Brazilian ethanol for transport - Life cycle inventories and guidelines

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Abstract

Biofuels have become increasingly important as they contribute to the independence of fossil energy in the transport sector and its consequent impacts on the environment, energy and economy. Brazil was a pioneer country that successfully managed to implement a biofuel in the transport sector: bioethanol from sugarcane. Road vehicle fleet suffered a huge investment, and the flex-fuel propulsion technology was very significant, allowing to use a fuel composed of 100% gasoline, 100% ethanol or a mixture of both. This thesis aims to analyze the life cycle "Well-to-Gate" of sugarcane ethanol in Brazil, and answer the following questions: Which processes exist in the production of ethanol? How much energy is required and greenhouse gas (GHG[1]) are emitted in this phase? Several life cycle studies will be compared with the same criteria and functional unit, and taking into account three levels of life cycle for the system boundary. Operations in the chain of production of 1 MJ of ethanol (FU) that consume more fossil energy and that emit more pollutants were identifyed, as well as the key factors that influence efficiency, energy consumption and greenhouse gases emissions. Finally, guidelines for the preparation of similar studies in the life cycle are presented. It was found that fossil energy consumption ranged from 0.03-0.15 $MJ_{fossil}/MJ_{ethanol}$, with major variations in life cycle Level 1 (sugarcane agriculture operation). Moreover, GHG emissions ranged from 10-25 $gCO_2eq/MJ_{ethanol}$, with major variations also in Level 1, in sugarcane agriculture operation, and also in Level 2, in chemicals and lubricants production.

Keywords: Bioethanol, Sugarcane, Life Cycle, GHG Emissions, Fossil Energy.

1 Introduction

The transportation sector accounts for 30% in US [14], Brazil [15] and Europe [6], and (within that sector) road transports cover 80% or more of total energy use. This sector has a major relevance in society, since it provides mobility and better access to goods, improving significantly our life-style. Unfortunately it has also become one major contributor to air pollution, global warming and fossil fuels depletion. Biofuels contribute to the independence of fossil energy in the transport sector and its consequent impacts on the environment, energy and economy. Brazil is a successeful example of a country that implemented an alternative fuel solution: ethanol, so sugarcane ethanol from Brazil was the fuel chosen for this work analysis. A Well-to-Gate (WTG) analysis of ethanol production and use was made. Every operation and resources were analyzed, the major causes of GHG emissions and energy consumption were detected as well as the parameters that most affect the entire process. The majority of world countries have enacted policies to regulate and promote renewable energies in the power generation, heating and cooling, and transport sectors [12]. Concerning to renewable energy policies for the transport sector, several biofuel mandates are now in place in 33 countries, requiring that specific shares of biofuels are mixed with petroleum-based fuels (see Table 1) [12]. Some vehicle technologies have suffered major investments in order to use biofuels blends, namely flex-fuel propulsion systems, which allow to use a fuel composed of 100% gasoline, 100% ethanol or a mixture of both.

[1]Gases that contribute to the increase of the greenhouse effect.

Table 1: Biofuel Blend Mandates both - and similarly to diesel/biodisel fuels.

Country	Mandate
Brazil	E27.5 (27.5% ethanol, 72.5% gasoline) and B7 (7% biodiesel, 93% petroleum diesel)
China	E10 (10% ethanol, 90% gasoline) in nine provinces
USA	E2 (2% ethanol, 98% gasoline) and B2 (2% biodiesel, 98% diesel) in Louisiana.

The main scope of this work is to propose guidelines and an LCA[2] methodology for biofuels, applied to ethanol from sugarcane and also to achieve the following goals: (a) find which processes exist in the production of ethanol; (b) analyze different LCA studies of Brazilian sugarcane ethanol, in what fossil energy consumption and GHG emissions is concerned; (c) adjust these studies to the same units and criteria so that they can be compared; (d) identify the major differences and why they occur; (e) find how much energy is required and how much GHG are emitted; (f) identify the activities that consume more energy and that emit more GHG; (g) identify the best and the worst of each study.

2 Ethanol as fuel

Bioethanol (or ethanol) is a biofuel that can be produced from biomass[4], such as sugarcane and corn. It can be used in internal combustion engines for road vehicles in two ways[3]:
- **blended with gasoline** from 2%-27%, to reduce petroleum use, boost octane ratings and cut tailpipe emissions. Other blends are available, like the E85 (51%-83% ethanol), but these high blended fuel kinds can only be used in flex-fuel vehicles (E85 can't be legally used in conventional gasoline-powered vehicles [4]);
- **pure ethanol**, a fuel containing 85%-100% ethanol (depending on country specifications), that can be used in flex-fuel vehicles, but not on conventional vehicles.

