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LIFE CYCLE ASSESSMENT OF THE METHANOL PRODUCTION FROM SUGARCANE BAGASSE CONSIDERING TWO DIFFERENT ALTERNATIVES OF ENERGY SUPPLY

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Abstract. *One of today's most important environmental issues is the pollution caused by traffic and transport. The substitution of conventional fuels (gasoline, diesel) by biofuels is considered such as a way to reduce pollution and support sustainable agriculture. This work presents an evaluation of life cycle energy balance and net environmental impacts of methanol production using Life Cycle Assessment – LCA as a tool for a plant with a capacity of 100.000 ton/y. In this study the methanol is produced from sugarcane bagasse by BTL (Biomass to Liquid) route and two study cases are considerate for supplying steam and electrical energy: A cogeneration bagasse system (operating with steam parameter – 10 MPa and 520°C) and a fossil system (boiler operating with fossil fuel and electrical energy supplied by local power network). The results obtained allowed to characterize the main environment impacts associated to methanol production from sugarcane bagasse for two case studies.*

Keywords: *Life Cycle Assessment, biofuels, methanol, sugarcane bagasse*

1. INTRODUCTION

Methanol (CH_3OH), also known as methyl alcohol is the simplest alcohol. It can be uses as a fuel, either as a blend with gasoline in internal combustion engines or in fuel cell vehicles. Besides, it is used as fuel, methanol also serves as a starting material for chemicals such as formaldehyde, acetic acid, and a wide variety of others products including polymers, paints, adhesives, construction materials, synthetic chemicals and others.

In 2005, the global methanol production capacity was about 40 Mt /year, the actual production or demand was about 32 Mt. Since the early 1980s, larger plants using new efficient low-pressure technologies are replacing less efficient small facilities. Among these new technologies is the methanol produced from biomass that can be employed in the automotive sector, and it can addresses several of the problems associated with the current use of mineral oil derived fuels, such as energy security and greenhouse gas emissions.

The purpose of this work is to present an evaluation of life cycle energy balance and environmental impacts of methanol from biomass. In this study the biomass is the sugarcane bagasse and tool used for evaluation environmental is Life Cycle Assessment.

In the first case study, the demand of bagasse, electrical and thermal energy for the process is supplied by a distillery plant. The goal is the methanol plant is close to distillery plant, so these units produce three products: ethanol and methanol. In second case study, the electrical and thermal energy is supplied by fossil system. The boiler is operated with fossil fuel and electrical energy is supplied by local power network.

2. METHANOL FROM BIOMASS

Any carbonaceous material such as coal, lignite, wood waste, agricultural residue and sugarcane bagasse can be utilized for synthetic methanol production. However, in contrast to natural gas, these raw materials requires several addition steps in all processing to refine the gas production into a final clean gas product (syngas) consisting mainly of H_2 and CO. The processing steps of methanol production from biomass are described summarized below (Hamelinck and Faaij, 2002):

- *Pretreatment*: The biomass must be pre-treated to meet the processing constraints of the gasifier. This involves conditioning and drying for purpose of material densification (Boerrigter, 2006).
- *Gasification*: Biomass gasification involves heating biomass in the presence of low levels of oxygen. Above certain temperatures the biomass will break down into a gas stream and solid residue. The composition of the gas stream is influenced by the operating conditions for the gasifier, with some gasification process more suited than others to producing a gas for methanol production. In particular, simple gasification with air creates a syngas stream that is diluted with large quantities of nitrogen. This nitrogen is detrimental to subsequent processing to methanol and so techniques using indirect gasification or an oxygen feed are preferred.
- *Gas clean-up*: The syngas produced by biomass gasification contains a range of contaminants, depending on feed and gasification process. Gas clean-up is required to prevent mechanical problems, and clean-up steps may include particulate and sulphur removal and scrubbing for chlorine compounds.

- *Syngas Conditioning*: For optimal production of methanol, three parameters are important:
  a) The ratio of CO_2 to CO should be optimized for methanol production.
  b) The syngas for methanol process is most efficient when feed gas contains the correct ratio of components, and the relation of $H_2 / (2CO + 3CO_2)$ must be approximately 1.
- *Methanol synthesis*: Available methanol synthesis uses a copper-zinc catalyst at temperatures of 200 – 280°C and pressures of 5 – 10 MPa. Methanol is produced by the hydrogenation of carbon oxides over a suitable catalyst (Cifre and Brad, 2007):

$$\begin{aligned} CO + 2H_2 &\leftrightarrow CH_3OH \\ CO_2 + 3H_2 &\leftrightarrow CH_3OH + H_2O \end{aligned} \tag{1}$$

- *Methanol purification:* The crude methanol from the synthesis process contains water produced during synthesis as well as other minor by-products. Purification is achieved in multistage distillation, with the complexity of distillation dictated by the final methanol purity required (Adams and Sims, 2001).

