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Life cycle assessment of gasoline production and use in Chile

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HIGHLIGHTS

- A well-to-wheel LCA of gasoline production in Chile was carried out.
- Volume, economic and energy allocations were considered for sensitivity analysis.
- Refinery and car emissions were the main contributors to environmental impacts.

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ABSTRACT

Gasoline is the second most consumed fuel in Chile, accounting for 34% of the total fuel consumption in transportation related activities in 2012. Chilean refineries process more than 97% of the total gasoline commercialized in the national market. When it comes to evaluating the environmental profile of a Chilean process or product, the analysis should consider the characteristics of the Chilean scenario for fuel production and use. Therefore, the identification of the environmental impacts of gasoline production turns to be very relevant for the determination of the associated environmental impacts. For this purpose, Life Cycle Assessment has been selected as a useful methodology to assess the ecological burdens derived from fuel-based systems. In this case study, five subsystems were considered under a "well-to-wheel" analysis: crude oil extraction, gasoline importation, refinery, gasoline storage and distribution/use. The distance of 1 km driven by a middle size passenger car was chosen as functional unit. Moreover, volume, economic and energy-based allocations were also considered in a further sensitivity analysis. According to the results, the main *hotspots* were the refining activities as well as the tailpipe emissions from car use. When detailing by impact category, climate change was mainly affected by the combustion emissions derived from the gasoline use and refining activities. Refinery was also remarkable in toxicity related categories due to heavy metals emissions. In ozone layer and mineral depletion, transport activities played an important role. Refinery was also predominant in photochemical oxidation and water depletion. In terms of terrestrial acidification and marine eutrophication, the combustion emissions from gasoline use accounted for large contributions. This study provides real inventory data for the Chilean case study and the environmental results give insight into their influence of the assessment of products and processes in the country. Moreover, they could be compared with production and distribution schemes in other regions.

1. Introduction

Crude oil represents the leading fossil fuel in the world, accounting for 33% of global energy consumption. Its relevance is even more important in South America with more than 45% of the total energy consumed in 2012 (BP, 2013). This remarkable dependence on oil and its derivatives involves major environmental problems, mainly associated with the emission of greenhouse gases (GHG). Around 11 Gt CO_2 were emitted globally in 2010 according to the last report of the International Energy Agency (IEA, 2012), with road transport as the largest contributing source (~5 Gt CO_2).

Within South American countries, Chile occupies the fifth position in terms of GHG emissions (IEA, 2012) associated with fuel use in industrial, transport and energy sector (Fig. 1a). These emissions are expected to increase by 400% in 2030 (O'Ryan et al., 2010). Around 70% of the total energy consumption in the transport sector is associated with road transport (O'Ryan et al., 2010). Fig. 1b reports the distribution of fuel products consumed in the Chilean transport sector, being diesel the most consumed fuel followed by gasoline (BNE, 2013). Passenger cars mainly run on gasoline (96%) and produce 32%, 24% and 20% of total NO_x, NMVOC and CO emissions of the transport sector (OCDE and CEPAL, 2005). Beyond the tailpipe emissions related

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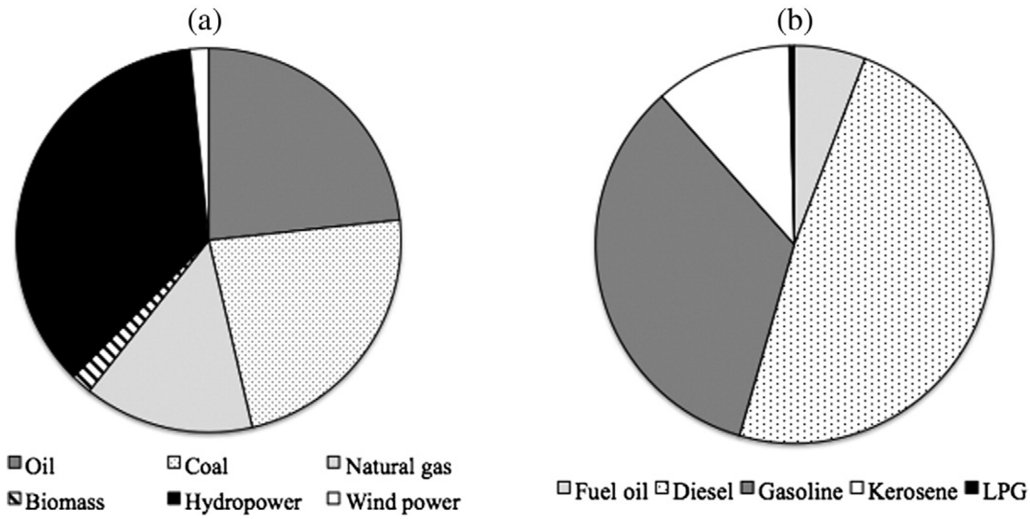

