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A method to measure the eco-efficiency of diesel locomotive

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ABSTRACT

Brazilian railroads transport over 490 million tons a year using diesel-electric locomotives. These locomotives emit several pollutants into the atmosphere and because of that, the railroads seek to reduce emissions and achieve global emission standards. Thus, it is important to analyze the environmental impact of the use of diesel and alternative fuels to reach environmental standards. This paper makes use of a method based upon the World Business Council for Sustainable Development (WBCSD) metrics to evaluate the locomotives' eco-efficiency. The method was applied to Estrada de Ferro Vitória a Minas (EFVM). Different scenarios representing the exchange of fuel sources and technologies were developed, tested and analyzed. The impacts were evaluated by seven eco-efficiency performance indicators and compared with United States Environmental Protection Agency (EPA) standards. The results offered cost savings and emissions reduction opportunities.

1. Introduction

Brazilian railroads transported over 490 million tons in 2013 and in 2016 it is forecasted that they will transport over 550 million tons (ANTF, 2014). Transporting such high volumes using diesel-electric locomotives means railroads will emit thousands of tons of pollutants into the atmosphere every year. Transporting the same volume by trucks through roads would be catastrophic, taking into consideration the already poor state that federal roads find their selves in and the high traffic they support, causing even more degradation. When it comes to emissions, it is known that moving freight by rail instead of truck reduces greenhouse gas emissions by 75 percent (AAR, 2015).

This paper presents a method to quantify the environmental impact caused by the use of locomotives, comparing petroleum diesel and also greener fuel alternatives. The method evaluates atmospheric emissions, energy efficiency and the costs concerning the different fuels. Petroleum diesel, biodiesel from soybean and liquefied natural gas (LNG) were compared in this paper. The eco-efficiency of the actual operation using petroleum diesel, was compared with the operation using alternative fuels.

The method is an approach to evaluate the cost/benefit to improve the economic and environmental aspects of the business. It is an evolution over the traditional energy-efficiency programs used by companies focused strictly on reducing fuel

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consumption and can be used by railroads in all countries, with all types of locomotives and fuels – including railroads with electric locomotives.

The method was applied to Vitoria a Minas Railroad (EFVM). EFVM transports 50% of the Brazilian railroads freight volume, has 905 km of length and a fleet of 265 locomotives and over 18,000 wagons, and transports over 100 million tons of iron ore and 20 million tons of general cargo (soy, corn, fertilizers, coal, steel etc.) every year.

This paper is structured as follows: Section 2 describes the concept of eco-efficiency. Section 3 presents a literature review. Section 4 presents the method to measure locomotives' eco-efficiency. Section 5 describes the characteristics of the operation of EFVM. Section 6 describes how the data were obtained, including the characteristics of the fuels, its consumption and emission rates. It also presents scenarios to be evaluated. Section 7 presents results and analysis of the results achieved. Finally, Section 8 presents the conclusions.

2. Eco-efficiency concept

The World Business Council for Sustainable Development (WBCSD) defines eco-efficiency as the skill in measuring the evolution of an economic activity in an environmentally sustainable manner to meet human needs and upgrade the quality of life, reducing environmental impacts and the consumption rates of natural resources, limited by the environmental capacities of the planet keeping the competitiveness of the companies. There are seven goals related to eco-efficiency, some of them are: (1) reduce the material intensity; (2) reduce the energy intensity; (3) reduce the dispersion of toxic substances; (4) enhance capacity of recycling material; (5) maximize the use of renewable resources; (6) extend the product life cycles; and (7) increased service intensity (WBCSD, 2000).

WBCSD proposes a framework containing three levels of organization for eco-efficiency information: categories, aspects and indicators. The categories are broad areas of environmental influence or business value. Each one has several aspects, which are general types of information related to a specific category. The aspects describe what should be measured. The indicators are the specific measurements of an individual aspect that can be used to demonstrate the eco-efficiency (WBCSD, 2000; D'Agosto and Ribeiro, 2004).

The Eco-Efficiency Measurement (*EM*) indicators are performance measurements obtained through the ratio of product/service value (*V*) by the environmental influence caused by the generation or use of the product/service (*EI*) (Eq. (1)) (WBCSD, 2000).

$$EM = V/EI \tag{1}$$

3. Literature review

A chronological report is made in this section considering some of the main papers about alternative fuels, locomotives and railroad emissions, and environmental impacts of this mode of transportation.

Plakhotnik et al. (2005) presented an analysis of the ecological situation at railway transportation of Ukraine with a specific focus on the Prydniprovs'ka regional railways. Large-scale pollutant was found and a comparison of the environmental impact of the different railway subdivisions was presented. Also, a computer simulator was developed to allow comparative data analysis. The paper only considered stationary emission sources, such as wagon and locomotive depot. It did not consider emissions from actual operation of the rolling stock.

In 2006 Rail Safety and Standards Board (RSSB) and the Association of Train Operating Companies (ATOC) investigated the use of biodiesel on Britain's railways and published a report on August 2010. The effects on the engine's performance and exhaust emissions was tested using increasing biodiesel blending with diesel fuel, in steps from 5% of biodiesel to 100% of biodiesel. From the research project results, the Diesel Metering Group (DMG) concluded that B20 (a 20% blend of biodiesel mixed with 80% diesel) was sensibly the highest blend that could be accepted without significant expenditure to retune engines. The use of B20 did not appear to cause any significant engine wear, but the fuel consumption performance was worse.

Lapuerta et al. (2008) collected and analyzed papers published in scientific journals about diesel engine emissions when using biodiesel fuels as opposed to conventional diesel fuels. The first section is dedicated to the effect of biodiesel fuel on engine power, fuel consumption and thermal efficiency, while the second section focus on the comparison of engine emissions from biodiesel and diesel fuels, paying special attention to the most concerning emissions: nitric oxides and particulate matter, the latter not only in mass and composition but also in size distributions. In this case the highest consensus was found in the sharp reduction in particulate emissions.

Papagiannakis and Hountalas (2003), Papagiannakis et al. (2010a, 2010b) conducted an experimental investigation to examine the effects of the emissions of a high speed, compression ignition engine where liquid diesel fuel is partially substituted by natural gas in various proportions, with the natural gas fumigated into the intake air. The experimental results disclose the effect of these parameters on nitric oxide, carbon monoxide, unburned hydrocarbons and soot emissions, with the beneficial effect of the presence of natural gas being revealed. They conclude that dual fuel combustion using natural gas as a supplement for liquid diesel fuel is a promising technique for controlling both NOx and particulate matter (PM) emissions on existing diesel ignition diesel engines, requiring only slight modifications of the engine structure. The observed dis-