There are two types of ethanol: hydrous and anhydrous. The difference relates to the amount of water present in each one [1]:
- **hydrous ethanol** contains 95.1% to 96% of ethanol and the rest is water;
- **anhydrous ethanol** has at least 99.6% of alcohol content.

Both follow the same manufacturing process until they are fermented (anhydrous goes through a dehydration process). Hydrous is sold as pure ethanol (E100), while anhydrous is the ethanol which is blended with gasoline. Ethanol afinity with water molecules is a problem in engines (e.g. lubrification and combustion issues), therefore anydrous is the most indicated choice. One of the main advantages in using ethanol is its higher octane number, allowing the engine to work at higher compression rations without "knocking", extracting more mechanical energy (higher efficiency). The termal efficiency is slightly increased due to the increased combustion speed, and tailpipe emissions of CO and HC are reduced due to the improved combustion process. *But why blending ethanol instead of using only pure ethanol fuel?* Below $13°C$ hydrous ethanol (E100) loses its ability to generate combustion, becoming unusable as fuel[1]. This problem (frequent in cold strat events) can be reduced by blending ethanol with some amount of gasoline, as well as implementing apropriate ignition control systems [1].

3 Methodology

3.1 Life cycle analysis of ethanol from sugarcane

Life cycle stage of Well-to-Pump (WTP), considers the resource recovery and extraction, transport, treatment, conversion or refining to the final form of energy/fuel, and finally the delivery to the gas pump. Pump-to-Wheels (PTW) considers the use of the fuel in the vehicle from the gas pump to the wheels. This involves the vehicle efficiency and operation. The combination of the WTP and PTW stages, is called the Well-to-Wheels (WTW). Well-to-Gate (WTG) is similar to

[2]Life cycle assessment (LCA) is the process of evaluating the total effects that a product has on the environment over its entire existence, starting with its production and continuing through to its eventual disposal. Accounts the energy and resource inputs, and polluting outputs[9].

WTP, except it doesn't consider transport of the fuel to the gas pump. The WTG stage was the boundary studied in this thesis and it was divided in two stages: **feed-stock production & transportation**, which corresponds to the sugarcane production and then transport to the conversion plant; and **feed-stock conversion** , which corresponds to the processes that "transforms" the sugarcane into ethanol. An extent literature review was made to understand the different approaches to the sugarcane ethanol LCA and its real application. Four studies were analyzed: Macedo[7], Seabra[13], Wang[8] and a study from Concawe[11]. The studies have their own division, rules and units. So, each study structure was verified and then adapted to the same criteria. They were divided in **3 different categories**: Resources Consumption, Energy Consumption and GHG Emissions. Each one of these categories was also divided in **3 Levels**: Level 1, Level 2 and Level 3 (see Figure 1) [7].

