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LIFE CYCLE ANALYSIS APPLIED TO THE UTILIZATION OF BIOMASS AND DIESEL FUELS FOR ELECTRICITY GENERATION

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Abstract: *The methodology of Life Cycle Analysis (LCA) is herein applied to the aspects of electricity production, comparing negative and positive environmental impacts of the use of different fuels in a generator group. The first analyzed fuel was diesel, which is fed to an internal combustion engine attached to a synchronous generator. The second fuel used was biomass (woody residues), which was gasified into poor syngas, also feeding the same combustion engine. In this case, the engine was converted (ottolization), and connected to a generator for the production of electricity. This information was introduced and processed by Simapro, a highly specialized software for LCA. The functional until considered was the production of 100 kWh of electricity. With positive results for environmental impacts, woody biomass helped produce energy in a more sustainable way (-285kg CO_2–eq), minimizing greenhouse gas effects. The diesel fuel presented unsatisfactory results, emitting much more greenhouse gases (335kg CO2–eq) into the atmosphere and therefore contributing to climate change in a much more unsustainable manner.*

Keywords: *LCA, Diesel, biomass, electricity, environment impacts.*

1. INTRODUCTION

Nowadays, the analysis of the world energy scenario still indicates an elevated dependence on fossil fuels. According to the International Energy Agency (IEA, 2011), in 2009 the fossil fuels (*e.g.*, mineral coal, petroleum and natural gas) represented 80,9% of the world's primary energy offer (mineral coal 27,2%, natural gas 20,9% and petroleum 32,8%).

The fossil fuels are non-renewable energy resources, and therefore, are not replenished. Also, the intensive use of fossil fuels is associated with various environmental impacts, such as air pollution in great urban centers, responsible for hundreds of thousands deaths by cancer and respiratory and cardiovascular problems, and climate change, which currently represents the main threat to the existence of human species on Earth (GOLDEMBERG; LUCON, 2007).

According to (BOTELHO, 2012), the Brazilian diesel oil is still a very pollutant fuel and of bad quality when compared to international parameters. This is due to the elevated sulfur content in its composition. The environmental impacts of the emissions are mainly related to the sulfur and polycyclic aromatic hydrocarbons present in the fuel. Incomplete burning also emits pollutants such as particulate material, carbon monoxide, and non-burned fractions of hydrocarbons **-** therefore combustibility also influences directly the emission of pollutants (PARENTE, 2003).

The limitation of natural resources of petroleum, as well as the undoubtedly proven effects of global warming, raise the necessity of alternative energy generation, which is more environmentally-friendly (FIGUEIREDO, 2012). In international and Brazilian markets, biomass has been considered as one of the main alternatives for the diversification of the energy matrix and consequent reduction in the use of fossil fuels (CENBIO, 2011).

In 2009, Goldemberg (2009) mentioned that the most important use for local biomass was its combined use with modern combustion technologies as a substitute to diesel oil. The use of biomass for the production of syngas, through gasification, is also a way to utilize this resource. Gasification is a thermal conversion process in which a gas fuel generically called synthesis gas (syngas) is produced from biomass. According to Sales, Andrade and Lora (2006), the biomass gas generated in gasifiers can be used for many purposes: in boilers for the generation of steam, in dryers for the drying of ceramic parts, in internal (Diesel and Otto) and external (Stirling) combustion engines, gas turbines, and in fuel cells.

The substitution of diesel in generator groups fuel by syngas reveals itself as economically viable, as biomass is reused and there are no excessive entailed costs. With Life Cycle Analysis (LCA) it iss possible to show which option produces less environmental impact. LCA can calculate and present the environmental impacts generated by the production of electricity with both fuels, as well as identify which stage of the process most contributed to impact generation.

The goal of this work is to quantify the environmental impacts generated by electricity production using diesel and syngas from gasification, in generator groups. In this way, it can be verified whether the use of diesel is advantageous.

