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Life cycle greenhouse gas emission assessment of major petroleum oil products for transport and household sectors in India

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HIGHLIGHTS

- ► LCA emissions are found to be higher by 4–12 per cent than direct fuel consumption emissions.
- ► Energy used in oil exploration, refinery and transportation in the LCA have a share of 72–77 per cent, 11–15 per cent and 6–8 per cent, respectively.
- ► Corresponding GHG emission shares are 60–66 per cent, 23–27 per cent and 5–8 per cent, respectively.
- ► The source of crude oil matters. E&P energy consumption is found highest for African countries.
- ► Differential carbon cess could be imposed without changing final delivery price to consumers.

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ABSTRACT

Energy security concerns due to high oil import dependence and climate change concerns due to related greenhouse gas emissions are important policy discussions in India. Could life cycle assessment (LCA) of petroleum oil products provide inputs to crude oil sourcing and domestic oil pricing policies to address the two concerns? This paper presents a baseline study on LCA of petroleum products in India from Well to Storage depending on the oil source, type of refinery, product and the selected destinations. The LCA based GHG emissions are found to be higher by 4–12 per cent than GHG emissions from direct fuel consumption alone for LPG, 7–10 per cent for Gasoline, 3–9 per cent for Diesel and 4–10 per cent for Kerosene based on various supply chain routes supplying oil to six largest cities in India. Overall the energy used in oil exploration, refinery and transportation in the LCA have a share of 72–77 per cent, 11–15 per cent and 6–8 per cent, respectively. The paper proposes imposing a relative carbon cess for various oil products in different Indian cities. States could accommodate this additional carbon cess by reducing their respective state taxes without increasing the final delivery price to the consumers.

1. Introduction

Predominantly, a coal dependant nation for its energy needs, India relies on oil for 24 per cent of the total fuel mix by type (IEA, 2009 and EIA, 2010). Having limited domestic oil reserves, it is heavily dependant on foreign imports that currently account to about 70 per cent of the country's total consumption. The major sources for imported oil include the countries in the Middle East region followed by Africa and East Asia. With the gradual increase in the consumption, the primary oil demand has been estimated to have a compound annual growth rate (CAGR) of 3.6 per cent in the next 25 years increasing the import pie by 20 per cent to about 24 billion barrels per year (IEA, 2010). Although the crude oil and a portion of petroleum product requirements are met by imports, India is expanding its refinery capacity to produce various petroleum products to meet its consumption demands and also to become a major exporter for many of the products. Petroleum oil product consumption contributed 15 per cent of Indian greenhouse gas emissions in 2009–2010, a number that is likely to increase in the coming decades. However LCA of the complete fuel life cycle if considered may increase the amount of greenhouse gas emissions (GHG). The four major petroleum products selected for this study include: two transportation fuels – diesel and motor spirit (or petrol/gasoline); and two household sector fuels – kerosene oil (or kerosene) and liquefied petroleum gas (LPG). Diesel is mainly used for transportation (road and rail), in agriculture and for power generation whereas petrol is used in passenger vehicles such as two-wheelers, three-wheelers and cars. Kerosene, used for cooking and also lighting, is classified as

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a common man's fuel and has observed a decrease in overall consumption due to transition towards LPG as a preferred cooking fuel in urban as well as rural areas (Parikh et al., 2007; Parikh and Parikh, 2011). Diesel accounted for 37.6 per cent of the total production mix in 2009–2010, while LPG and petrol constituted 8.8 per cent and 8.6 per cent, respectively. All the four products constituted to 63 per cent of the total consumption of petroleum products with the sales for petrol being the highest for the eleventh five year plan with a CAGR of 10.3 per cent, followed by diesel (8.0 per cent), and LPG (7.1 per cent). The transport sector consumed the largest share (59 per cent) of the petroleum products in 2011 (Central Statistics Office, 2011; Basic Statistics on Indian Petroleum & Natural Gas, 2010–2011).