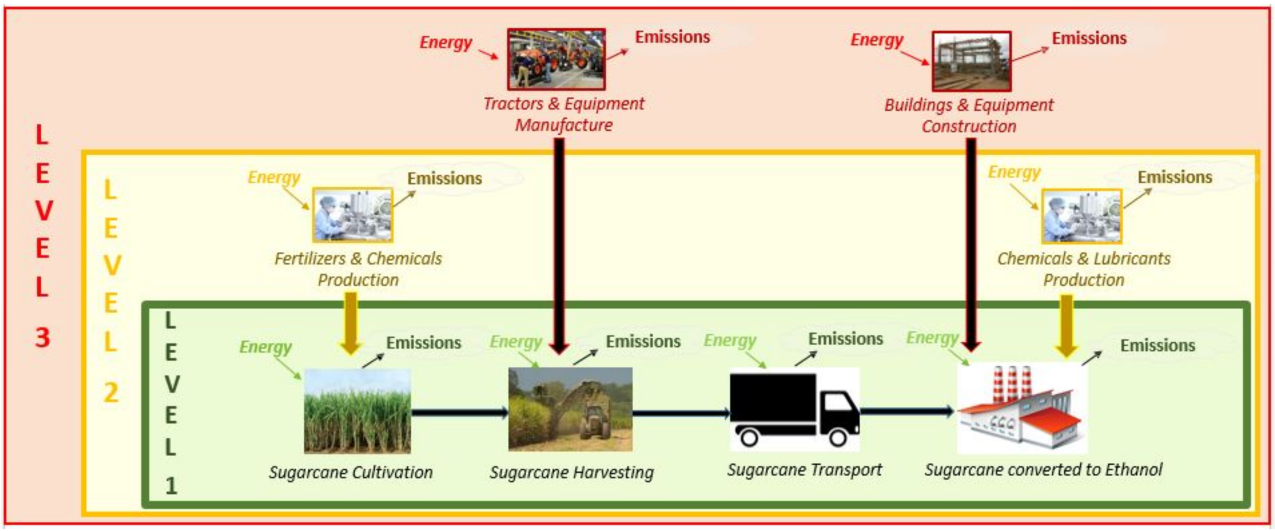

Figure 1: LCA Levels

Resources

Human resources weren't considered in this study, only material resources needed for each operation.

Level 1 – Water, fuel, fertilizers and chemicals. Basically all the resources needed for the direct developing processes.

Level 2 – Resources needed for the manufacturing of the Level 1 Resources.

Level 3 – Resources needed for the manufacture, construction and maintenance of equipment and buildings/factories.

Energy consumption

The energy consumed in $MJ/MJ_{ethanol}$ is focused in the fossil energy consumption (fuel oil and diesel). Studies may refer electricity or thermal energy, but only the share produced from fossil energy is considered.

Level 1 – Only the direct consumption of external fuels and electricity (direct energy inputs) is considered.

Level 2 – Additional energy required for the production of resources used in the agricultural and industrial processes.

Level 3 – Additional energy necessary for the manufacture, construction and maintenance of equipment and buildings.

GHG emissions

Only GHG [3] were compared in $gCO_2eq/MJ_{ethanol}$: CO_2, CH_4 and N_2O.

Level 1 – Emissions related to the direct consumption of external fuels and electricity (direct energy inputs).

Level 2 – Emissions from the production of chemicals and materials used in the agricultural and industrial processes

Level 3 – Emissions from the manufacture, construction and maintenance of equipment and buildings.

[3] GHG taken into account shall be CO2, N2O and CH4. For the purpose of calculating CO2 equivalence, those gases shall be valued according to a 100 year equivalence factor: CO2 = 1; N2O = 298; CH4= 23

”Macedo” [7], ”Seabra”[13] and ”Wang” [8] approach specificaly brazilian sugarcane ethanol, so they are more detailed on ethanol’s LCA. Concawe [11] contains an overall dataset for several fuels, so it doesn’t present enough details to allow the same comparison with the other studies. But the existant data was compared (see Table 2).

Table 2: Inventory review

Key Parameters	**Macedo**	**Seabra**	**Wang**	**CONCAWE**
Cane Productivity [tonnecane/hectare]	106	86.7	-	-
Liters of ethanol per tonne of sugarcane	97.3	82	91	86
Allocation	NO	YES (but no relevant)	NO	NO
Mechanical Harvesting [%]	35%	48%	-	-
Co-Products				
Electricity [kWh/tonnecane]	-	41[10]	51.9	-
Bagasse [kg/tonnecane]	140	140	140	140
Surpluses[12]				
Electricity [kWh/tonecane]	16.83[11]	10.7	23.1	-
Bagasse [kg/tonecane]	21	8.7	0	-

Electricity surplus can be exported to the powergrid and bagasse can be sold as biomass fuel. The values differ because of the efficiency and quality of the equipment. The more efficient, the less bagasse is needed in the boiler to achieve the same power. Macedo doesn’t refer the amount of electricity generated, it just considers the electricity that covers the factory needs. A factory can increase the production of surplus electricity by increasing the amount of bagasse burned in the boilers, therefore decreasing the excess bagasse [7]. This explains why Wang considers zero bagasse surplus and practically the double amount of electricity surplus of Seabra and Macedo.

4 Results

4.1 Fossil Energy Consumption

The following values are related to a **MJ of ethanol produced by the pathway**, not to the output of each particular operation. Also, these values represent the MJ of fossil energy expended to achieve the 1 MJ of ethanol. To make a more fair comparison, the same LHV for diesel and ethanol was considered in every study. In Figures 2 and 3 the values of fossil energy consumption for Level 1 and Level 2 respectively are presented:

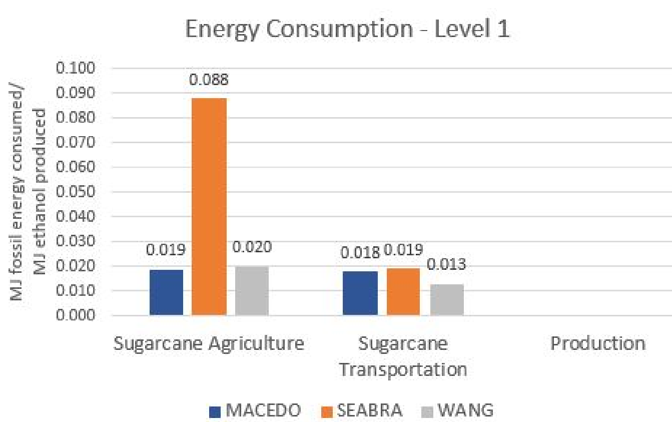

Figure 2: Fossil Energy Level 1

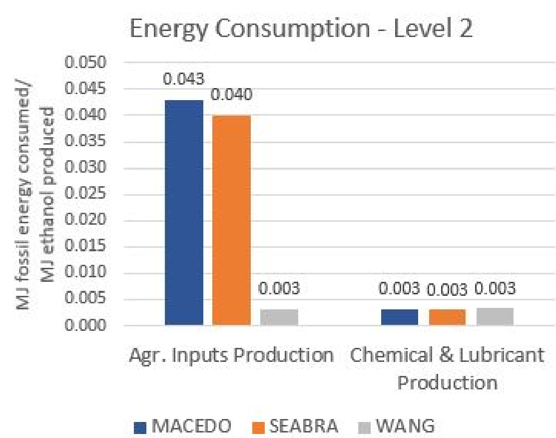

Figure 3: Fossil Energy Level 2

10Using the surplus value they refer, plus the energy they consider is saved by using electricity instead of fossil fuels

11Average electricity produced. Macedo refers that the bought electricity is almost irrelevant, and that all produced electricity is consumed. So in the overall energy balance - generated and consumed energy - the electricity has a zero value.

12Surpluses are the excess and are important, because they are accounted as produced energy.

Seabra considers a huger diesel consumption than the remaining studies, therefore fossil energy consumption in **sugarcane agriculture** is higher. *Why this huge difference in diesel consumption?* First of all, Seabra considers 48% of mechanical harvesting, which means that during the harvesting of the sugarcane 48% is assured by machines and the rest by manual labour. Macedo assumes 35% of mechanical harvesting. There may be other reasons, such as technologies used, land type (format, declivity,...), trucks course along the field. **Sugarcane transportation** reveals smaller differences, since every study considers diesel fuel and an average distance of $20km$ from the field to the mill. Concerning **production of ethanol**, all studies consider cogeneration (producing heat and electricity from bagasse). Bagasse is the residue of sugarcane after the juice has been extracted, and because of its high carbon content, it serves as an excellent source of process fuel in sugarcane mills[8]. The studies refer that most of the factories use bagasse, so are self-sufficient in what energy is concerned. About **Level 2**, Wang only considers seeds production and not the production of chemicals and fertilizers, therefore the smaller value in **agricultural inputs**. Concerning **Level 3**, Macedo considers an estimative of thermal (70%) and electric (30%) energy used, and 13% of electricity is generated from fossil fuels. Concerning thermal energy, an estimative was made based on the percentages of renewable thermal energy used in each sector, and a value of 30% for renewable thermal energy usage was reached. The remaining 70% are from fossil energy. Macedo is Wang's source for these values, therefore the similarity of values. The small differences have probably to do with conversion factors. **Level 1** is the main responsible for fossil energy consumption in Seabra and Wang. But Seabra doesn't mention Level 3 and Wang is an incomplete study in what Level 2 is concerned. Macedo is by far the most complete study, and according it Level 2 is the main responsible for fossil energy consumption.

4.2 GHG Emissions

In Figures 4 and 5 the emissions related to Level 1 and Level 2 operations, respectively, can be seen:

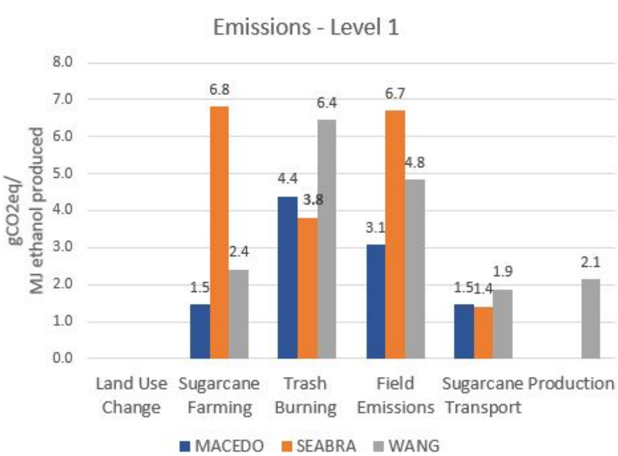

Figure 4: Fossil Energy Level 1

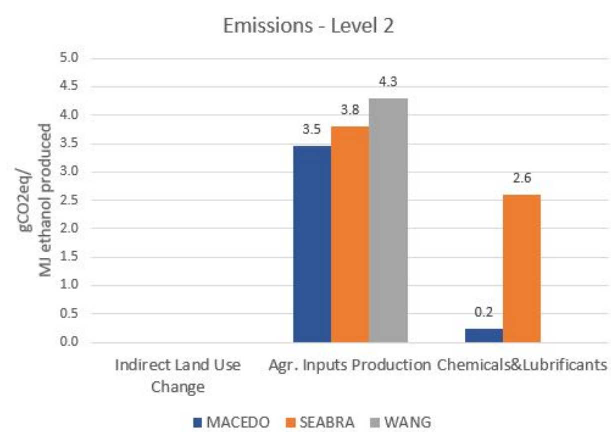

Figure 5: Fossil Energy Level 2

These values should be proportional with fossil energy consumption. Energy consumption in **sugarcane agriculture**[4] is much higher in Seabra and the GHG emissions are also much higher. The emissions of **sugarcane transport** in Wang are higher, but Wang considers a lower fossil energy consumption in this operation. Macedo doesn't specify which portion of emissions are responsible for agriculture and which are for transport, so it's not 100% guaranteed that the value is correct. Other possible explanation for the high value presented in Wang for sugarcane transport is the technology considered in each study: older trucks pollute a lot more. About **trash burning emissions**, Seabra considers 35% of unburned harvested cane, while Macedo and Wang consider 20%, therefore the emissions are lower in Seabra. About **field emissions**[5], Seabra considers more fertilizers consumption (7237 $g/tonne_{cane}$, versus 1741 $g/tonne_{cane}$ from

[4]Macedo includes sugarcane farming and sugarcane transport in one single dataset. To present some reliable data, it was considered that the amount of diesel is the same in both activities, so an equal split for the emissions was made.

[5]field emissions are emissions from the soil duo to fertilizers and chemicals

Macedo and 6773 $g/tonne_{cane}$ from Wang), therefore has a higher value. These quantities aren't exactly proportional to the GHG field emissions, since some fertilizers pollute more than others (e.g. nitrogen fertilizer usage increases the emissions of N_2O [2], which has a very high GWP). The values for N fertilizer usage are very similar between studies, so Macedo hasn't that much of a difference in the GHG field emissions. About **ethanol production**, Macedo considers zero GHG emissions in this stage, because it assumes the carbon released in the boiler is uptaken by the sugarcane. GHG emissions should be proportional to the fossil energy usage. But that doesn't happen, especially in the chemicals and lubricants section, and the main reason can be the fertilizers/chemicals themselves, since different fertilizers/chemicals will have different manufacturing processes with different emissions quantities. Wang has the highest value of emissions for the agricultural inputs, probably because it considers the entire agricultural inputs manufacturing emissions. Macedo is the only study that presents data about **Level 3** emissions: 1.1 $gCO_2eq/MJ_{ethanol}$ for agriculture equipment and 1.6 $CO_2eq/MJ_{ethanol}$ for industrial equipment and buildings manufacture.
Level 1 is the main responsible for the GHG emissions (sugarcane farming, trash burning and field emissions are the main responsibles inside this Level). But according to Wang [8] open-field burning practice of sugarcane "leftovers" will be gradually phased out. If this practice was already gone how would it affect the emissions' Levels share? Considering this scenario, Level 1 remains as the main responsible for the GHG emissions, but it represents a decrease of 42%, 20% and 36% in the Level 1 GHG emissions for Macedo, Seabra and Wang respectively. Considering all Levels, it represents a decrease of 26%, 15% and 29% of the GHG emissions for Macedo, Seabra and Wang respectively. These values are quite significant, which means that ending the open-field burning is indeed an excellent practice to reduce the GHG emissions of the sugarcane ethanol pathway.

