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Carbon footprints of Liquefied Petroleum Gas transportation in the Indian Himalaya

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ABSTRACT

In developing countries such as India, supply of modern kitchen fuels such as Liquefied Petroleum Gas (LPG) involves a chain of carriers contributing directly or indirectly in emission of Greenhouse Gases (GHGs) mainly Carbon dioxide (CO_2). In view of the above, the present case study was carried out in the Himalayan region to estimate the carbon miles (CO_2 emitted per km of travel) of LPG transportations. The methodology included relevant variables in the LPG supply chain viz., the vehicular types and loads, fuel types and vehicular performance, distances travelled, and supply routes in the mountainous and the plain regions. These were collated by intensive monitoring, primary data collection, and using records obtained from line departments. In the analysis, it is estimated that on an average 60 g of carbon is emitted by transporting a cylinder of 14.2 kg per km of distance thus defining the carbon miles of LPG transportations. The vehicular types and distances travelled were the most determining factors influencing the carbon miles. It is recommended that considering LPG's ever increasing consumer growth, the cumulative and the multiplying effect, there is a need to review efforts in environmentally efficient transportations of such fuels especially in growing economies such as India.

1. Introduction

There is an excessive volume of human-generated Greenhouse Gases (GHGs) in the atmospheric system majorly the Carbon dioxide (CO_2) which accounts for an estimated 77% of GHGs (Rahman et al., 2017). Globally, several steps are being taken up for the mitigation of carbon emissions for an e.g., the mensuration of GHGs intensiveness of different products, bodies, and processes, is one such vital mitigation strategy (Wiedmann and Minx, 2007). Due to its large quantity present in the atmosphere and also because of its human induced nature, more focus on CO_2 emissions have been given and thus it is sometimes also referred to as carbon emissions as in carbon footprint (Seyfang, 2008). Since the year 2000, the increased CO_2 emissions are driven by enhanced economic growth and increased carbon intensity (Le Quéré et al., 2016). In all the Intergovernmental Panel on Climate Change (IPCC) scenarios of fossil fuel, an increase in CO_2 emissions over the next few decades with a large spread in emissions estimated up to the year 2100 is depicted (Myhre et al., 2009).

India that constitutes 17.31% of the world's population is still in dilemma and often following the developmental markers set and tested in different socio-techno-economical spheres of the developed countries. Modern kitchen fuels such as Liquefied Petroleum Gas (LPG) are considered a better environmentally suitable alternative of primitive cooking energy i.e., those obtained from biomass (fuelwood, crop residue, etc.). The current and future scenarios become more crucial since after the countries such as China and USA, India at present is the third largest consumer of LPG in the domestic sector. In the country, nearly 3 million LPG cylinders are being delivered, daily (MOPNG, 2017). The total consumption is ever growing with an annual increase of 8% due to coupling of rapid growth of population and rising paying capacity.

In one of the studies on GHG emissions, Johnson, E. 2009 on the basis of comparison of carbon emissions analysed that cooking with LPG rather than charcoal combats global warming and deforestation. The author studied the carbon footprint of LPG distribution and assessed it to be 42 kg CO_2e/t LPG. Singh et al., 2014 evaluated and compared environmental performances of 10 fuel sources used in Indian households using life cycle assessment methodology. In the study LPG was considered a preferred fuel for urban areas based on its lower environmental impact as compared to others. Ramachandra et al., 2017 analysed household activities

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and socioeconomic parameters in the LPG consumption by the domestic sector. However, in the study an important aspect of the fuel transportations was not widely considered within the assessed scope. There are very limited studies available in the literature covering the crucial aspect of carbon emissions in fuel transportations.

In view of the above issues, the present case study aimed to analyse the carbon footprints (direct CO_2 emission) in the supply chain of LPG transportation in the mountainous state of India and define the carbon miles (CO_2 emitted per km of travel) of LPG transportation. The study was carried out taking the case study of the Indian Himalayan region, where in the next coming decade it is envisaged that more and more consumers will be dependent on LPG as kitchen fuel. In such typical mountainous societies, the supply chain originates from far-off non-mountainous parts of the country (India or Nepal) or neighbouring countries (such as Bhutan).

In the present case study, the methodology adopted different variables in the LPGs supply chain viz., the vehicular types and loads, fuel types and vehicular performance, distances travelled, and supply routes in the mountainous and the plain regions. The data was gathered using intensive monitoring, primary data collection, and records were obtained from various line departments and websites. In the following section, the data collected and methodology used for the study is described in detail.

