the SimaPro software determines the impact indicators of the productive chain, according to the contribution of each productive step. There are several methodologies for evaluating the impacts of an LCA. In this study was used the CML-IA baseline (2003) which is an evolution of CML 2 (2000). The analysis was focused on the 8 categories of impacts found in the consulted literature: abiotic depletion, abiotic depletion (relative to fossil fuels), global warming potential (GWP), ozone layer reduction, human toxicity, photochemical oxidation, acidification, eutrophication. The results are expressed in graphic form in Figure 05 Case 01 and 02, in the first case study, generation only of first-generation ethanol. In the second case study, generation of first-generation ethanol integrated with second generation.

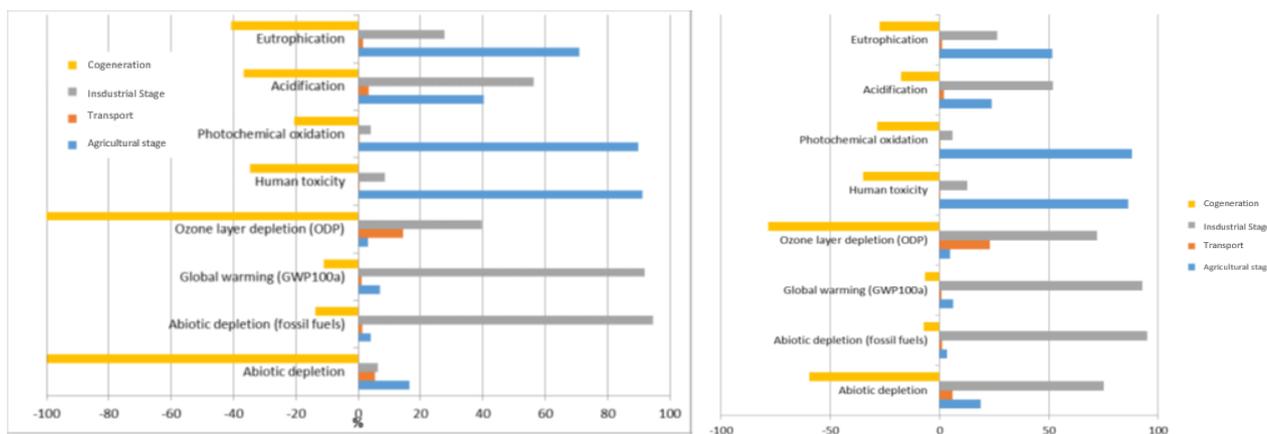


Figure 05 – Results of impact indicators of Case 01– Biorefinery of ethanol and Case 02

In Case 01 it can be observed that the industrial processing stage is responsible for the major environmental impacts indicators in the abiotic depletion categories (as for fossil fuel consumption), global warming, ozone depletion and acidification. The agricultural stage has large participation in acidification and predominant participation in photochemical oxidation and eutrophication. Moreover, the agricultural stage is also responsible mainly for the impacts related to human toxicity. The cogeneration stage has a positive impact, since it produces all the energy (thermal and electrical) of the process, in addition to producing a surplus that is sold to the energy company.

The transport stage, has little contribution to the environmental impacts when compared to the other stages, having greater relevance in depletion of the ozone layer, due to emissions from burning fuels, besides the abiotic depletion due to the use of fossil inputs. In Case 02 the agricultural stage is primarily responsible for the impacts of eutrophication, photochemical oxidation and human toxicity. Transportation continues presenting relatively small impacts, with

emphasis on the depletion of the ozone layer and abiotic resources. And cogeneration continues to have positive impacts due to the fact that the steam and electric energy used by Biorefinery are produced in less impacting ways

Below it is presented the radar diagrams of the standardized data (Figure 06), to make it possible to compare the results with different units (Case 01 and Case 02) when the results are normalized the comparison of the different indicators can be compared:

