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LIFE-CYCLE ASSESSMENT AND TECHNOLOGICAL STUDY OF THE CURRENT CONTRASTING PRODUCTION OF BRAZILIAN ETHANOL

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Abstract. *In this study we analyze the present context of the Brazilian ethanol mills. The goal of the study is to show how the technological, geographical and environmental differences influence the energy consumption and the greenhouse gas emissions through a Life Cycle Assessment (LCA). The contrasting production chain can be identified by the differences in the geographic localization. For the LCA, we analyze information provided by qualified employees during technical visits to eight ethanol mills of different geographical zones of the country. The mills of the Southwest and Southeast region of the country have relatively mechanized production processes, while in the North and Northeast region it is used labor-intensive production. The results showed that the majority of GHG emissions of the mills of the Southeast and Southwest regions, during the stages of the ethanol production, occur mainly by burning fossil fuels, by machinery use and stillage irrigation, while in the mills of the North-Northeast region the burning of sugarcane, before manual harvest, is the main responsible for the GHG emissions. Regarding the current technologies and infrastructure, the environmental legislation and geographical conditions we can say that the Southeast and Southwest regions have advantages in terms of legal, climate, soil and geographical conditions in comparison with the North and Northeast region, with respect to the Brazilian ethanol production.*

Keywords: *Sugarcane ethanol, Life cycle assessment (LCA), Energy consumption, GHG emissions*

1. INTRODUCTION

Nowadays, new challenges were raised in the field of food security and energy demand in order to supply the increasing world population, shortage of fossil fuels and climate change. Several efforts are underway to address these challenges. Since the year 1972 the energy demand increased from 4.672 Mtoe (Million Tonnes of Oil Equivalent) to 8.979 Mtoe in 2012 as a result of the intensive use of fossil fuels mainly due to industrial and transport expansion (IEA, 2014). Considering that the price of a barrel of oil reached $53.20 per barrel in 2015 (EIA, 2015) and a recent work by KNOEMA (2015) shows that this price is going to move to $103.40 in 2025, then the research into new energy resources is essential.

The total CO_2 emissions in the member countries of OECD (Organization for Economic Co-operation and Development) decreased from 13.005 Mton in 2005 to 12.146 Mton in 2012 due to new policies and regulations implemented for the issue of GHG emissions in the atmosphere (IEA, 2014). Recent studies show that the concentration of CO_2 in the atmosphere has intensified causing global warming and climate change (IPCC, 2013).

According to a recent study (IPCC, 2012) climate change is responsible for the high frequency and intensity of extreme weather events that have caused disasters in various regions of the world with considerable socio-economic losses. Therefore the search for fuels that reduce greenhouse gas emissions such as those produced from biomass is extremely necessary.

Increased production of biofuels such as ethanol made from sugarcane has raised concerns in relation to their competition with food purpose crops and the use of natural resources like water and land use (FAO, 2011). However, the food safety can be guaranteed with the uses of lignocellulosic material and straw for the production of biofuels.

In this study we try to show how the different technologies of Brazilian ethanol production derive from a composite interaction of harvesting methods, different levels of research and practices, geographical location and political norms besides its direct impact in the energy consume and the environment through the GHG emissions.

2. THE TECHNOLOGY IN THE ETHANOL PRODUCTION IN BRAZIL

Different technologies to harvest sugarcane and produce ethanol are used in Brazil, with Center, South and Southeast regions of the country using mechanized production technologies, despite the North and Northeast regions using labor-manual technologies, as shown in Table 1.

Table 1. Indicators by region of ethanol industry for 2013-2014 season. Source: the authors based on: (UNICA, 2014; Compean, 2011)

Ethanol industry	Unit	Center, South, Southeast		North, Northeast, Northwest		Total
Sugarcane area	million ha	7.7	87%	1.1	13%	8.8
Sugarcane grinding	million tn	597.1	91%	56.5	9%	653.5
Sugarcane yield	tn/ha	77.7		50.8		
Ethanol production	million m^3	25.3	93%	1.9	7%	27.2
Sugarcane grinding destiny for ethanol	million tn	278.7	89%	33.5	11%	312.2
Productivity	m^3/tn	0.09		0.06		
Cogeneration	MWh	3,460.8	76%	1,063.5	24%	4,524.3
Installed plants		334	80%	83	20%	417
Total investment	million R$	1,109.5	78%	304.8	22%	1,414.3

Until now, few previous analysis, (Billister, 2012a ; EXXON-MOBIL,2005), have overlooked the consequences of the different methods of production technologies and how these differences impacts the environmental and economy of the country.