2. MATERIALS AND METHODS

2.1 Life Cycle Analysis

LCA studies began in the 60's (with the Coca-Cola LCA), and after the oil crisis, society started to question itself about the limits of natural resource extraction, especially fossil fuels and mineral resources (Zaporalli, 2011). According to Zaporalii (2011), the first studies aimed at calculating the energy consumption and therefore were referred to as "energy analysis". However, LCA returned in the 80's due to growing interest in the environment. From 1990 onwards, LCA studies have been progressively expanding and received a boost due to the normalization of the series ISO 14040 (Zaporalli, 2011).

In Brazil, the first LCA studies began in the 2000's and since then, many initiatives have emerged, consolidating this important tool for environmental management. The following initiatives deserve to be highlighted: the Brazilian Project of Life Cycle Inventory (LCI), developed by Inmetro, Brazilian Institute of Science and Technology Information (BISTI), University of Brasilia (UnB), University of Sao Paulo (USP) and Technological Federal University of Paraná (TFUPR); the Brazilian Program of Life Cycle Analysis established by the Meteorology, Normalization and Industrial Quality National Council (Conmetro); and the Regional Center (Latin America) Project of Life Cycle, which seeks to facilitate the exchange of LCA information and incentivize the development of regional LCI's (Zaporalli, 2011).

LCA is a method for the evaluation of material and energy flows, quantifying the consequential environmental impacts of a system throughout its life cycle. The term "life cycle" refers to the activities in the course of the product's lifetime, including manufacture, utilization, maintenance, and final waste scenario, including the acquisition of raw materials necessary for manufacture (Vicente, 2004).

In a LCA study of a product or service, all the extractions of resources and emissions to the environment are determined, when possible, in a quantitative way along all life cycle, since it "borns" until it "dies", being based in these data that the impacts in the natural resources, in the environment and in the human health are evaluated (GUINÉE, 2001; GUINÉE, 2002).

The LCA process is a systematic approach constituted by four components: goals and scope definition; inventory analysis; impact analysis; and results interpretation (GUINÉE, 2001; GUINÉE, 2002; ISO 14040; ISO 14044):

- **Goal and scope definition** – defines and describes the product, process or activity. Establishes the context in which the evaluation must be carried out and identifies the limits and environmental effects to be reviewed during evaluation.
- **Inventory analysis** – identifies and quantifies the energy, water and materials used, as well as the environmental discharges. (e.g.: emissions to the air, deposition of solid residues, discharge of liquid effluents).
- **Impact analysis** – analyzes the ecologic and human effects of the utilization of energy, water, and materials plus the environmental discharges identified in the inventory analysis.
- **Interpretatio**n – evaluates the results of the inventory and impact analyses for selection of the best product, process or service with a clear understanding of the uncertainties and assumptions utilized to generate the results.

2.1.1 Analysis tools

Many software and databases have been developed to support the conduction of LCA studies, e.g., software: SimaPro (PRÉCONSULTANTS, 2015), Umberto (IFU, 2015), and GaBi (GABI, 2015), and databases such as EcoInvent (2015) and Agri-footprint (2015). The software utilized herein as SimaPro® 8.0.3, developed by Pré *Consultants* (2015). It is a flexible tool that allows for the environmental analysis and monitoring of products, services and processes within the perspective of life cycle. SimaPro®was developed for LCA studies, following the recommendations of ISO 14040 e 14044 (ISO 14040; ISO 14044).

The information in SimaPro® is organized in projects, which can include several life cycles of one or many products whose processes can be extracted from SimaPro® databases (PRÉCONSULTANTS, 2015). Once the life cycle is defined, SimaPro® calculates the sum of environmental interventions associated with the functional unit defined in the modeling (ZAPORALLI, 2011).