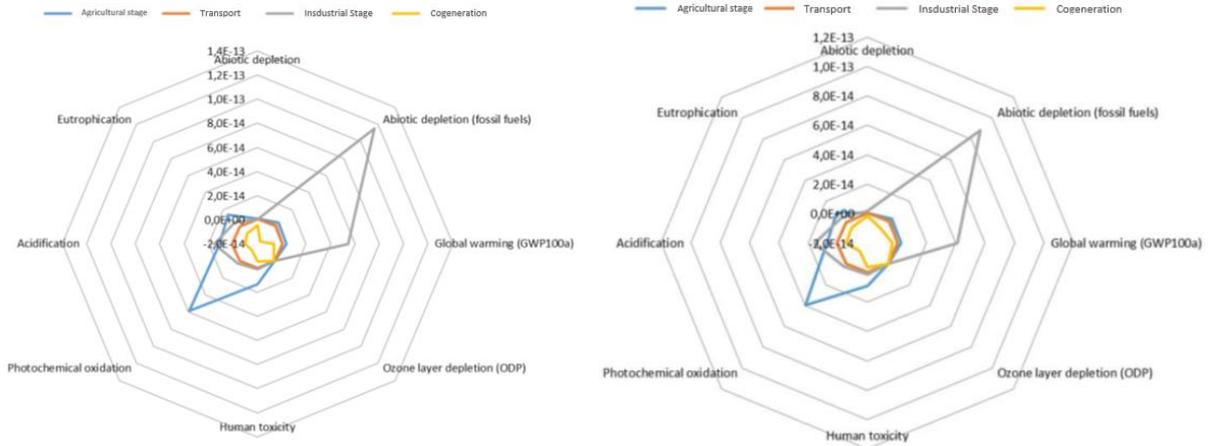


Figure 06-Radar diagram for the standard result of Cases 01 and 02.

3.4 Comparison between Cases 01 and 02

Analyzing both cases isolated from one another, we cannot evaluate whether there is indeed an improvement in environmental impacts when the production of cellulosic ethanol is implemented in a conventional ethanol distillery. Below are the comparisons of the results of Cases 01 and 02 in Figure 06. Overall, the performance of the second case was better than the first in four of the eight impact categories analyzed. The fact that the second case has greater impacts than the first one in four categories can be explained by the need to increase the biorefinery plant, increase the consumption of chemicals in the cellulosic ethanol process and the emissions of this process. For the abiotic depletion indicator, the greater demand for chemical inputs is responsible for the inferior performance of the second case. Depletion of the ozone layer is affected by process emissions.

For the categories in which the second case had better results, the differences were apparently not as considerable. The production of a greater amount of ethanol that can replace the use of fossil fuels may have contributed to these small changes. For a better comparison of the differences between the categories of impact presented between Cases 01 and 02 will be presented the comparisons of the results of Cases 01 and 02 and a radar diagram of the normalized data in Figure 06. In the comparison of the normalized results, the area occupied by Case 02 is lower than Case 01. This means that the production chain of the biorefinery that integrates the production of first generation ethanol with the second-generation ethanol generates lower environmental impacts of the than conventional biorefinery. However, this improvement does not seem to be very significant.

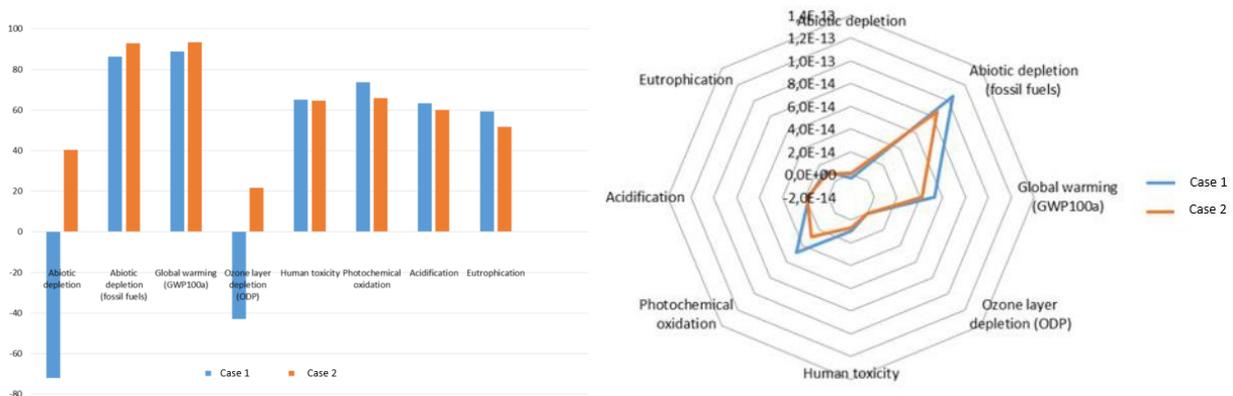


Figure 07 - Comparison between the indicators of impacts of Cases 01 and 02 and radar diagram of the comparison of the normalized results of Cases 01 and 02.

4. CONCLUSION

The ethanol production chain demands large quantities of chemicals such as fertilizers, herbicides, chemical inputs, and fuels. It has been noted that the industrial stage responds for the most part of the environmental impacts. The agricultural stage also generates considerable environmental impacts, but of inferior magnitude when compared to the industrial stage.

The transport stage has little involvement in the impacts compared to the other stages, which does not mean that its impacts are small. The cogeneration stage delivers positive environmental impacts, since the production of the energy demanded in the process prevents the use of other resources for its production.

Case 02 presented lower environmental impacts than case 1, due to a better use of sugarcane, since greater amounts of ethanol are produced for the same quantity of sugarcane planted, but the difference was minimal. Moreover, the increase in biofuel production would also avoid the use of other forms of fossil fuels, besides its emissions. However, the industrial stage of cellulosic ethanol is still in development, and the researcher's greatest concern is in relation to improving processing performance, so that it becomes more environmental, technical and economically viable.

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