3. LIFE CYCLE ASSESSMENT

Life Cycle Assessment (LCA) studies involve the collection, assessment and interpretation of data from an environmental perspective over a product's lifecycle (production, use, and end of life). Studies can evaluate entire product life cycle, often referred to as cradle-to-gate. The ISO 14040 series of standards contain the international standards for LCA. These series were developed by international experts on LCA from more than fifty countries over a period of more than 10 years. According to ISO 14040, the four phases of an LCA are (1) Goal and Scope Definition, (2) Life Cycle Inventory, (3) Impact Assessment, and (4) Interpretation.(Weidema, 2000), (Marsmann, 2000).

Goal and scope definition is the phase of the LCA process that define the purpose and method of including life cycle environmental impacts into the decision-making process. In this phase, the following items must be determined: the type of information that is needed to add value to the decision-making process, how accurate the results must be add value, and how the results should be interpreted and displayed in order to be meaningful and usable.

Life Cycle Inventory (LCI) involves compiling data about relevant inputs and outputs of a product system that may contribute to multiple environmental issues. Material and energy balances are performed. The data collection is carried out for each process as defined in the goal and scope definition (e.g., air emissions, solid waste disposal, waste water discharges) (SAIC, 2006).

One of the most important and frequent methodological problems to be tackled, when carrying out the life cycle inventory is the allocation of environmental loads in processes in which there are several useful products (co-products). The various allocation principles may be divided into five groups (González, 2003):

- Allocation based on natural causality. If there are natural identifiable causalities for environmental loads, allocation must be based on these.
- Allocation based on some physical parameter. Examples of physical quantities are: mass, volume, energy, number of moles, etc.
- Allocation based on social causes of the process. The justification for a process is that it produces value. These values may or may not be measurable in economic terms.
- Allocation based on an arbitrary number. This criterion should only be based in case there is no other possibility.
- Extension of system boundaries, avoiding the allocation problem.

Life Cycle Impact Assessment (LCIA) phase of an LCA is the evaluation of potential human health and environmental impacts of the environmental resources and releases identified during the LCI. So, Impact Assessment should address ecological and human health effects; it should also address resource depletion. A LCIA attempts to establish a linkage between the product or process and its potential environmental impacts (Guinée, 2002).

According to ISO 14044, Life Cycle Impact Assessment proceeds through two mandatory and two optional steps:

1 – Selection of impact categories and classification, where the categories of environmental impacts, which are of relevance to the study, are defined by their impact pathway and impact indicator, and the elementary flows from the inventory are assigned to the impacts categories according to substances' ability to contribute to different environmental problems (mandatory).

2 – Characterization, where the impact from each emission is modeled quantitatively according to the underlying environmental mechanism. The impact is expressed as an impact score in a unit common to all contributions within the impact category applying characterization factors. A characterization factor is a substance-specific factor calculated with a characterization model for expressing the impact from the particular elementary flow in terms of the common unit of the category indicator (mandatory).

3 – Normalization, where the different characterized impact scores are related to a common reference, e.g. the impacts caused by one person during one year, in order to facilitate comparisons across impact categories (optional).

4 – Weighting, where a ranking and/or weighting are performed of the different environmental impact categories reflecting the relative importance that is assigned in the study (optional).

There are many LCIA methodologies that apply essentially the same principles or minor variations for impact categories. In this work was selected CML 2000, it aims to provide best practice for midpoint indicators. It includes recommended methods for normalization but no recommended methods for weighting (Guinée, 2002). This method also considers the following categories of impacts:

- Abiotic depletion, it refers to the exhaustion of natural resources such as iron ore, which are regarded as non-living.
- Global warning, it is the impact of greenhouse gases emissions on the radioactive forcing of the atmosphere.
- Ozone layer depletion, it is the increased stratospheric concentration of chlorine from industrially produced CFCs, halons and selected solvents. Once in the stratosphere, every chlorine atom can destroy up to 100.000 ozone molecules.
- Human toxicity, it includes the impacts on human health of toxic substances emitted to the environment.
- Fresh water aquatic ecotoxicity, it refers to the impact of toxic substances emitted to freshwater aquatic ecosystems.
- Marine aquatic ecotoxicity, it refers to the impact of toxic substances emitted to marine aquatic ecosystems.
- Terrestrial ecotoxicity, it refers to the impact of toxic substances emitted to terrestrial ecosystems.
- Photochemical oxidation, it is the formation of reactive chemical compounds, such as ozone, by the action of sunlight on certain primary air pollutants. These compounds may be injurious to human health, ecosystems, materials and crops.
- Acidification, it is result of acidifying pollutants emissions, such as SO_2 or NO_x, to the air. These emissions have negative impacts on soil, groundwater, surface waters, biological organisms, ecosystems and materials.
- Eutrophication, it is the consequence of high levels of macronutrients, such as nitrogen and phosphorous, in the environment.

Interpretation is the final phase of an LCA. In the interpretation, an investigation of significant environmental aspects (energy use, greenhouse gases), significant contributions of stages in the life cycle. This step helps provide more certain conclusions, recommendations and sensitivity analysis (Azapagic, 1999).