2.1.2 Method for environmental impact calculation

Due to current concerns with climate change, the selected method for environmental impact evaluation was IPCC GWP 100a (IPCC, 2013), which expresses the environmental impact in kg CO_2-equivalent (kg CO_2-eq). The Global Warming Potential (GWP), established by the Intergovernmental Panel on Climate Change (IPCC, 2013), for a specific substance is the relationship between the contribution to radiation warmth absorption, resulting from the instant discharge of 1 kg of a greenhouse effect gas (GHG) and an equal emission of carbon dioxide (CO_2).

$$GWP_i = \frac{\int_0^T a_i c_i(t)\,dt}{\int_0^T a_{CO2} c_{CO2}(t)\,dt} \tag{1}$$

Where GWP_i represents the global warming potential of substance i expressed in CO_2-eq, T represents the time horizon (which can be 20, 100, 500 years), a_i is effect of a substance mass unit (i), c(t) is the concentration of substance (i) throughout time (t), and a_{CO2} and c_{CO2}, are corresponding parameters for the reference substance (CO_2).

Long horizons of time (100 and 500 years) are used for cumulative effects, while short time horizons (20 years) translate an indication of the short time effects of the emissions (IPCC, 2013). global warming is defined by the expression:

$$Global\ Warming = GWP_i . m_i \tag{2}$$

Where m_i is the mass (kg) of the emitted substance. The result of the effect is expressed in kg CO_2-eq (VICENTE, 2004; IPCC, 2013).

2.2 Case study

The generator group studied is located at the federal University of Paraíba (Northeast Brazil), Innovation laboratory. The generator group is constituted by one internal combustion engine MWM (reference 229, 4 cylinders), one generator Bambozzi 36 kVA and one resistor bank, which simulates the system load (Figure 1).

Figure 1 – Generator group

The structural changes in the engine for fuel substitution are minimal and can be disregarded in the LCA. In this analysis, a functional unit of 100 kWh of electricity was considered, using diesel and syngas in maximum and minimum powers. An average transportation distance of 10 km was considered for the diesel and biomass fuels from point-of-sale to the laboratory.

Average diesel consumption was 9 L/h, according to information by the manufacturer. Considering the engine operation in low and in high power, consumptions of 107 and 34.6 liters of diesel were obtained, respectively, for the production of 100 kWh of electricity. According to the Brazilian Reference Center in Bioefuels (CERBIO, 2004), the specific mass of diesel is 0.85 kg/L, and its calorific power is 41.29 MJ/kg. Table 1 shows data associated with diesel consumption in the engine. For biomass, operational data are depicted Table 2 (calorific power of the selected biomass: 3600 kJ/m³). Simapro® counts with a great variety of databases, which enabled the execution of a LCA in a complete and realistic way. The selected processes were from the Ecoinvent (Ecoinvent, 2015) database.

Table 1 – Diesel consumption data.

Generation model	Diesel consumption (MJ)	Diesel consumption (L/100 kWh)	Diesel consumption (kg/100 kWh)
Low power generation	3756	107	90,95
High power generation	1215	34,6	29,40

Table 2 – Table of data of the biomass consumption.

Generation model	Power (kW)	Time (min)	Biomass consumption (kg/kWh)	Gas consumption (m³/kWh)
Low power generation	8,4	12,23	2,100	7,21
High power generation	26,0	10,87	1,024	3,67

According to these data, the processes were implemented in Simapro® for analysis and comparison of fuels for the production of electricity. For the analysis of biomass in low power operation, an amount of 3756 MJ of diesel was no longer consumed and was considered an "avoided product". For biomass utilized in high power operation, 1215 MJ of diesel was also considered an "avoided product". This consideration is justified by the fact that when syngas is utilized, diesel is no longer used.

2.3 Results and discussion

Table 3 presents information on the electricity production using diesel as fuel. The table demonstrates numerically the negative environmental impact resulting from the high emissions of CO_2 to the environment.

Table 3 – Environmental impacts associated with the production of 100 kWh of electricity with diesel.