2.1 Production capacity and transportation infrastructure

There are two main sugarcane-producing regions in Brazil. The larger and most important is next to the São Paulo state. This region has a flat, uniform and fertile soil, perfectly suited for growing sugarcane, as there are ample nutrients to nourish the sugarcane through its growing stages, producing an easily mechanically harvested sugarcane. According to (UNICA, 2014) over 62% of all sugarcane grown in Brazil is from São Paulo.

The Northeast, is the second sugarcane producer region, specifically in the states of Pernambuco and Alagoas. The soil there is much less appropriated to growing sugarcane, as it is on hills (about 70% of the sugarcane in the Northeast regions is on slopes) (Cortez, 2010; Franco et al.,2011). As mentioned, in the previously item, at Northeast region the harvesting stage manual labor is much more intensive, and the mechanical harvesting are ineffective in these areas. The reason for the prevalence of sugarcane plantations is largely historical in the northern states of Brazil because in this region were located the firsts Brazilian sugarcane plantations and sugar mills (MAPA,2012).

Manual sugarcane harvesting is predominant in Northern Brazil, where mechanized harvesting is difficult to implement because of geographical factors and conditions: the use of machinery is difficult to operate in slope areas. The manual harvesting is less productive than mechanized harvesting, consuming a longer time. An important factor about the harvesting is that the mechanical harvesting leaves an amount of dry leaves in the soil that helps the conservation of soil from erosion, adding organic matter and recycling nutrients that help to improve the productivity for the sugarcane production (AEA, 2010; MAPA, 2012).

Another factor that difficult the sugarcane plantation in the North region of Brazil is the extremely dry weather that this area has. Among the technical visits made to the ethanol mills of the North-Northest region it was attended that the irrigation is necessary to produce ethanol at this part of the country, and for making this possible the producers have to adapt themselves to some economic irrigation techniques known as "drip irrigation". The drip irrigation technique is the most economic one because the water is applied directly through drops into the soil, giving to the plant a better root development.

2.2 Technological approach, and advances in research and development

The difference in the ethanol production of the North and South regions is partially consequence of the financial capability of the mills of the Southern regions to invest in agricultural research conducted by universities and research institutes, new technologies and infrastructure updates (Billister, 2012b).

As shown in Table 1, the total investment in ethanol production was 56% higher in the Southern regions than in the Northern regions in the season 2013-2014. As the production in the South increased to meet higher demands, the cost of production decreased due the economy scale. In addition, several technological innovations took place in the South region, particularly in fermentation technology to increase the ethanol yield liquor, which resulted in substantial reductions at energy requirements for ethanol production, because it could reduce energy consumption in fermentation and distillation, and, at the same time, decrease the stillage volume, (Walter, *et al.*, 2008).

Additionally, research on energy efficiency improvements of ethanol production through efficient distillation and heat-recovery design took place. At the same time, ethanol concentration increased through absorption, vapor recompression and multiple-effect evaporators. Innovations on crystallization, use of molecular sieves and reverse osmosis, which would reduce energy requirements as well, happened more prominently in the South than in the North of Brazil. Other chemical technologies implemented by the ethanol sector include anaerobic digestion to treat effluent, non-toxic hydroalcoholic solutions, substitution of azeotropic distillation for improved molecular sieves and bioscanning for pollution and sugar loss identification (Ensinas, *et al.*, 2011).

Presently, harvesting using optimization software with satellite systems and remote sensors (geographical information systems and global positioning systems) are in operation in ethanol mills in the South region. Similarly, digital-monitoring systems that automate ethanol production industrial processes figure in modern ethanol mills in this region. Integration of management procedures using internal electronic data exchange networks, among other enterprise resources for planning, have also been implemented in several industrial units, particularly in the state of São Paulo (Billister, 2012b).