4.3 European studies with reference to imported ethanol from Brazil

Concawe[11] contains the total amount of fossil energy expended in the WTT pathway of the ethanol. It considers the expended energy to transport ethanol to Europe, which was not analyzed in this study. Yet a comparison can be made, because **the values presented by the other studies should be lower than the one presented by Concawe**. The fossil energy expended value presented in Concawe is just for Level 1 range (see Table 3):

Table 3: Level 1 fossil energy consumption - Concawe comparison

Fossil energy expended (MJ/MJproduced ethanol			
Concawe	Macedo	Seabra	Wang
0.040	0.036	0.107	0.032

Seabra value is much higher, so it may not to be the most reliable value.
Concawe also has data for **Level 2** fossil energy consumption (see Table 4).

Table 4: Concawe fossil energy consumption LEVEL 2

	Fertilizers& Chemicals	**Fossil energy consumption MJ/MJ**	$\sum$ **Concawe fossil energy consumption MJ/MJ**	$\sum$ **Other Studies fossil energy consumption MJ/MJ**
Feed-Stock production	N	0.0083	$\sum = 0.0134$	$\sum_{Macedo} = 0.043$ $\sum_{Seabra} = 0.040$ $\sum_{Wang} = 0.003$
	P_2O_5	0.0012		
	K_2O	0.0019		
	CaO	0.002		
Feed-Stock Conversion	Lime	0.0024	$\sum = 0.0041$	$\sum_{Macedo} = 0.003$ $\sum_{Seabra} = 0.003$ $\sum_{Wang} = 0.003$
	Sulfuric acid	0.0017		

The value presented by Concawe in the **feed-stock conversion** stage is very similar to the others. The same doesn't happen for the **feed-stock production** value, but considering that Concawe also presents a much lower consumption of

agriculture resources it makes sense the fossil energy used is also lower.
Concawe also presents the GHG emissions for each operation of ethanol's pathway (see Table 5):

Table 5: GHG emissions Level 1 comparison with Concawe values

	Emissions gCO2eq/MJ			
	Macedo	Seabra	Wang	**Concawe**
Sugarcane agriculture	8.91	17.30	13.69	**14.45**
Road transport	1.46	1.40	1.88	**0.85**
Production (Avoided Emissions)[25]	-11.35	-6.40	0.00	**-9.84**

Concawe doesn't mention the share of mechanical and manual harvesting, so the smaller values of Macedo can have to do with the fact of Macedo considering more manual harvesting than Concawe. For **road transport**, Concawe considers a smaller energy consumption and by consequence it also considers a smaller value for GHG emissions. Concawe doesn't mention the road transportation distance, which can explain some differences. For the **avoided emissions** it was considered the value presented by Macedo that represents the avoided emissions by using bagasse instead of fuel oil **in other industries**. It's not the avoided emissions for using bagasse instead of fuel oil in the ethanol production, but for a matter of comparison it was mentioned here. And it has the smaller relative error.

European directive comparison

To calculate the biofuel emissions according to the european directive [10]:

$$E = e_{ec} + e_l + e_p + e_{td} + e_u - e_{sca} - e_{ccs} - e_{ccr} - e_{ee} \tag{1}$$

e_{ec} includes sugarcane farming, trash burning, field emissions (Level 1) and agricultural inputs production (Level 2); $e_l = 0$, since no land-use change emissions are considered; e_p includes production (Level 1) and chemicals&lubricants production (Level 2); e_{td} includes transportation to the factory (Level 1) plus the distribution to the fuel stations; $e_u = 0$, because ethanol is a biofuel; e_{sca}, e_{ccs} and e_{ccr} weren't considered, for lack of information; e_{ee} includes emissions saving from excess electricity produced in cogeneration systems, instead of using electricity from power plants. In Table 6 are the values of every parameter for each study analyzed in this thesis, as well as the relative error between the default values of the parameters presented by the european directive [10] and the ones of each study:

Table 6: Emission parameters of each study

	Emissions (gCO2eq/MJ)				***Variation between studies and directive (%)***		
	Seabra	**Macedo**	**Wang**	**Default values of european directive**	*Seabra*	*Macedo*	*Wang*
e_{ec}	21.10	12.37	17.99	14.00	*50.71*	*-11.65*	*28.47*
e_l	0.00	0.00	0.00	-	-	-	-
e_p	2.60	0.24	2.13	-	-	-	-
e_{td}[18]	1.40	1.46	1.88	9.00	-	-	-
e_u[19]	0.00	0.00	0.00	0.00	-	-	-
e_{ee}	3.70	-	-	-	-	-	-