4. METHANOL LIFE CYCLE ASSESSMENT

The purpose of this study is to evaluate the life cycle energy balance and environmental impacts of methanol production from bagasse sugarcane. The scope of study involves the agricultural stage of sugarcane until to methanol synthesis in the plant. The system boundaries are presented in Fig. 1, and the functional unit used in this study was 1 kg of methanol.

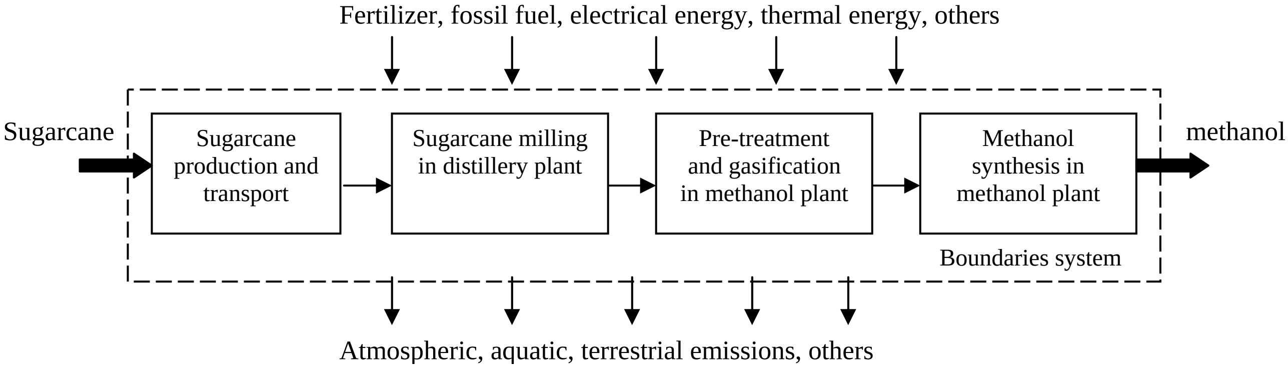

Figure 1. Boundaries system of methanol production

In Fig. 1 can be noted some input and output dates, in this work the main inputs considered were: fossil fuel used in agricultural production and sugarcane transport, fertilizers and pesticides consumed in sugarcane harvesting; steam and water consumed in sugarcane milling; electricity and steam consumed during the whole LCA. The LCA ends at methanol production, not including the stages of distribution and the final use.

In relation the outputs of methanol process, these refer to emissions and residues generated in different stages of the process. They are generated in combustion of fossil fuel, harvesting emissions, residues produced in gasification process and others.

As input and output dates are computed according to the functional unit (1 kg methanol). These dates are found in bibliography references. Except for bagasse gasification, that uses the software CSFMB (Comprehensive Simulator of Fluidized and Moving Bed Equipment).

The CSFMB software provides information such as: flow rates of gases and solids leaving the equipment, carbon conversion, mixing rate, residence time of each solid species, flow rates of tar or oil leaving with gases and others, which allows the selection of main data for this study.

In the Table 1 are presented the main collected inputs data for methanol production and adjusted to unit functional used in this work.

Table 1. Input data of methanol production

			References
Sugarcane production, harvesting, transportation	Fertilizer utilization (kg)		Macedo *et al.* (2008)
	P_2O_5	0,012	
	K_2O	0,011	
	Nitrogen	0,0045	
	Lime (kg)	0,18	
	Insecticide (kg)	$1{,}53 \times 10^{-5}$	
	Herbicide (kg)	0,00021	
	Stillage (m^3)	0,013	
	Diesel (l)	0,03	
	Area of cultivation (ha)	$9{,}54 \times 10^{-5}$	
Sugarcane milling	Water (m^3)	0,046	Camargo *et al.* (1990)
	Steam (kg)	0,65	
	Temperature: 260 to300°C		
	Pressure: 1,9 a 2,1 MPa		
	Sugarcane (ton)	0,0083	
Pre-treatment	Electrical energy (kWh)	0,14	Rocha (2008)
	Bagasse (kg)	1,66	
Gasification	Oxygen (kg)	0,46	Simulation of CSFMB software
	Steam (kg)	1,51	
	Temperature: 435°C		
	Pressure: 2,27 MPa		
	Electrical energy (kWh)	0,00013	
	Bagasse (kg)	1,66	
Methanol synthesis	Electrical energy (kWh)	0,1059	Vaswani (2000)
	Steam (kg)	0,79	
	Temperature: 165°C		
	Pressure: 0,68 MPa		
	Syngas (kg)	4,16667	

In the Table 1 is possible to observe the high demand of electrical energy (0,245 kWh) and steam (2,95 kg) for producing 1 kg of methanol. The electrical energy demand is high because is necessary the pressurization of syngas, and steam consumption is high, mainly due to gasification process and methanol synthesis.

While main outputs from methanol production, in Tab. 2 is presented the emissions, residues and others produced during all stages of methanol production. They were adjusted to 1 kg of methanol.