Generation model	Process	Quantity	Emissions of CO_2-eq	TOTAL kg CO_2-eq
Low power generation	Diesel	$3{,}76^{3}$ MJ	334	335
	Transportation of fuel	0,91 tkm	0,459	
Low power generation	Diesel	$1{,}22^{3}$ MJ	108	108
	Transportation of fuel	0,29 tkm	0,146	

The main contributor for the final emissions is the use of diesel itself, as its a fossil fuel. Transportation of the fuel to the generation site is expressed in tonne*kilometers: tkm. Table 4 shows data for the electricity production process, using biomass as fuel.

Table 4 – Environmental impacts associated with the production of 100 kWh of electricity with biomass.

Generation model	Process	Quantity	Emissions de CO_2-eq	TOTAL kg CO_2-eq
Low power generation	Emissions avoided: Diesel	$3{,}76^{3}$ MJ	- 334	- 285
	Transportation of the fuel	2,1 tkm	1,05	
	Synthesis gas	721 m³	48,1	
High power generation	Emissions avoided: Diesel	$1{,}22^{3}$ MJ	- 108	- 83
	Transportation of the fuel	1,2 tkm	0,602	
	Synthesis gas	367 m³	24,5	

It is observed that there is a positive environmental impact with the use of biomass for the generation of electricity. This originates from the avoided emissions of diesel, which is a fossil fuel, and generates high emissions of CO_2 during burning. When diesel is substituted by biomass-originated syngas, the emissions of CO_2 are dramatically reduced, avoiding the emission of -334 kg of CO_2-eq in low power generation and -108 kg of CO_2-eq in high power generation.

Simapro has the option of visualizing a process network, where the components are showed and it is possible to observe graphically which are the greates contributors to the environmental impacts. Figure 2 shows the environmental impacts associated with the production of 100 kWh of electricity, in low power, with diesel (left) and biomass (right).

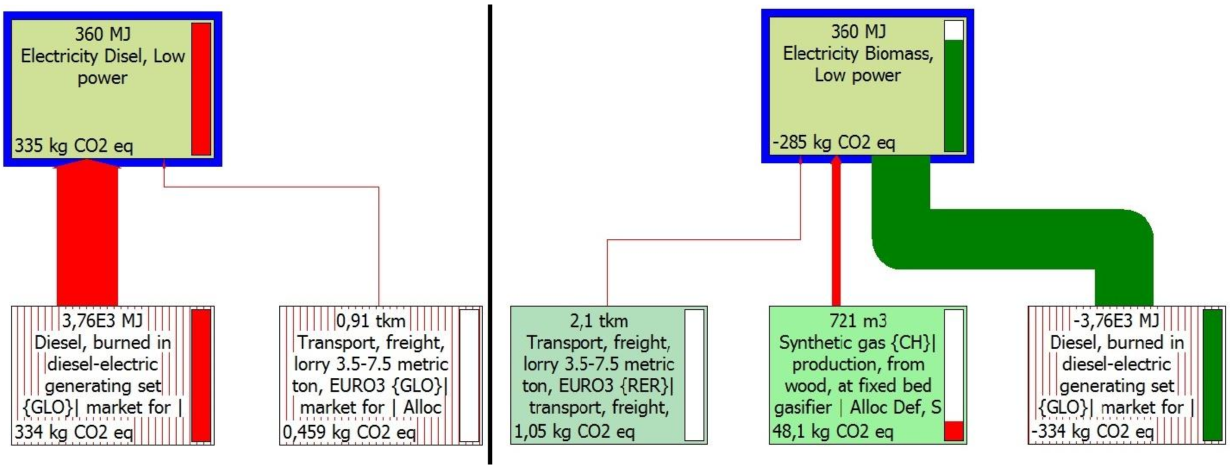

Figure 2 – Sankey diagram of the production of 100 kWh of electricity, at low potency using diesel (left) and biomass (right).

The thickness of the ribbons that connect the processes is proportional to its environmental impact. In the case of biomass, the avoided emissions appear as contributions in green.

Simapro also allows for the comparison of processes. Figure 3 evidences the high emissions of CO_2-eq from the use of diesel, even at high power. The use of biomass waste for the production of syngas is an environmentally viable alternative for the generation of electricity.