Only e_{ec} parameter can be compared (e_{td}, in the directive [10], includes emissions from the transportation of the fuel to Europe). Macedo has the lowest relative error, which indicates it has more reliable data. Seabra on the other hand has the highest error, probably to do with the really high emissions (and energy consumption) of the agriculture operations. Macedo considers avoided emissions from the use of bagasse in other industries, but since e_{ee} are the avoided emissions

[25] The negative values are the conventional way to present the values of avoided emissions. The concept of avoided emissions is better explained in the end of chapter 3

[18] These values are only related to the WTG analyzes

[19] Emissions related to the vehicle in function were not analyzed

from cogeneration's electricity excess, two distinct scenarios for Macedo were made: $e_{ee} = 0$ and e_{ee} = to the avoided emissions from bagasse usage in other industries. For e_{td} two distinct scenarios were also assumed: $e_{td} = 9$ (default value assumed by the directive [10]) for the case where ethanol is exported to Europe and e_{td} = to values presented by each study (so emissions from transportation to the pump weren't considered). $E_f = 83.8\ gCO2eq/MJ$ is the directive's [10] default value. Scenario 1 is an approximation of the ethanol produced and consumed in Brazil and Scenario 2 is an approximation for ethanol produced in Brazil and exported to Europe.

Table 7: Emissions and emission savings according to the european directive formula

	Scenario 1 e_{td}= value from studies		Scenario 2 $e_{td} = 9$	
	E $gCO2eq/MJ$	**GHG savings** $(E_f - E)/E_f \times 100\%$	**E** $gCO2eq/MJ$	**GHG savings** $(E_f - E)/E_f \times 100\%$
Seabra	30.00	64.20	29	65.40
Macedo	14.07	83.21	21.61	74.21
Wang	22.00	73.75	29.12	65.25
Macedo w/e_{ee}	2.73	96.75	10.27	87.75

According to [10] the GHG savings must be approximately 71% for the ethanol exported to Europe and approximately 86% for ethanol produced and consumed in Brazil [5]. Macedo is by far the study more close to these values, which reforces the idea of being the most reliable study. And if the emissions saved by using bagasse in other industries are considered, the GHG savings are really high (96.75% and 87.75%).

4.4 Guidelines for ethanol production LCA studies

Some guidelines are now presented with the intention of guiding following researchers in similar studies, highlighting topics that are usually discarded but demonstrated in this study to have great importance.

LEVEL 1 - Sugarcane agriculture, transportation and conversion to ethanol in the factory are the main operations of sugarcane ethanol production.

Agriculture:

- Which and how many fuels, fertilizers and seeds are needed? The fertilizers will have an impact in field emissions, so knowing which type and how many are used will be very useful to calcutate field emissions.
- What is the percentage of manual and mechanical harvesting?
- Does that specific field pratice trash burning? If so, how many leaves and tops are burned? This is important for emissions calculation.
- How much water is it needed in agriculture stage?
- Even if the factory uses cogeneration, how many GHG emissions are emitted? Attention, some studies may consider zero GHG emissions because of the carbon uptaken by sugarcane.
- Is it possible to replace any of the chemicals for natural fertilizers?

Transportation:

- Which fuel is needed for this operation?
- What is the distance travelled by vehicles from the field to the mill?
- Type of vehicle used and its age?

Ethanol Production:

- Does the factory use the bagasse in a cogeneration system? If not, which fuels are needed to power the factory?
- Which chemicals are needed?
- Does the factory produces sugar and ethanol, and uses allocation?

LEVEL 2 - Englobes operations involved in the manufacture of Level 1 resources.

- Which and how many fuels, fertilizers, chemicals and seeds are needed? Different reources will have different manufacture processes.
- Distance travelled of fertilizers and chemicals to the agriculture fields and ethanol production factories. Are the fertilizers imported? Fertilizers with small GHG emissions manufacture can represent huge GHG emissions if they travel great distances.

LEVEL 3 - Operations involved in the manufacture of machinery and buildings.

- Which machinery and buildings are used in Level 1 operations?
- For each machinery and buildings, how many and which types of energy were used in their manufacture? If info is hard to find check which materials were needed and then research for each material sector info. If electric and thermal energy were needed in any operation, check the percentages of fossil and renewable energy needed to generate them.
- Is the machinery imported? If so, which distance does it travel?
- Is there any machinery, more recent that the ones used, that has lower values of energy consumption and GHG emissions in its manufacture process?

Finally, how many liters of ethanol are produced with one tonne of sugarcane? Efficiency is crucial to determine the impact of emissions and energy consumption.