In the Table 2 can be observed the high emissions provide from sugarcane transportation (truck emissions), this is explained by diesel consumption of these vehicles. The opposite for gasification and methanol synthesis, these processes are “clear” technologies, because they emit to environment low atmospheric pollutants.

In relation to allocation of environmental loads for the methanol production, this is necessary in milling stage, in which are formed two products: bagasse and juice. So, in this study the selected allocation was energy of the products.

According Olivério (2006), the distribution of energy sugarcane after milling process is approximately 51 % for juice and 49% for bagasse. So, with this distribution was computed the allocation of environmental loads for bagasse and juice.

Table 2. Output data of methanol production.

Sugarcane production, harvesting, transportation	***Sugarcane Production (ton)***	0,0083	***Tractor emissions***		**References**
	Truck emissions		HC (g)	0,2253	Macedo *et al.* (2008)
	CO_2 (g)	7,14	CO (g)	0,6200	
	NO_x (g)	0,058	NO_x (g)	1,553	Lloyd e Cackette (2001)
	CO (g)	0,309	PM10 (g)	0,1624	
	Fine particles (g)	0,032	SO_x (g)	0,1104	
	Organic carbon (g)	0,0064	***Harvesting emissions***		EPA (1991)
	Nitrate (g)	$7{,}025 \times 10^{-5}$	Nitrous oxide (N_2O) from denitrification (kg)	0,001622	
	Silicon (g)	0,00021	Nitrogen oxide (NO_X) from denitrification (kg)	0,0027	Renouf *et al.* (2008)
	Carbon (g)	0,010	Ammonia (NH_3) from volatilization (kg)	0,000429	
	Ammonium (g)	0,00022			
	Sulfate (g)	0,00032			
	Emissions to air from pre-harvest cane burning				
	CH_4 (kg)	0,000277	SO_x (kg)	0,000124	
	N_2O (kg)	1,91 x 10-5	NMVOC (kg)	0,00062	
	NO_x (kg)	0,001011	NO_3 (kg)	0,004465	
			P (kg)	0,000229	
Gasification	***Emissions to air***		***Syngas production*** (kg)	4,1667	Baker *et al.* (1986) Liu and Gibbs (2003)
	HCN (kg)	0,00036	***Solids residues*** (kg)	0,078	
	H_2S (kg)	0,0000996			
	NH_3 (kg)	0,00036			
Methanol synthesis	Methanol production (kg)	1	***Emissions of methanol from storage tank (g)***	$8{,}65 \times 10^{-4}$	Vaswani (2000)
	Purge gas (kg)	0,2	***Fugitive emissions from methanol synthesis***		
			CO	$2{,}5 \times 10^{-2}$	
			CH_3OH (VOC)	$6{,}49 \times 10^{-2}$	

4.1. Electrical and thermal systems

First case study (cogeneration system)

In the first case study of energy supply system, the distillery plant with a capacity of 6.000.000 ton canes produces ethanol from sugarcane juice, and the electrical and thermal demand is supplied by a cogeneration process. The methanol plant is annexed to distillery, and it is also supplied of energy by the same cogeneration process.

Cogeneration system results a number of benefits. Among them, it is regarded as clean system with respect to the environment; the net contribution of greenhouse gases from a bagasse-based cogeneration plant is negligible, since the carbon dioxide absorbed during sugarcane growth is more than that emitted by the cogeneration plant.

In this work the cogeneration system selected was CEST (Condensing Extraction Steam Turbine) system, operating with high steam parameter (10 MPa and 520°C). This system produces steam from the entire quantity of bagasse produced during the crushing season. Surplus power production can be extended during off-crushing season by operating the turbine in the condensing mode, provided off-crop season fuel is available abundantly and cheaply.

The cogeneration process proposed in this work was simulated in software Gate-Cycle 5.51, it is represented in Fig. 2. In Tab. 3 it shows the general parameters adopted for the entire configuration proposed.