In addition, to improve the efficiency of the ethanol industry, research groups and universities have developed and tested new sugarcane varieties with continuously improved yields (Walter, *et al.*, 2008), and the research in the integration of the ethanol of second generation, this leadership in research and development on sugarcane varieties focused mostly on the Southern regions of the country during the early years of the ethanol program. *The Centro de Tecnologia Canaviera* (CTC), *Embrapa*, and other important public research programs began focusing their research on improved cane varieties and agricultural processes as a means of obtaining financial resources. Ethanol producers from the North regions have not been able to finance this type of research. Therefore, research for new sugarcane varieties suitable for the soil type of the North has taken a lower priority than in the South (Walter, *et al.*, 2008).

2.3 Environmental and political legal norms

The subsidies to sugarcane cultivation and consequently to the ethanol production in the Northeast helped to consolidate existing production systems and increase monoculture, allowing inefficient producers to stay in business (Alves *et al*., 2008).

With lower oil prices during the 1990s, the subsidies to ethanol became an increasing burden to the already tight Brazilian budget. The national sugar and ethanol Institute *(Instituto de Açucar e Alcool,* IAA*)*, recognized as one of the main supporters of the North sugar producers was closed in 1990. This episode caused problems specifically for the producers in the North; because IAA had been responsible for stabilizing price fluctuations by transferring funds between good and bad harvest years, this episode accelerated the decline of sugarcane industry in the North.

More recently, the Brazilian national and regional environmental legal framework has also driven technological changes in the ethanol sector. Seeking environmental conservation, state regulations requiring mechanized harvesting in the southern states of the country, have been established. Particularly in the states of the North it has not passed, in part due to the difficulty of mechanizing sugarcane harvesting because of topographical factors. The agriculture and environmental protocol for the sugarcane and ethanol industries signed by the Sao Paulo's government in 2007 aimed legal deadlines to eradicate sugarcane burning and implementing mechanized harvesting instead (CTC, 2008).

2.4 Production capacity and transportation infrastructure

Transportation infrastructure is one of the factors that originates regional differences in terms of productivity in the Brazilian ethanol industry. Trucks transport the sugarcane that is loaded in full length (manual harvesting) or in chopped parts of 20-25 cm (mechanical harvesting). Quick loading and transportation of sugarcane are fundamental to avoid losses of the amount of sucrose per sugarcane ton. Because of that, the deficient road infrastructure in the North and Northeast regions, where distances are large, reduces sugarcane productivities as it takes more time than in the South to carry sugarcane to the ethanol plants. Losses of 6 -10 kg in the amount of total reducible sugars per ton of cane (TRS) are common in the North. In contrast, highways in São Paulo State and in its surrounding areas are considered the best of the country, and land transportation is exceptionally efficient by Brazilian standards (Hira and de Oliveira, 2009).

3. METHODOLOGY FOR THE QUANTIFICATIONS OF ENERGY CONSUMPTION AND ENVIRONMENTAL EFFECTS OF THE ETHANOL PRODUCTION IN THE BRAZILIAN REGIONS

Having the largest ecosystem of the planet, such as the Amazon biome, Brazil is highly vulnerable to climate change. Global analysis indicates Brazil is one of the main GHG emitters and the third CO_2 emitters after China and

India (Khatiwada *et al*., 2012). The Kyoto Protocol of the United Nations Convention on Climate Change was signed in 1998 and ratified in 2002. Brazil is not included in the numerical limitations of this protocol because Brazil was not a major contributor to the GHG emissions during the industrialization period. Nevertheless, without the commitment to reduce according to the Kyoto Protocol target, developing countries share the common responsibility that all countries have in reducing emissions.

To estimate the GHG emissions, the principles of the LCA methodology were applied in accordance with (ABNT, 2001; ABNT, 2004; IPCC, 2006). The Emissions of CO_2, CH_4 and N_2O (GHG) were accounted, as well as kilograms of CO_2 equivalent (kg CO_2eq). The energy consumption and the emissions estimates were made considering a hectare of land cultivated in one year (functional unit). The energy consumption was accounted as MJ/ha.yr and the emissions of CO_2, CH_4 and N_2O (GHG) were accounted, as well as kg of CO_2 equivalent (kg CO_2eq).