2. Emission factors, activity data and methodology

In the transport of LPG from supply points, road transportation majorly by heavy and light duty vehicles was utilised. Such vehicles mainly use non-renewable fossil fuel energy sources such as diesel/petrol and hence the emissions were majorly a contribution by these fuels. For quantification of carbon emissions (kg/kg LPG) of LPG transportation from supply points to bottling plants different supply points, the distance travelled, types of transportation, actual weight of LPG and the loaded capacities of vehicles were taken into consideration. Depending upon the loaded capacity, a detailed study of carbon emissions on a company wise transportation of LPG to bottling plants was calculated.

2.1. Quantification of emission factors

For the LPG transportations to households, emission profile included quantitative measurement of CO_2 for diesel and petrol vehicles using tier 1 method and default emission factors following revised IPCC guidelines 1996. Following the tier 1, or 'top down' approach, CO_2 emissions were calculated by estimating fuel consumption in a common energy unit, multiplied by an emission factor and the carbon content was computed. In this approach, the un-oxidised carbon was corrected and finally oxidised carbon was converted to CO_2 emissions. The tier 1 emission factors are readily available national or international factors such as those provided by the IPCC and therefore is feasible for all countries. In this study, the use of tier 1 emission estimates majorly included the following information:

- data on the amount of fuel combusted
- a default emission factor (Solomon et al., 2007).

In the calculation of emissions inventories following the IPCC, 2006 guidelines, for all the oil and oil products, the oxidation factor used was 0.99 (99% of the carbon in the fuel is eventually oxidised, while 1% remains unoxidised). To calculate the CO_2 emissions from a gallon of fuel, the carbon emissions were multiplied by a ratio of the molecular weight (m.w.) of CO_2 (m.w. is 44) to the m.w. of carbon (m.w. is 12) i.e., 44/12 (IPCC, 2000). The U.S. Code of Federal Regulations (40 CFR 600.113) provides values for carbon content per gallon of petrol and diesel fuel i.e., 2421 g and 2778 g respectively. Thus, by taking 4.55 L equals to 1 gallon and the emission factors for diesel and petrol as given under (i and ii), the carbon emissions (kg/kg of LPG transported) at different levels in the supply chain of LPG were calculated.

$$\text{Emission factor for diesel} = 2,778\text{g x } 0.9\text{x}(44/12) = 10,084\text{g} = 10.1\text{kg/gallon} \tag{1}$$

$$\text{Emission factor for } petrol = 2,421\text{ g x } 0.99\text{x}(44/12) = 8,788g = 8.8\text{kg/gallon} \tag{2}$$

2.2. System boundary

For comprehensive study of carbon footprint analysis in the supply chain of LPG transportation, a framework was chalked out consisting of all possible activities that contributed significantly to LPG carbon footprint and a boundary was defined. The inventory followed a "top-down" approach i.e. at the different levels of supply points of LPG to the consumers as the main economic sectors. Three components were included in the calculation viz., the types of infrastructure used for carrying LPG, types of fuels and vehicles which accounted for the carbon emissions. The carbon emissions in the production stage and in the LPG consumption as a fuel in households were excluded in this case study (Fig. 1).

Most of the activity data were collected from on-field interviews of the transporters and the vehicle drivers (e.g. Appendix A). The collected data was on the types of vehicles, their models, distances travelled by vehicles, mileage of LPG filled vehicles (loaded) and empty vehicles (unloaded), cylinder capacities; and vehicles descriptions such as kerb weight, Gross Vehicle Weight (GVW), power and payload (these were noted from the manufacturing companies' website).

2.3. Transport emissions

All emissions that emanated by the transport of LPG from their tap-up points or supply points to households i.e. the distances covered from the supply points to the LPG bottling plants/companies storages and then further to the households' in the rural/urban setups contributed to the emissions.

LPG transport details such as modes of transport for the distribution were taken from distributors located in the cities and towns. The distances covered, the transport modes used, the carrying capacities and diesel consumptions were compiled and standard IPCC emission factors for fuels (diesel/petrol) were utilised to calculate carbon emissions. The activity data included fuel consumed in transportation of LPG by on-road vehicles. Emission controls such as cold start emissions (extra emissions due to cold starts) and evaporative emissions (extra emissions due to evaporation (Non-methane volatile organic compounds (NMVOCs)) were excluded since such emissions are not taken to be significant (IPCC, 2000). The data on vehicular speed was not available therefore to account for the types of roads and vehicular speed, mileage of vehicles fuel consumption were taken as proxy. In the case study, the emissions were estimated using the following equation adopted from Eggleston (1998).