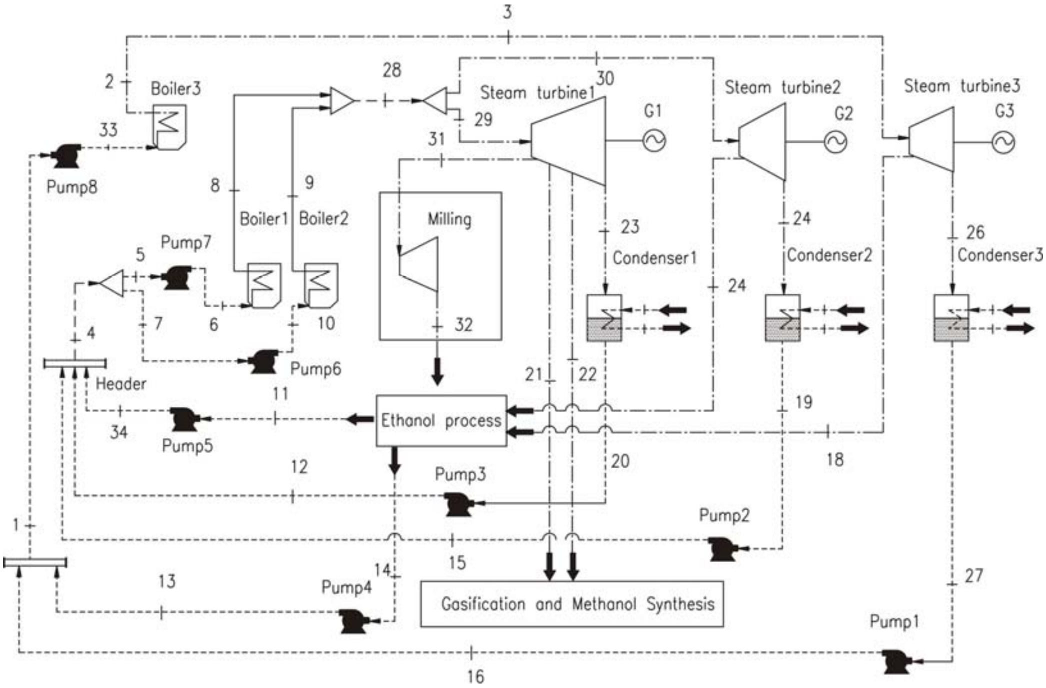

Figure 2. CEST system applied for attending electrical energy and steam demand for methanol production

Table 3. General parameters adopted for the global plant system

Cane milling system		**Cogeneration system**		**Methanol and Ethanol System**	
Cane harvest duration/FU [%]	210/88	Boiler efficiency [%]	88	Ethanol production [m^3/d]	2594
Cane percent of bagasse	27	Steam turbines isentropic efficiency [%]	90	Methanol production [m^3/d]	656
Mills 1 – 6 Multiple stages turbine		Installed power [MW]	78	Process steam consumption [kg_s/tc]	486
Inlet steam pressure [MPa]	2	Steam production [t/h]	600		
Inlet steam temperature [°C]	320	Atmospheric pressure [MPa]	0,10		
Exhaust steam pressure [MPa]	0,170	Atmospheric temperature [°C]	25		
Mechanical energy consumption [kWh/tc]	15	Bagasse LHV [kJ/kg]	7560		

In Figure 2, the cogeneration system has a boiler operating 320°C and 2 MPa, and two boilers operating 10 MPa and 520°C. The system also is composed for three condensing extraction steam turbines. The cogeneration system applied presents an electrical efficiency of 15,58 %.

Second case study (fossil system)

In the second case study, the electrical energy demand of methanol plant is supplied by power network and thermal demand is supplied by boilers operating with fossil fuel. The distillery plant is important for providing surplus bagasse to methanol plant, but in this case, the methanol plant is not annexed to distillery plant.

In this work was considerate that electrical energy from power network consists mainly of hydropower and thermal power energy (80% and 20% respectively). These two systems are most responsible for electrical energy production in Brazil.

The main data related to electrical energy production from hydropower were gotten in Ribeiro (2003), this work presents the electricity production from ITAIPU (Hydropower – Brazil). While thermal power system, in this work the data was based in typical fuels consumed for power system in Brazil, that are gas (9%), natural gas (43%), oil (30%) and coal (18%) (MME, 2009).

In relation, the steam production in boilers operating with fossil fuel, the main data of this process were gotten in Vaswani (2000). In this work was considerate the typical boiler efficiency of 80%, and the fossil fuels applied was coal, oil and natural gas.

4.2. Environmental impacts energy balance of methanol production

The environmental impacts were computed with base in inputs and outputs data of Tab. 1 and Tab. 2, as well as the software SIMAPRO 7 was applied for getting the main impact categories of methanol production, with the CML 2000 method. The software SIMAPRO 7 is considerate a professional tool to collect, analyze and monitor the environmental performance of products and services (Pré Consultants, 2009).

The results gotten in SIMAPRO 7 with CML 2000 method are presented in Fig. 3, Fig. 4, Tab. 4 and Tab. 5. It shows the order of magnitude of the environmental problems generated by the products' life cycle.