The study is based on information provided by qualified employees during technical visits for the season crops 2012-2013 and 2013-2014 of eight Brazilian ethanol mills, to facilitate the analysis, the mills analyzed were divided in three groups, *A, B, C*, respectively, being the group A formed by three mills located in the North-Northeast region, the group B is formed by three mills located in the Southeast region and the group C formed by two mills located in the Southwest region. In all the mills of the groups *A*, *B and C,* the sugarcane sowing happens in an annual cycle and in certain hectares the plantation is make using stalks of sugarcane for replanting.

The methodology used is described in Díaz (2010), and the emission factors used were obtained from several sources: (Hira, de Oliveira, 2009; IPCC, 2006; Boddey *et al*., 2008; Macedo *et al*., 2008). These authors provide emission factors for the main processes of agriculture. For the agricultural waste burning and release of N_2O in the soil we used the emission factors recommended by the IPCC.

This LCA study aims evaluate the life cycle of Brazilian ethanol when it is recognized the activities in the production chain which are responsible for the main energy and environmental impacts, quantifying the inputs items, calculating their emissions and energy consumption in the cycle. The object of this LCA study is the ethanol produced from sugarcane in autonomous Brazilian mill; The function of the ethanol is to be used as fuel in motor vehicles for transport; the functional unit used to obtain and standardize data is a hectare of sugarcane for a period of one year (ha.yr); the ethanol chain production analyzed have the following stages: Sugarcane sowing, Plantation handling, Harvesting and Industrial processing; the frontiers of the system analyzed are defined by the stages that were included in the study and were listed below, including processing, manufacturing of the input items, reuse and waste treatment, depending on availability of data and resources.

The energy consumption was quantified using the entry items of the ethanol chain production, to calculate the energy consumption the input items were classified in thirteen items: "sugarcane transport", "stillage disposal", "insecticides", "feedstock transport", "seeds", energy consumed in fertilizer fabrication "Potassium", "Phosphorous" and "Nitrogen", fabrication of "Lime" and "Herbicides" fabrication, "Labor", "Diesel oil" and "Machinery" used in the agricultural stages of the sugarcane production.

The items responsible for the GHG emissions of the ethanol chain production were classified into sixteen items: "Soil emissions", "Mineralization of residues", "Burn emissions", "Sugarcane transport", "Stillage disposal", "Insecticides", "Feedstock transportation", "Seeds", Fertilizer consumption "Potassium", "Phosphorus" and "Nitrogen", consumption of "Herbicides" and "Lime", "Labor", "Fuel consumption", and emissions of "Machinary" employed in the agricultural stages of sugarcane production.

All the fuel consumption data (oil diesel consume, sugarcane transport, feedstock transportation) and the information about the use of machinery was gathered from the databases of the plants analyzed. It was observed that the use of light vehicles moved by gasoline is very small in comparison with bigger machinery, reason why this fuel consumption was not taken into account in the quantification of emissions. Likewise, in the industrial stage, fuel is not used for the calculation of GHG emissions, since electricity is generated by burning bagasse sugarcane.

In the Figure 1, is showed all the energy consumption by the applications of the entry items used in the agricultural stages and the use of the diesel oil. In all of the mills, there is transportation of seedlings, since sugarcane stalks are re-planted in the soil. Also the mills analyzed uses the filter-cake, ash and sediment generated in the industrial stage as fertilizers in crop areas of sugarcane.

For calculations of emissions in transportation of lime and fertilizer, it was considered the use of a truck with cargo load of 12 tons, with consumption of 2.5 km/L and 25 km between the supplier and the second crop (Macedo *et al*., 2008).

All of the mills use fertirrigation, using stillage irrigation, and residuals water of the industrial process, especially in the sugarcane culture. In the harvesting, mechanical harvesters are often used, with capacity of 45 and 35 tons/hour, with a consumption of 40.4 and 9 l/hour, respectively.

We considered the use of N in the ammoniacal form; P_2O_5 (superphosphate) and K_2O (potassium chloride), which are the most common sources of fertilizers in Brazil. As for the lime, dolomitic type is the most used. No data found detailed the production process of seedlings.