5 Conclusions

Different sugarcane ethanol LCA studies were analyzed, presenting different values for energy consumption and GHG emissions. There are some reasons for these differences, such as: the year of study, the analyzed region and also by the share of mechanical and manual labour, the technology and configuration of the procedures in the agriculture stage and in the factories, the vehicles' type used in transportation (older vehicles will consume and pollute more), resources types and quantities used.

One great achievement was the evaluation of an LCA based on the three Level criteria, which allows to call for attention that an LCA is not just Level 1 based, and it also helps to focus efforts in three different categories. Level 1, which concerns the direct operations of the pathway, was found to be the major responsible for fossil energy consumption and GHG emissions from two studies, with values ranging 0.032-0.107$MJ_{fossil}/MJ_{ethanol}$ and 17.7-18.7$CO_2eq/MJ_{ethanol}$. For the most reliable study - Macedo - the main responsible for energy consumption is Level 2, which concerns the production of resources used in the agricultural and industrial processes, with a total value of 0.046$MJ_{fossil}/MJ_{ethanol}$; and the main responsible for GHG emissions is Level 1, with a value of 10.4$CO_2eq/MJ_{ethanol}$. The operation mainly responsible for Level 1 emissions is open-field burning (fortunately according to Wang this practice will be abolish). Level 3, which concerns the manufacture of equipment and buildings necessary for Level 1 operations, is the less detailed level and some studies don't even consider it. According to Macedo Level 3 is responsible for the emission of 2.7$CO_2eq/MJ_{ethanol}$ and it consumes 0.017$MJ_{fossil}/MJ_{ethanol}$.

References

[1] Nova Cana. https://www.novacana.com/etanol/. Accessed: 2016-03-28.

[2] Scientific Reports. http://www.nature.com/articles/srep28230. Accessed: 2016-09-02.

[3] Sugarcane Org C. http://sugarcane.org/sugarcane-products/ethanol. Accessed: 2016-03-25.

[4] US Department of Energy. http://www.afdc.energy.gov/. Accessed: 2016-03-25.

[5] Arnaldo Walter, Paulo Dolzan, O. Q.-J. G. C. d. S. F. P. A. S. A sustainability analysis of the brazilian ethanol. Tech. rep., UNICAMP, 2008.

[6] EUROPEAN COMISSION. *EU Transport in Figures - Statistical Pocketbook*, 2014. http://ec.europa.eu/transport/facts-fundings/statistics/doc/2014/pocketbook2014.pdf.

[7] ISAIAS DE CARVALHO MACEDO, MANOEL REGIS LIMA VERDE LEAL, J. E. A. R. D. S. Assessment of greenhouse gas emissions in the production and use of fuel ethanol in brazil. Tech. rep., Núcleo Interdisciplinar de Planejamento Energético da Universidade Estadual de Campinas, 2004.

[8] MICHAEL WANG, MAY WU, H. H., AND LIU, J. Well-to-wheels energy use and greenhouse gas emissions of brazilian sugarcane ethanol production simulated by using the greet model. Tech. rep., Center for Transportation Research, Argonne National Laboratory, 9700 South Cass Ave, Argonne, IL 60439, USA, 2007.

[9] NIZA, S. Life cycle assessment. University Lecture, 2014.

[10] OFFICIAL JOURNAL OF THE EUROPEAN UNION. *DIRECTIVE 2009/28/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL*, April 2009. http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX

[11] R. EDWARDS, J-F. LARIVÉ, J.-C. B. Well-to-wheels analysis of future automotive fuels and powertrains in the european context. Tech. rep., Concawe, 2011.

[12] RENEWABLE ENERGY POLICY NETWORK FOR THE 21ST CENTURY. *RENEWABLES 2015 GLOBAL STATUS REPORT*, 2015. http://www.ren21.net/wp-content/uploads/2015/07/REN12-GSR2015_Onlinebook_low1.pdf.

[13] SEABRA, J. E. A. Life cycle assessment of brazilian sugarcane products: Ghg emissions and energy use. Tech. rep., UNICAMP and Brazilian Bioethanol Science and Technology Laboratory (CTBE), 2011.

[14] STACY C. DAVIS, SUSAN W. DIEGEL, R. G. B. *Transportation Energy Data Book*, 33 ed. Oak Ridge National Laboratory, 2360 Cherahala Boulevard Knoxville, Tennessee 37932, July 2014. http://cta.ornl.gov/data/chapter2.shtml.

[15] TOLMASQUIM, M. T. *Balanço Energético Nacional*. Empresa de Pesquisa Energética, 2013. https://ben.epe.gov.br/downloads/S