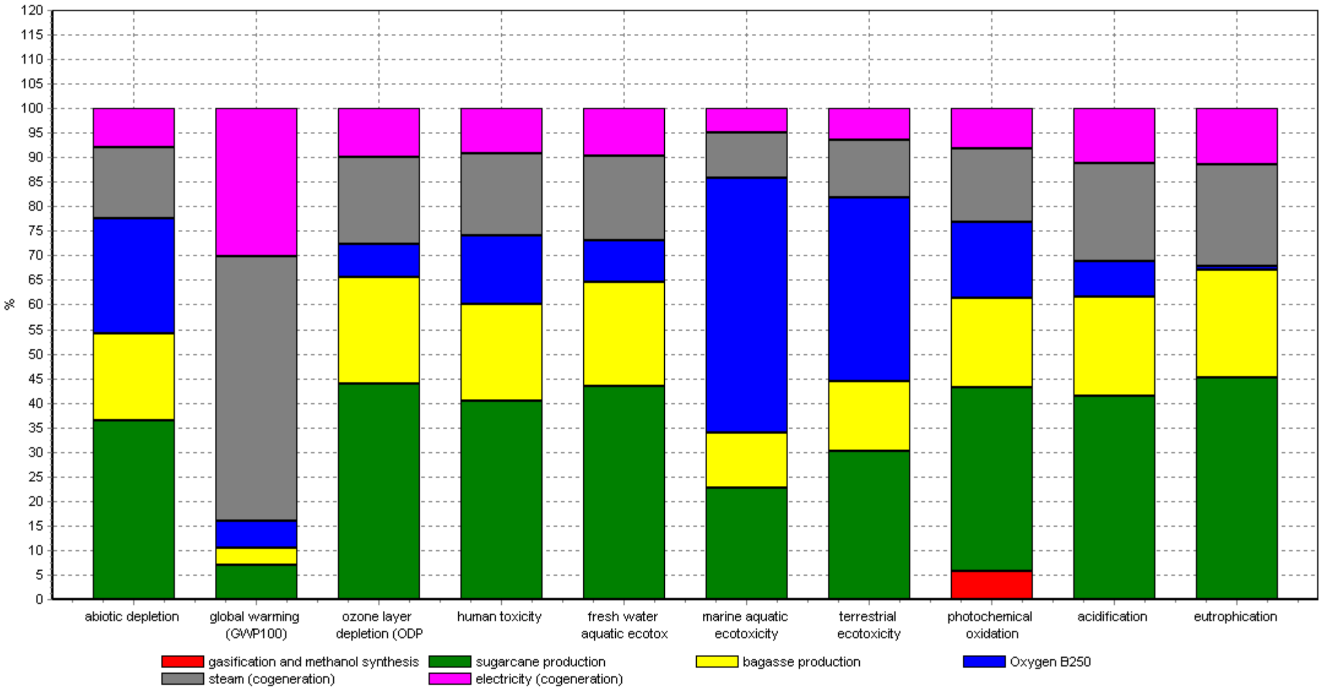

Figure 3. Main environmental impacts of methanol production system for cogeneration system

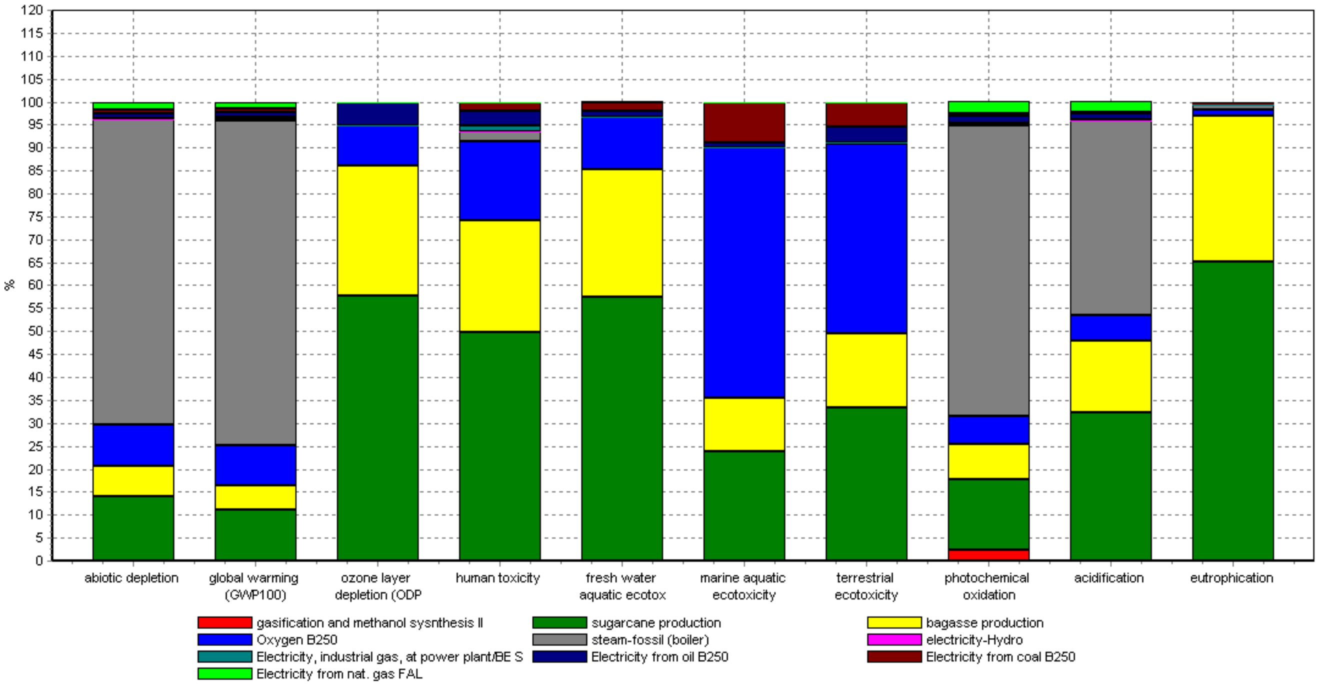

Figure 4. Main environmental impacts of methanol production system for fossil system