All energy used in the industrial stages of the process is generated from the burning of sugarcane bagasse; hence, there are no GHG emissions due to the use of fossil fuels in the energy generation. The direct GHG emissions are mainly associated to the release of CO_2 during the burning of the bagasse and the fermentation of sugarcane juice, but these emissions, as indicated above, are not taken into account in the quantification of GHG emissions, because the carbon released is absorbed by vegetation (sugarcane) during the next crop (IPCC, 2006).

4. RESULTS

The Figure 1 shows the energy consumption for each item analyzed for all the mills visited, being the principals items with the higher energy consumption the diesel oil consumption, item "Diesel oil", followed by the energy consumed during the herbicides fabrication, item "Herbicides". There is one mill (B1) belonging to the group of the mills of the Southeast region where its principal energy consumption corresponds to the item Herbicides, it is because the intensive use of this item in the Sugarcane Sowing stage. Is remarkable to observe in the Figure 1 that in the mills B2 and B3 the energy consumption is lower in comparison with the others mills, it is because their agricultural operations are characterized by not be mechanized (furrowing cultivation and mechanized fertilization).

The Figure 2 depicts the quantity of GHG emissions emitted by each item analyzed for all the mills visited, is remarkable to observe that the principal GHG emission responsible is the item "Burn emissions" and the group with the highest values is the group of the mills belonging to the North-Northeast region (group A) the responsible for this phenomenon is the burning of sugarcane before manual harvesting, in the mills of the group A, the manual harvesting is applied in 90%, 100% and 83% for the mills A1, A2 and A3, respectively. Is possible to observe that the items "Diesel Oil", "Herbicides" and "Lime", "Potassium", "Phosphorus", "Nitrogen" (Fertilizers) are the another principals responsible for the GHG emissions.

The use of diesel oil in the mills of the groups B and C (mills of the regions Southeast and Southwest) during the agricultural stages occur mainly by burning fossil fuels (transportation of raw materials and the sugarcane transportation from the field to the mill) and because their machinery use is intensive. The Herbicides, Lime and Fertilizers application, which are responsible the release of N_2O in the soil, also account for significant amounts of GHG emissions.

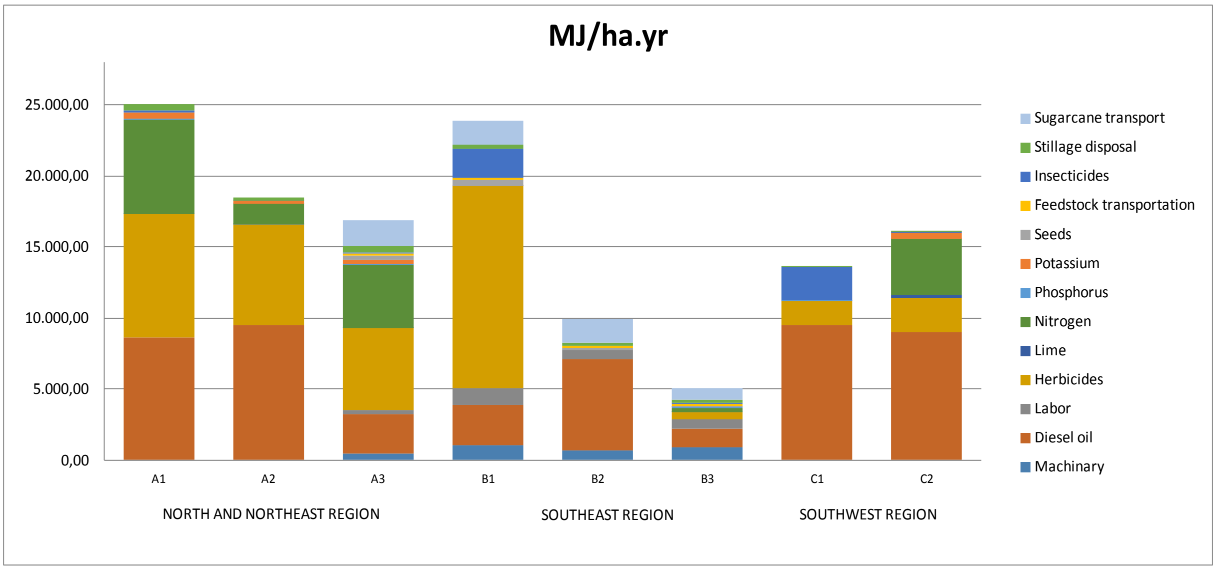

Figure 1. Energy consumption of the LCA of ethanol production for each mill analyzed.

