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Life cycle energy assessment of a standby diesel generator set

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A B S T R A C T

The global demand for emergency standby power (ESP) diesel generators continues to grow because of increasing population and urbanization in developing countries. In order to better understand and further reduce the environmental impact of these products, the life cycle assessment (LCA) methodology was applied to an 455 kW ESP diesel generator set to quantify the energy demands of each life cycle stage: materials, manufacturing, transportation, use, and end-of-life disposal. The life cycle inventory (LCI) was completed based on the information acquired from the manufacturing company and its suppliers, and the impact assessment, i.e., energy demand calculation was done using the data from the Ecoinvent and the Inventory of Carbon and Energy (ICE) databases. The results revealed that, similar to on-highway engines, diesel generators consumed most energy (>95% of the entire life cycle) during the use phase, followed by materials, transportation, and then manufacturing. Therefore, increasing fuel efficiency will have the largest energy and potentially environmental benefits. Printed circuit boards (PCBs), although of small mass, accounted for ~35% of energy demands during the materials stage. The materials-related energy demands can be considerably reduced by increasing remanufacturing and recycling rates. Results from this study are expected to help the genset manufacturers to optimize their product design, supply chain, and service so as to minimize the lifetime environmental impact of the product.

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1. Introduction

Increased environmental awareness among the public urges industries to proactively evaluate the impact of their operations on the environment. Industries are now moving beyond environmental compliance by incorporating sustainability in the list of company values, which sends a message to the public that their employees are taking actions to protect the environment and conduct business in a sustainable manner. These actions prompt environmental managers and decision makers to look at their products and services from cradle to grave. As a result, the need for Life Cycle Assessment (LCA) continues to grow. LCA is a method for evaluating the cumulative environmental impacts resulting from all stages in the product life cycle (Environmental Protection Agency, 2006). It started as a tool to evaluate individual products but has now developed into a standardized method for providing a scientific basis for environmental sustainability in various industries (Curran, 2013; Kouchaki-Penchah et al., 2016a, 2016b).

This study describes a life cycle assessment (LCA) performed on a standby diesel generator set in cooperation with a large diesel engine manufacturing company in the United States, which also produces power generation products. A standby diesel generator set, hereafter referred to as a genset, is a combination of a diesel engine with an alternator to convert chemical energy in diesel fuels to electricity (Fig. 1). Emergency standby power (ESP) gensets are used to supply power to electrical appliances during the power interruption of the utility source. ESP gensets are essential for applications that require an uninterrupted power supply. Today, nearly every industry needs an ESP genset, as economic loss can be far more expensive than the capital expenditure for the backup power equipment (RNCOS Market Research, 2014).

The genset market is driven by the rapidly expanding global population and urbanization of cities throughout the world (Diesel Service and Supply, 2016). The genset demand will continue to increase as industries such as oil and gas, electronics, semiconductors, textiles, food processing units, automotive, shopping malls, and data centers turn to diesel generators to deal with unexpected power outages (Sverdlik, 2013). This demand is especially

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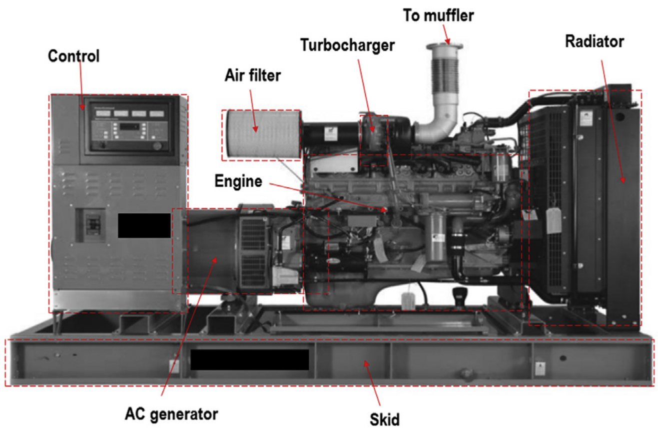

Fig. 1. A typical diesel generator set and its major components. Air filter, turbo charger, and connecting hoses were excluded for assessment due to limited data availability. Note the picture is for demonstration only and may not represent the actual unit investigated in this study.

prevalent in Asia-Pacific, where the data center industry is rapidly expanding, especially in Singapore, Malaysia, Philippines, Thailand, and Australia. Data centers require gensets with a capacity of up to 20 MW (MW) for ESP applications, and therefore, the demand for large diesel gensets with a power output capacity between 1 MW and 3 MW is on the rise (Frost and Sullivan, 2013). It was predicted that the market for 1–3 MW diesel gensets will grow from ~$590 million in 2012 to ~$800 million in 2017 (Sverdlik, 2013). Another study found that the Indian diesel generator market grew 9.5% between 2012 and 2013, and the market would grow at a compound average growth rate of around 11% in value terms during 2014–2018 (RNCOS Market Research, 2014). The global genset market will continue to be driven by the lack of grid infrastructure in remote locations and increasing industrialization in developing countries.