Fig. 1. (a) Chilean Energy Matrix (2012) (BNE, 2013); (b). Distribution of oil derivatives consumed in the Chilean transport sector (2012) (BNE, 2013).

with gasoline use, there are many other upstream processes (such as crude oil extraction, refining, transport, etc.) that need to be considered in the environmental profile of gasoline due to their associated environmental effects.

Regarding solid and liquid emissions, the extraction stage of crude oil typically requires the removal of sludge and water in settling tanks, both streams polluted with hydrocarbons and heavy metals (Capelli et al., 2001). Moreover, the refining process is a large consumer of water for cooling, steam production, washing and reaction processes as well as it produces solid wastes such as petroleum coke and sludge from different process units (ENAP, 2012b). Both the extraction of crude oil as well as its transport and refining involve leaks of crude oil that cause pollution of groundwater and land (Al-Majed et al., 2012). Gaseous emissions (either direct or indirect) such as hydrocarbons, CO, SO_x and NO_x, are one of the main contributors to the environmental impacts in the refining related activities. These emissions are produced in different steps such as the topping, flaring or storage of refining products.

In Chile, environmental management was institutionalized just over the last decade. Chilean governments have made remarkable progress in designing and implementing environmental policies and regulations for the industrial sector (CONAMA, 2010), which has positioned Chile as the Latin America leading country in terms of environmental protection. Moreover, Chile occupies the 29th position in the Environmental Performance Index (Esty et al., 2014).

The promotion of new standards in order to control and reduce pollutant emissions in Chile has forced oil companies to make significant efforts to implement and improve environmental technologies. Chilean refineries have paid attention to the identification and control of environmental risks in order to accomplish with the general rules and regulations applicable to their processes. The crude oil extraction, production and refining in Chile are based on international environmental standards such as ISO 14001 (ENAP, 2012b).

The quantification of the environmental profile associated with a process or product throughout its life cycle can be performed by means of the Life Cycle Assessment (LCA) methodology (ISO, 2006b). In agreement with numerous studies where the environmental profiles of fuel production and use have been quantified by LCA (Keesom et al., 2012; Restianti and Gheewala, 2012; Singh et al., 2010; Spatari et al., 2010), this methodology has been chosen to qualitatively evaluate the environmental loads of the gasoline production and use in Chile. Commonly, LCA studies for fuels have been performed from a well-to-wheel perspective (Borrion et al., 2012; Cherubini et al., 2009; González-García et al., 2010, 2012; Pont, 2007; Restianti and Gheewala, 2012), taking into account not only fuel production but also its final use. Concerning gasoline, its environmental profile has been quantified under the same perspective in Europe (Furuholt, 1995; Keesom et al., 2012; Querini et al., 2011), USA (Skone and Gerdes, 2009; Unnasch et al., 2009) and Indonesia (Restianti and Gheewala, 2012).

This study aims to perform an environmental analysis of the gasoline produced and used in Chile by means of the LCA methodology because no LCA study is available for gasoline in the Chilean or Latin-American context. In addition, the environmental *hotspots* (that is, the processes responsible of the largest contributions to the environmental profile) all over the life cycle will be identified in order to future improvement alternatives.

2. Methodology

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

The objective of this study was to perform the environmental analysis of the Chilean gasoline production and use in passenger cars, following the LCA methodology from a well-to-wheel perspective. The functional unit provides a reference to which the input and output process data are normalized. Generally, the results for transportation fuels are related with the distance traveled (Cherubini et al., 2009). The functional unit used in this study was 1 km driven by a middle size passenger car. An average consumption of 0.15 L gasoline per km was assumed (EPA/DOE, 2014).

2.1. System boundaries description

All the processes or activities carried out from the crude oil extraction and production up to the gasoline use in a passenger car were considered within the system boundaries. Production of the different consumable materials (chemicals, electricity, machinery, etc.) as well as infrastructure construction and maintenance were also included.

Fig. 2 shows an overview of the Chilean gasoline system under study. The system was divided into five subsystems, which will be described in detail below: crude oil extraction (Subsystem 1); gasoline importation (Subsystem 2); refinery (Subsystem 3); gasoline storage (Subsystem 4) and distribution and use (Subsystem 5).