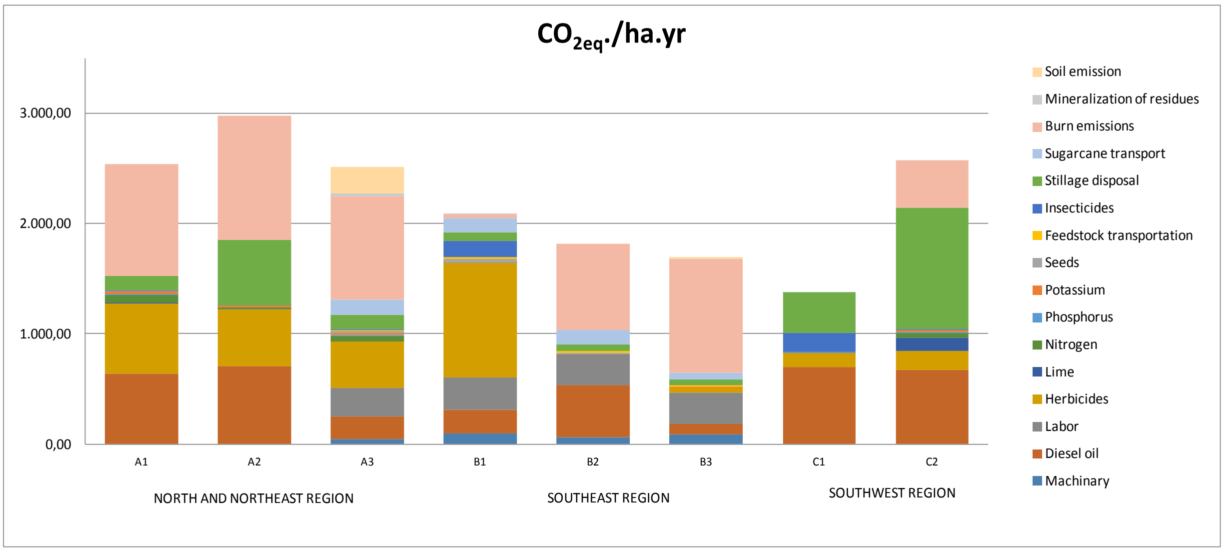

Figure 2. GHG emission of the LCA of ethanol production for each mill analyzed.

With the aim of linking the energy consumption and the GHG emissions with the ethanol yield, the Figure 3 depicts circles where its areas represent the yield of each mill in terms of ethanol liters per hectare in one year of production (L/ha.yr). Is possible to notice that the mills with the highest values of energy consumed and GHG emission have not necessarily the best results in terms of yield. The mills belonging to the group A have the best results in terms of yield but at the same time, they have the highest values of GHG emissions, this result is consequence directly of the burning emissions during the pre-harvesting in this mills.

Is important to remark that the mills B2 and B3 have the lowest valor of GHG emissions but their yield is lower in comparison to the another groups of mills, the reason for this is related closely to the drought that the region had during the season 2013-2014, this problem produce the lost of sugarcane of the area for being harvesting during the season and consequently for the fall of their yield and another consequences like economic loses, during the visits to the region B we can observe that many of the mills located in this region were affect directly with the drought.

