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Environmental assessment of a bi-fuel thermal power plant in an isolated power system in the Brazilian Amazon region

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A B S T R A C T

This study presents an environmental assessment of a bi-fuel Thermal Power Plant (TPP) in the Brazilian Amazon Region. The TPP was originally designed to use Heavy Fuel Oil (HFO), but with the Natural Gas (NG) extraction in the Amazon basin, the TPP was modified to use NG and HFO concomitantly. In order to observe the differences, a comparative study of this power plant was performed in two situations: using only heavy fuel oil and using HFO and NG concomitantly. The life cycle assessment methodology was conducted from "cradle-to-gate". The CML baseline method was used to assess the midpoint impacts. Primary data were collected by personal visits for environmental emissions, wastewater, fuel used, and technical specifications. Eleven impact categories were considered and Monte Carlo (MC) Analysis was used to assess and to obtain robust results. The study shows that upstream processes have more impacts except global warming potential, eutrophication, acidification, human toxicity and photochemical oxidation where TPP showed the main contribution. The bi-fuel conversion resulted in lower power plant participations in the impacts as, for example, a reduction of 61.1% in Eutrophication Potential. In addition, throughout the life cycle the bi-fuel power plant, when the operation is compared with HFO only, has six potential impacts lower. Furthermore, this study showed that bi-fuel operation has lower local and regional impact, and according to the MC analysis, statistically, bi-fuel operation does not contribute to exacerbate global trends in GHG emissions when compared with monofuel operation. It is an interesting observation that global warming results by MC analysis showed that there are no statistical differences between the two modes of operation.

1. Introduction

Energy is an essential service for humankind because it provides mobility, heat, light and it is the fuel that drives the global economy (UN, 2017). Our consumption of food, water and energy (directly or indirectly) impacts on ecosystems and natural resources that society depends on for survival (Hanlon et al., 2013). In agriculture, water is required for irrigation which in turn requires a lot of energy. A recent study that estimated the area equipped for irrigation in 2035 and 2060, showed that the requirement of water for irrigation has increased in the Americas (Valipour, 2016), putting greater pressure on energy production. The increase in the area equipped for irrigation will possibly affect the state of Amazonas where agriculture only contributes 4% to the state's Gross Domestic Product (GDP) (GEEA, 2011), showing a huge field for progress in the agriculture. This trend will also affect industries due to major pressure to produce and, consequently, more energy will be required.

In the field of energy, Brazil is considered one of the countries with the cleanest grid power in the world with about 71% of its energy from renewable sources, mainly hydroelectric plants (63%) (IEA, 2017). On the other hand, 27% of the energy consumed in Brazil is produced by Thermoelectric Power Plants (TPPs), although, in Amazonas State, energy from TPPs represents 87% of the energy generation (EPE, 2016). This difference is due to the geographic characteristics of the region, composed of dense and heterogeneous forest, as well as large and extensive rivers, which hamper the

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construction of very long transmission lines that allowed the connection to the National Interconnected System (NIS), which is the electric power generation and transmission system with a size and characteristics that allow it to be considered unique worldwide (ANEEL, 2008). The TPPs mostly use fossil fuels such as Diesel and HFO. Currently, the use of natural gas from Urucu in the Amazon basin has been incorporated into the system.

Energy production in the Amazon is crucial for the development of the region, because on the contrary of what happens in others regions of Brazil, in the Amazon the electrical system is still isolated (ANEEL, 2013). Therefore, the energy produced there is used by local consumers. In the Amazon, the major consumer is the Manaus Free Trade Zone (MFTZ), that was conceived as a free import and export trade area with special tax incentives (Almeida, 2011). According to the Manaus Free Trade Zone Superintendency (SUFRAMA, in Portuguese), the Manaus industrial center has approximately 600 high-tech industries, which generate more than half a million jobs (SUFRAMA, 2016). The MFTZ is characterized by being a large external importer and a large domestic exporter, as can be seen in Table 1.