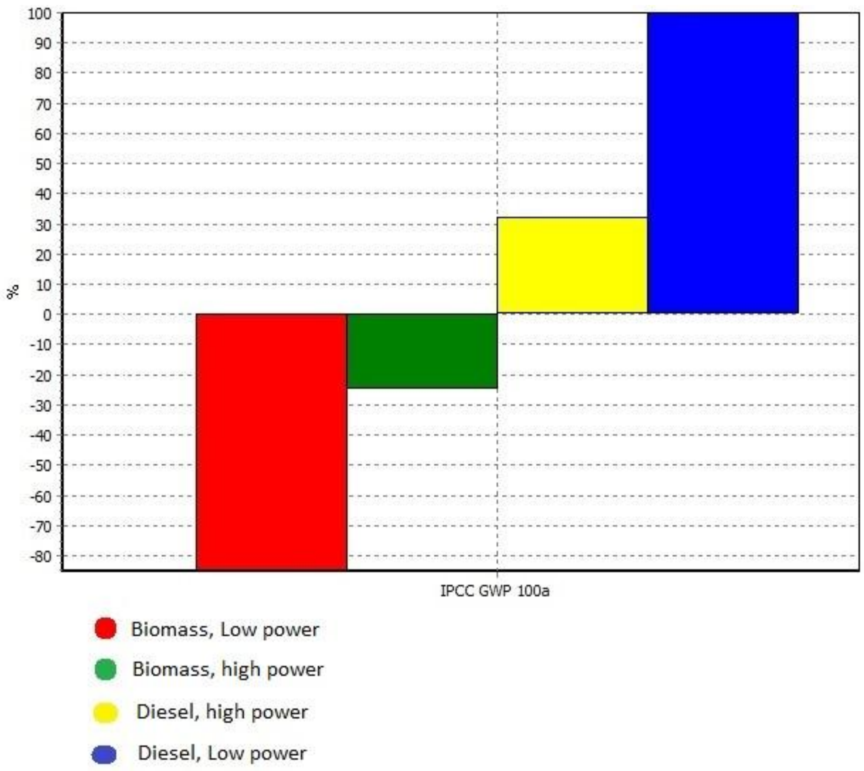

Figure 3 – Environmental Impacts according to the utilized fuel.

Other studies on the gasification of biomass also presented good results: Figueiredo (2012), where the generator group presented good performance using syngas, without distortions in the quality of the generated energy. The work of Udaeta et al. (2004) showed a comparison between diesel and biodiesel, concluding that diesel is favorable from technical-economic and political analyses, and biodiesel presented environmental and social benefits.

The use of biomass proved to be an alternative fuel with attractive characteristics for its use, avoiding emissions of up to 334 kg CO_2-eq due to the substitution of diesel, as shown herein.

3. CONCLUSIONS

There is an increasing search for the substitution of fossil fuels by alternative fuels, due to the issue of depletion of fossil fuels along with the incremental energy required for its extraction (the deeper you mine, the more expensive it is). Biomass can substitute, with moderation, natural gas or diesel in generator groups. With a calorific power obviously lower, a greater amount of biomass is required for the generation of the same amount of energy. Biomass presents currently a low market value, but depending of the volume needed, requires correct storage.

Life Cycle Analysis was an extremely useful tool, allowing for the quantification and identification of environmental impacts. The impacts were expressed in terms of CO_2emissions. The comparative analysis presented herein verified the real possibilities of mitigation of climate change. It is highlighted that LCA enabled the selection of mitigation of climate change as study variable, although effects on human health could also have been selected and could have provided different results.

This work quantified the environmental impacts associated with the utilization of diesel and biomass (syngas) in a generator group, producing 100 kWh: 335 and -285 kg CO_2-eq were emitted for high power operation and 108 and -83 kg CO_2-eq for low power operation, respectively, for diesel and biomass syngas.

The utilization of biomass as an energy resource can help contribute to the mitigation of climate change, and can be used in Brazil to help fulfill its voluntary actions of reducing greenhouse gas emissions.

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