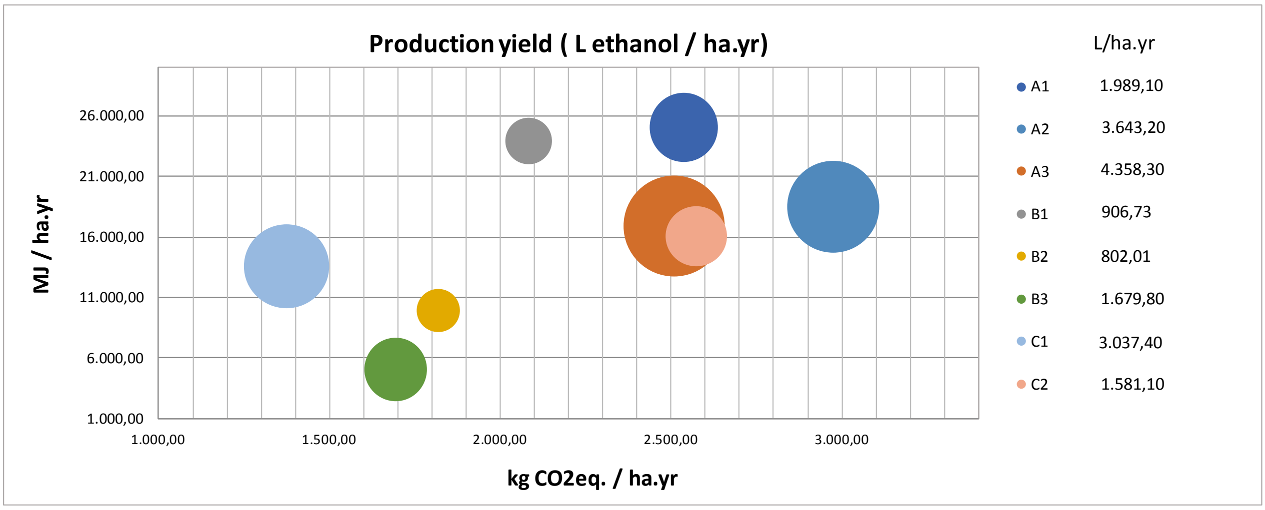

Figure 3. Comparison of the energy consumption and the GHG emissions with the ethanol yield for each mill analyzed.

5. CONCLUSIONS

With the aim of understanding, capturing and evaluating the most of the regional variables and technological differences utilized in the production of the Brazilian ethanol, technical visits were made to ethanol mills of different regions of Brazil. During the visits was noticed that political, geographical and environmental factors can distinguish the production of one mill with respect to the others. Factors like the technology applied during the agricultural stages and the sugarcane process, the geographic localization, road conditions, weather conditions may affect the energy consumption, GHG emissions and production yield.

The results showed that in all mills analyzed the item "diesel oil" is the principal responsible for the energy consumption (Figure 1); the majority of GHG emissions of the mills of the group A (mill of the North and Northeast region), during the stages of the ethanol production, occur mainly by the emission of CH_4 and N_2O during the burning of sugarcane before manual harvest, item "Burn emission", the CO_2 emissions during the burning of sugarcane was considered like neutral because it was absorbed during the sugarcane growing by the photosynthesis; while in the mills of the groups B and C (mills of the Southeast and Southwest regions respectively) the majority of the GHG emissions occur by burning fossil fuels and by the emission during the fabrication of the machinery used in the agricultural stages of the sugarcane production (Figure 2).

Herbicide and lime application, which are responsible for the release of N_2O in the soil, also account for significant amounts of energy consumption and GHG emissions. In this case, it can be said that the total energy consumption and GHG emission is very sensitive to herbicides and lime in the soil, since it has a high emission factor due to high energy use in the production of fertilizers as well as in the release form the soil of N_2O contended in the herbicides and lime applied. Figures 1 and 2).

We can consider that the items: fuel consumption, GHG emissions from the burning of sugarcane, herbicides fabrication and application, the release of N_2O in soil and the consumption of lime are critical. Once these critical items were recognized, the next step would be to deepen the investigation of different technologies of production and their application, with the aim of looking for a better route to reduce the energy consumption and GHG emissions for each step of the production chain. Such alternative routes are under evaluation in a subsequent study, by considering different technological scenarios and their specific applications and consequences in the energy consumptions and GHG emissions. .

Regarding the current environmental legislation and geographical conditions, it is possible to say that the Southeast and Southwest regions have advantages in terms of legal by the current state laws that forbid the sugarcane burn; in terms of soil and geographical conditions because this region has a flat, uniform and fertile soil, in comparison with the North and Northeast region. Nevertheless, it is also important to take into account that strong weather phenomenon, like the drought that affected the Southeast Region in the 2013-2014 season, could affect dramatically the sugarcane plantation and consequently the Brazilian ethanol production.

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