With uncertain raw material availability, unstable raw material prices, non-discrete inventory, high transportation costs, high inventory costs, high physical risks, and equally high risk of contamination, petroleum (oil) supply chain is quite different from other manufacturing supply chains (Varma et al., 2007). A comprehensive life-cycle inventory for petroleum products in India has not yet been published. India's growing dependence on oil for transport sector, shift towards renewable sources of energy, increasing restrictions on pollution emission standards, and the climate change issues are some of the important reasons for the growing interest in the LCA of oil supply chain. Additionally, the life cycle studies conducted are observed to majorly focus on the alternative forms of energy especially for the transportation sector to compare the total energy consumption, environmental emissions and cost-benefit analysis (Hendrickson et al., 2006; Hekkert et. al, 2005). From an environmental perspective for any petroleum product supply chain, the type of oil reserve, the grade of oil, its exploration and various modes of transportation from wells to the refinery play an important role in the upstream while the type of processing used and transportation logistics are vital in the downstream supply chain (Hackney and De Neufville, 2001; Yasushi et al., 2004; Brinkman et al., 2005; Kristin and Timothy, 2009; Brand et al, 2012). LCA studies have been conducted in Europe and US using toolkits such as EIO-LCA, Sima Pro, GaBi 4.0 LCA, Open LCA, Umberto LCA, GREET and ECOBIAN. Governments like USEPA recommend quantifying confidence of environmental life cycle models using uncertainty analysis (Lloyd and Ries, 2007). Sima Pro, a process based inventory model that allows data assembled by the user, provides a platform to conduct various Impact Assessment studies. The developer version also performs Tier II uncertainty analysis through Monte Carlo simulation (Mark et al., 2010; Theis et al., 2006).

Like all commodities, the escalation in the consumption of the petroleum products will lead to greater demand for the crude feedstock in the coming years in spite of limited domestic resources. Hence, future crude purchases will rely on economic considerations based on geological reserves available and the transportation of crude to the refineries. Today, the product prices in India are not impacted by the international prices and the refining cost, but are heavily influenced by subsidies, under-recoveries and taxes even after abolition of administered price mechanism (Datta, 2010). Revenue generation from petroleum products include central taxes in the form of excise duty, custom duty, cess and state taxes which includes sales tax, royalties, octroi and others. Taxes on the products are driven by government interventions as well as inflationary prices. Carbon tax, the tax levied on the fuel in accordance to its emission potential has not yet been introduced in India for oil products, although there is a carbon tax on coal. Datta (2010) concludes that an environmental tax should depend on fuel's with elastic demand and emission potential. The emission potential takes into account generally the use phase of the entire fuel cycle.

This study attempts to create a baseline at 2010–2011 level and provides a comparison on the energy consumption, and environmental emissions for each of the selected petroleum products (Diesel, Petrol, Kerosene and LPG) from the crude oil extracted at exploration wells (domestic as well as international), refined in six public refineries and transported to the storage facilities located in six major Indian cities, using the Sima Pro 7.2.4 model. The baseline life cycle is segregated in four distinctive phases to compare the petroleum products on the basis of their sources (domestic and international), the selected refineries, the production of individual fuels and transportation to their final distribution centres. A basic Monte Carlo simulation has been conducted on selected routes taking into account the uncertainties caused by input parameters and the model generated. The collected information has been used to discuss the long-term policy trade-off required in terms of the sources of oil, the type of production at the refinery; technology used (at production and refinery-level) the transportation of crude and final products for India as an emerging economy. Effects of these policies on environmental taxation of the selected fuels have also been studied.

2. Methodology and data sources

2.1. Life cycle assessment model and methodologies

The supply chain of the petroleum industry divides itself into two major parts, with refinery being the point of division. The upstream supply chain involves the exploration, production, and the logistics management of crude from the remotely located (onshore and offshore) wells to the refinery, while the downstream segment resembles the traditional manufacturing supply chains including retail distribution and product use-phase (Schwartz, 2000). In case of a classical life cycle analysis, two important aspects are analyzed that are associated with all the stages of a product's lifetime (cradle to grave), namely energy requirements and pollutant emissions.

The goal and scope of this study is to determine the critical global environmental impacts at various stages of the Well to Point of Storage (WTS) cycle as shown schematically in Fig. 2 namely: (1) Crude exploration and production (A), (2) Crude transportation to the refinery (T1, B, T2), (3) Crude conversion to petroleum products at the refinery (C), (4) Final product transportation to the distribution centre (T3) and (5) Product storage at the distribution centre (D). The paper does not consider the retail distribution and use phase of the fuels in vehicles or households.

Crude in India is imported from more than 40 countries around the world for the 22 refineries (public and private) which have total installed capacity of 266 MMTPA out of which 150 MMTPA is in the public sector mainly for domestic consumption. Six different refineries owned by the public companies Indian Oil Corporation Limited (IOC), Oil and Natural Gas Corporation Limited (ONGC), Bharat Petroleum Corporation Limited (BPCL) and Hindustan Petroleum Corporation Limited (HPCL) have been selected depending on their locations, main destination cities for their finished products, their share in total Indian refining capacity, and representation of major public oil companies in refining business in India. These 6 refineries together represent 58 per cent of public sector refining capacity and include at least one refinery each from all the four major public oil companies in India. Fig. 1 shows the locations of the refineries, the existing pipelines all over the country and the locations of the six selected destination cities. Fig. 2 presents the schematic layout for selected routes and the coding used. To reduce the complexity of the study, only the main destination cities were considered for each