Table 4. Main environmental impacts of methanol production system for cogeneration system

Environmental impact	**Unit**	**Methanol production**	**Sugarcane production**	**Bagasse production**	**Oxygen production**	**Steam (cogeneration)**	**Electricity (cogeneration)**
Abiotic depletion	kg Sb eq.		0,00118	0,000571	0,000761	0,000467	0,000259
Global warming	kg CO_2 eq.	3,82 x 10^{-5}	0,13	0,0634	0,104	1,01	0,562
Ozone layer depletion	kg CFC-11 eq.		1,34 x 10^{-7}	6,6 x 10^{-8}	2,06 x 10^{-8}	5,4 x 10^{-8}	3 x 10^{-8}
Human toxicity	kg 1,4-DB eq.	2,19 x 10^{-5}	0,0706	0,0343	0,0247	0,029	0,0161
Fresh water aquatic ecotox.	kg 1,4-DB eq.		0,0115	0,00562	0,00226	0,0046	0,00255
Marine aquatic ecotox	kg 1,4-DB eq.		32,9	16,1	75,4	13,2	7,32
Terrestrial ecotoxicity	kg 1,4-DB eq.		0,000275	0,000131	0,00034	0,000107	5,95 x 10^{-5}
Photochemical oxidation	kg C_2H_4 eq.	9,87 x 10^{-6}	6,55 x 10^{-5}	3,19 x 10^{-5}	2,68 x 10^{-5}	2,61 x 10^{-5}	1,45 x10^{-5}
Acidification	kg SO_2 eq.		0,00423	0,00205	0,000729	0,00205	0,00114
Eutrophication	kg PO_4 eq.		0,0016	0,000781	3,06 x 10^{-5}	0,000734	0,000407

Table 5. Main environmental impacts of methanol production system for fossil system

Environ. impact	**Unit**	**Methanol produc.**	**Sugarcane produc.**	**Bagasse produc**	**Oxygen produc.**	**Steam fossil (boiler)**	**Electr. gas**	**Electr. oil**	**Electr. coal**	**Electr nat. gas**	**Electricity hydro**
Abiotic depletion	kg Sb eq.		0,00118	0,000571	0,000761	0,00561	1,32 x 10^{-5}	8,59 x 10^{-5}	7,53 x 10^{-5}	0,000143	8,22 x 10^{-8}
Global warming	kg CO_2 eq.	3,82 x 10^{-5}	0,13	0,0634	0,104	0,834	0,00763	0,0134	0,0095	0,0157	0,000942
Ozone l. depletion	kg CFC-11 eq.		1,34 x 10^{-7}	6,6 x 10^{-8}	2,06 x 10^{-8}	0	6,12 x 10^{-11}	1,16 x 10^{-8}	2,13 x 10^{-10}	1,42 x 10^{-11}	0
Human toxicity	kg 1,4-DB eq.	2,19 x 10^{-5}	0,0706	0,0343	0,0247	0,00283	0,00192	0,00449	0,00268	0,000132	6,97 x 10^{-6}
Fresh water aquatic ecotox.	kg 1,4-DB eq.		0,0115	0,00562	0,00226	6,38 x 10^{-6}	8,09 x 10^{-6}	0,000249	0,000385	2,39 x 10^{-5}	2,82 x 10^{-8}
Marine Aquatic ecotox	kg 1,4-DB eq.		32,9	16,1	75,4	0,000358	0,0455	1,33	12,2	0,0658	3,4 x 10^{-6}
Terrestrial ecotox	kg 1,4-DB eq.		0,000275	0,000131	0,00034	8,64 x 10^{-7}	3,98 x 10^{-7}	2,85 x 10^{-5}	4,42 x 10^{-5}	4,13 x 10^{-7}	9,59 x 10^{-10}
Photo. oxidation	kg C_2H_4 eq.	9,87 x 10^{-6}	6,55 x 10^{-5}	3,19 x 10^{-5}	2,68 x 10^{-5}	0,000269	6,58 x 10^{-7}	6,76 x 10^{-6}	1,95 x 10^{-6}	1,12 x 10^{-5}	7,86 x10^{-7}
Acidifi.	kg SO_2 eq.		0,00423	0,00205	0,000729	0,00555	6,59 x 10^{-6}	0,000178	5,36 x 10^{-5}	0,000283	1,13 x 10^{-6}
Eutrophi.	kg PO_4 eq.		0,0016	0,000781	3,06 x 10^{-5}	2,64 x 10^{-5}	6,73 x 10^{-7}	3,92 x 10^{-6}	3,44 x 10^{-6}	7,36 x 10^{-6}	7,78 x 10^{-8}

In Table 4 can be observed that abiotic depletion environmental impact is mainly contributed by sugarcane production, bagasse production and oxygen production (36%, 18%, 24% respectively). This can be explained for consume of fossil fuels and others fossil sources in theses stages. The same occurs in Tab. 6, but the contributions are respectively: 14%, 7%, 9%.