The existence of this area caused the Manaus region to become highly dependent on the industries installed there. In 2001, for example, the share of MFTZ's industrial activity represented 2/3 of the Amazonas state's GDP (Filho, 2005). In this sense, a great part of the products placed on the national market is produced in the Amazon region, since more than 90% of the MFTZ's products are directed to the national market. The products with the highest revenues in 2015 were: telephones, radios, bicycles, toys, cell phones, televisions, air conditioning, motorcycles, among others (SUFRAMA, 2015). Therefore, the industries installed in the MFTZ are directly dependent on thermoelectric plants. These TPPs operate primarily using fossil fuels such as Heavy Fuel Oil (HFO), which is a source of emission of Sulfur Oxides (SOx, SO_2), Nitrogen Oxides (NO_x, NO and NO_2), Monoxide and Carbon Dioxide (CO and CO_2 respectively), in addition to other gases (Mansor, 2014), which contribute to impacts such as terrestrial and aquatic acidification and global warming (Agrawal et al., 2014; Phumpradab et al., 2009). There are other impacts related to TPP. For example, in the United States (USA) the largest water withdrawal is for TPP (Chandel et al., 2011). Thus, the contribution of natural gas to electric generation is of interest not only to reduce the impacts of energy production, but for all industries that use the energy provided by the TPP of the region.

In this context, given the growing energy demand and the current consensus about the need for an ecologically balanced environment, it is necessary to reflect on the generation of energy from non-renewable sources and its consequent impacts. Thus, this study aims to perform an environmental assessment of the energy production in a bi-fuel power plant which uses reciprocating engines as main drivers.

It is the first study of its kind for the Brazilian Amazon region power sector to assess environmental impacts using the Life Cycle Assessment (LCA) approach for a bi-fuel thermal power plant and from primary data collected by personal visits. Besides, the results of the study may be used for future environmental studies that propose to assess products and services that use energy produced by an isolated power system in the Brazilian Amazon region. In addition, the comparative LCA will be evaluated by Monte Carlo Analysis, which can be considered the most effective quantification method for uncertainties among the environmental system analysis tools (Sonnemann et al., 2003), bringing more consistent results.

2. Methodology

LCA evaluates the environmental burdens of a production system by identifying resources and energy consumptions as well as emissions to different environmental compartments. Furthermore, LCA allows identifying priority areas where improvement actions will have the greatest effects on reducing the environmental impacts (ISO, 2006). In this study, the environmental profile was performed according to ISO 14040 specifications (ISO, 2006).

2.1. Goal and scope definition

The goal of this LCA study is to perform the environmental analysis of energy production in a power plant in Manaus. The installed power capacity is 85 MW (ANEEL, 2016). The TPP is equipped with five Wärtsilä 18V46-C2 motors as main drivers, whose waste heat is used to produce thermal energy in the form of steam for fuel heating. Corrosion inhibiting additives are used in the engine cooling water. In 2009, the Wärtsilä 18V46-C2 engines began to be converted to Wärtsilä 18V46-GD (Gas-Diesel) (Ojutkangas, 2011). With this conversion, it is possible to operate the system with Heavy Fuel Oil (HFO) and Natural Gas (NG) in different proportions (WÄRTSILÄ, 2014). According to the manufacturer, the GD engine uses the diesel cycle in all operation modes. In the gas mode, natural gas is injected at high pressure together with air in the combustion chamber. The ignition temperature of HFO is around 260 °C while natural gas is around 550 °C, in this way, initially there is combustion of HFO which provides the energy required for the ignition of the natural gas and air mixture in the cylinder (COGEN, 2011). In bi-fuel mode, the ratio between liquid and gaseous fuel can be controlled and varied during operation (WÄRTSILÄ, 2014).

Therefore, in this study, a comparison was made between two types of operations, which are: monofuel (using only HFO) and bi-fuel (use of HFO and NG). Besides that, the Life Cycle Impact Assessment (LCIA) was shown for the bi-fuel operation, because it is the current operation.

Table 1
Trade Balance of Manaus Free Trade Zone.

Year	Foreign Market (Millions)			Domestic Market (Millions)			Final Balance
	Export	Import	Balance (A)	Export	Import	Balance (B)	(A)+(B)
2010	1.04	10.20	−9.14	34.10	7.22	26.80	17.70
2011	0.84	11.20	−10.40	40.30	9.05	31.20	20.80
2012	0.87	11.10	−10.30	36.70	7.28	29.40	19.10
2013	0.86	12.40	−11.50	37.70	7.24	30.40	18.90
2014	0.72	11.60	−10.90	36.40	6.79	29.60	18.80
2015*	0.36	5.48	−5.12	14.30	2.93	11.40	6.27

Note: *2015 year, partial data until July.
Values in US$ 1000 (Millions).
Source: (SUFRAMA, 2015)