Despite the rapid growth in market demand, only a few LCA studies have been done on diesel gensets. Most of them entailed a comparison of different energy production devices including gensets. Gmünder et al. (2010) compared jatropha oil fueled gensets with diesel gensets, photovoltaic panels, and power grids with respect to greenhouse gases (GHGs) emission and other environmental impacts such as acidification and eutrophication, and concluded that jatropha oil fueled gensets significantly reduced GHGs emission when compared to the other three systems. However, no information was provided regarding the consumption of energy and materials during the manufacturing, transportation, or disposal of the diesel genset. Fleck and Huot (2009) compared a small wind turbine with a diesel genset for residential off-grid use, and reported that although the wind turbine was slightly more expensive than the diesel genset over the entire life cycle, it delivered 93% reduction in GHGs emission. Numerous simplifications and assumptions were made during the assessment of the genset. For example, the material composition of the diesel genset was approximated to be 60% steel, 35% aluminum, and 5% copper. Obviously, this and similar simplifications may cause considerable uncertainties in the final LCA results. Pascale et al. (2011) compared a 3 kW community-scale hydroelectric system with a 7 kW diesel genset in rural Thailand, and found that the hydroelectric system offered better environmental and financial benefits than the genset. However, similar to the study by Gmünder et al. (2010), no information was provided regarding materials and energy consumption during the genset manufacturing or transportation.

LCA studies have also been done on diesel engine and alternator, the two major parts of a diesel genset. Li et al. (2013) investigated the energy consumption and environmental impacts of an on-road diesel engine over its entire life cycle, and reported that the use phase accounted for >99.0% of the total primary energy demand, 97.7% of the total GHGs emission, and 94.2% of the total acidification potential. Cooney et al. (2013) compared mass transit buses driven by diesel engines and electric motors, and concluded that the use phase was dominant in causing global warming, carcinogens and other environmental impacts for both diesel-powered and electric buses. Zhang et al. (2015) compared remanufactured diesel engines with newly built ones, and found that engine remanufacturing reduced the eutrophication potential by 79% and the GHGs emission by 67%. Schau et al. (2012) investigated the economic and environmental benefits from remanufacturing of alternators, and revealed that remanufactured products caused only 12% of the GHGs emission and costs when compared with new ones.

Although efforts have been made to assess the life cycle of diesel gensets and their key components, a detailed systematic investigation is still lacking, especially for large-capacity gensets. To manufacturers, an LCA will allow decision makers to better report, understand, and interpret the environmental impact of their product in a manner that promotes sustainable product and process choices in the future (Curran, 1996). In 2013, the company who manufactured the diesel genset in this study partnered with a master student from the Massachusetts Institute of Technology (MIT) to perform an LCA on a 15 L displacement engine used in the on-highway application (Bolin, 2013). The primary focus of that study was to understand the energy demands of the life cycle stages prior to the use phase because it was well recognized that the use phase was the most energy intensive for on-highway applications. This genset study not only includes the engine information, but extends the analysis to the full life cycle of the engine as a part of the genset.

2. Methodology

2.1. Goal and scope definition

The goal of this study is to perform an LCA on a standby genset in order to quantify the energy demand for each life cycle stage and identify which is the most energy intensive one. The life cycle stages of this analysis include materials, manufacturing, transportation, use, and end of life (EoL), making the study a "cradle-to-grave" analysis. This LCA has been streamlined in order to align the results of the assessment with the goal of the study. A combination of the streamlining techniques described by Keith Weitz at the United States Environmental Protection Agency (USEPA) conference on streamlining LCA was used to perform this streamlined LCA (Weitz and Sharma, 1998, Weitz et al., 1999).

2.1.1. Functional unit

The subject of this study is a standby diesel genset. This particular model is equipped with a heavy-duty 15 L engine with a 455 kW rating. As an emergency standby power supply, the primary function of the genset is to convert chemical energy in diesel fuels to mechanical energy (by a diesel engine) and then to electricity (by an AC alternator) during power grid disruptions. The functional unit of the genset is based on the amount of diesel fuels consumed, which is a function of fuel economy and operation time. Under normal conditions, the genset has a life expectancy of 20 years and an operation time of 50–100 h per year, according to the manufacturer.

2.1.2. Process description and system boundaries

To conduct the LCA, the generator was divided into five main

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