The global warming in Tab 4 is influenced mainly by cogeneration process; the electricity produced contributes 30% and the steam production with 54%. This is related to bagasse combustion in boilers that emits considerable dioxide carbon rates. Moreover, in Tab. 6, the global warming is also influenced mainly by boilers (71%), but in this case the boilers operate with fossil fuels, resulting considerable greenhouse gases and others emissions.

The ozone layer depletion in Table 4 is influenced by sugarcane production (44%), bagasse production (22%) and steam production (18%), but the CFC-11 eq (chlorofluorocarbons) emissions are very small. Also, this happens for human toxicity. The contributions are 40% (sugarcane production), 20% (bagasse production) and 17% (steam production), with small emissions of 1,4-DB eq (dichlorobenzene).

While fossil system, in Tab. 5 the ozone layer depletion is more influenced by sugarcane production (58%) and bagasse production (28%), but is little expressive the CFC-11 eq emissions. For human toxicity is also influenced for these two stages, sugarcane production (50%) and bagasse production (24%), with small emissions of 1,4 –DB eq.

The ecotoxicity impacts presented in Tab. 4 and Tab. 5, the results are expressive for marine aquatic ecotoxity, because the 1,4-DB eq emissions are bigger than other system (fresh water aquatic and terrestrial system). In cogeneration system the marine aquatic ecotoxicity has more contribution of oxygen production system (52%), because this process presents high aquatic emission of toxic elements (Mercury, Lead, and others). The same can be observed in fossil system (Tab. 5), but in this case the oxygen production has 55% of contribution.

In Table 4, the photochemical oxidation is influenced by sugarcane production (37%), bagasse production (18%) and oxygen production (15%), it is related to hydrocarbons emission by the process. Also, for acidification impact, the sugarcane production (41%), bagasse production (20%) and steam production (20%) are major contributor for acidification. This is explained by SO_2 and NO_x emissions during fossil fuel consume.

In Table 5, the photochemical oxidation is more influenced by boilers operating with fossil fuels (65%), and sugarcane production (16%), this impact is related to hydrocarbons emission by the process. The same for acidification impact, the boiler contributes 42%, and sugarcane production contributes 32%.

The eutrophication impact is related to macronutrients in environmental, so the sugarcane production, responsible by consume of many nutrients (Nitrogen, P_2O_5, K_2O), consequently it affects significantly the eutrophication impact in both cases (fossil and cogeneration systems). For fossil system it contributes 65% (Tab. 5), and cogeneration system contributes 45% (Tab. 4).

Another observation of the results, it is the low impact caused by gasification and methanol system of two case studies. The main reason is the low emissions of pollutants deriving from these technologies.

For energy analysis, in this work was computed the life cycle energy efficiency. This indicator is the energy ratio of fuel produced by primary energy used during its production. Another ratio computed was fossil energy ratio (fuel energy / fossil energy). This ratio refers the fossil energy demand for producing methanol. Both indicators refer to 1 kg methanol production. The results are presented in table 6.

Table 6. Energy ratio for methanol production system.

	Fossil system	
	Ratio	**Value**
Life cycle efficiency	21 MJ / 59,70 MJ	0,35
Fossil energy ratio	21 MJ / 12,26 MJ	1,66
	Cogeneration system	
Life cycle efficiency	21 MJ / 102,86 MJ	0,20
Fossil energy ratio	21 MJ / 2,23 MJ	9,4

In Table 6, it is observed the low value of life cycle efficiency of cogeneration system (0,20). The main cause is the high demand of primary energy (biomass energy) of methanol chain production (102,86). While the fossil system, the demand of primary energy is smaller (59,70), because the biomass energy is necessary only to produce methanol, the thermal and electric energy is supplied by fossil energy.

For fossil energy relation, there is expressive difference in two results. The demand of energy fossil of fossil system is approximately 6 times bigger than cogeneration system, so it proves that this system is more sustainable.

5. CONCLUSIONS

In this work was presented an evaluation of life cycle energy balance and environmental impacts of production of methanol from biomass. The biomass selected was sugarcane bagasse and the tool for evaluation environmental was Life Cycle Assessment.

Two case studies was analyzed, the first the demand of electrical and thermal energy of methanol production was supplied by a distillery plant that has a bagasse cogeneration system. The second case study the thermal energy of methanol production was supplied by boilers operating with fossil fuel and the electrical energy by local power network.

The main conclusions of these analyzes were:

- The implementation of cogeneration system in production chains for biofuels increases the sustainable of the same. Because it is reduced the fossil energy demand of fuel production, so the environmental impacts decrease.
- The use of renewable energy (sugarcane) is more expressive in cogeneration system, so this methanol production route is more viable when it is whished high global energy efficiency and low environmental impacts.
- The integration of methanol plant (methanol from bagasse) to ethanol distillery appears as alternative for diversifying the biofuel production in Brazil.

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