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Role of urban growth, technology, and judicial interventions on vehicle exhaust emissions in Delhi for 1991–2014 and 2014–2030 periods

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ABSTRACT

Between late 1980s and 2014, the Greater Delhi region has witnessed an increase in vehicular fleet, four sets of emission standards, and changes in engine technology and fuel usage. This paper presents and evaluate these measures on on-road vehicle exhaust emissions under four counterfactual scenarios – (a) no penetration of 4-stroke (4S) 2-wheelers (2Ws) (b) no introduction of compressed natural gas (CNG) (c) no implementation of emission standards post 2000 and (d) no dual emission standards (supply of better fuel in the metropolitan areas and a grade lower for the rest). Introduction of 4S engines reduced VOC emissions by 90%, thus being the most effective compared to the three emission standards (BS-II, III, and IV) combined. Introducing CNG reduced 50% of $PM_{2.5}$ and increased 20% of NO_x emissions in 2014, mostly from buses and light duty vehicles. Implementation of emission standards affected all pollutants, with 60% reduction in VOCs and 20–30% reduction for the rest. Dual emission standards increased the $PM_{2.5}$ emissions from heavy duty vehicles, as much as the reductions from passenger vehicles, thus negating the benefits of the latter. Under the proposed roadmap of emission standards and vehicular technology by the Auto Fuel Policy 2025 committee, $PM_{2.5}$ emissions in 2030 will be halved, CO emissions will reach three times, and VOC and NO_x emissions will at least stabilize,

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compared to 2014 estimates. If leapfrogged to BS-VI in 2017, there will be additional reduction in NO_x and VOC emissions.

1. Introduction

The Greater Delhi region, with a combined population of 22 million (Census-India, 2012), is among the most polluted cities in the world (WHO, 2014). A large share of this pollution originates from manufacturing industries, power plants, brick kilns, dust resuspension, and vehicle exhaust (CPCB, 2010). For year 2010, Guttikunda and Goel (2013) estimated, for certain locations in Delhi, more than a third of total $PM_{2.5}$ (particulate matter (PM) with aerodynamic diameter <2.5 μm) concentration can be attributed to road transport emissions. Further, Apte et al. (2011) reported that the on-road exposure of $PM_{2.5}$ concentration is 1.5 times that of the ambient concentrations. Delhi, like most cities in India, has a vibrant mix of motorized vehicles plying on the roads. In this context, the knowledge of the estimates of on-road emissions as well as their contribution becomes an integral part to formulate pollution management policies.

In Goel and Guttikunda (2015), an integrated, dynamic, and multi-pollutant modeling framework for estimating annual on-road emissions was presented, for a period of 40 years, between 1990 and 2030, with projections to 2030 under business as usual scenarios. The modeling framework is an activity based emissions inventory model, in which the PM, nitrogen oxides (NO_x), carbon monoxide (CO), and volatile organic compounds (VOCs) emissions were estimated using

$$E_{v,f,g,p} = NV_{v,g} \times S_f \times VKT_{v,g} \times EF_{v,f,g,p} \quad (1)$$

and sulfur dioxide (SO_2) and carbon dioxide (CO_2) emissions were estimated using

$$E_{v,f,g,p} = NV_{v,g} \times S_f \times VKT_{v,g} \times FE_{v,f,g} \times PC_{f,p} \quad (2)$$

where, v = vehicle; f = fuel (petrol, diesel, and gas); g = age group; p = pollutant; E = the total emissions (tons/year) calculated by pollutant (p), vehicle type (v), fuel type (f), and by age (g); NV = the number of vehicles on-road by vehicle types (v) and by age (g); S = the share (%) of vehicles on-road for each vehicle type (v); VKT = the annual average vehicle kilometers traveled by vehicle type (v) and by age (g); EF = the fleet average emission factor (gm/km) by vehicle type (v), fuel type (f), age group (g), and by pollutant (p); FE = the fuel economy (km/lit) by vehicle type (v), fuel type (f), and age group (g); and PC = the carbon content (kg/lit of fuel) and sulfur content (ppm) of the fuel. In this study, the key parameters in the equations were used for Delhi, based on primary surveys conducted at the fuel stations and data collected from the emission testing labs, to establish the age mix, fuel economy, vehicle usage, and updated dynamic emission factors for the fleet (Goel et al., 2015). The emissions were classified by vehicle types; into 4Ws (passenger cars, jeeps, and vans), 2Ws (motorcycles, scooters, and mopeds), 3Ws (three-wheeled scooter rickshaws with 3 to 7seats), buses (intra- and inter- city operations), HDVs (heavy duty trucks), LDVs (light duty trucks), and others (off-road tractors and trailers).

For the period of 1990 and 2013, the framework included the emission control measures, mix of command and control measures, elimination of lead, reduction of sulfur and benzene content from the fuels, implementation of catalytic converters for cars, introduction of the "pollution under check" (PUC) program, implementation of emission standards, retirement of old public transport fleet, and introduction of compressed natural gas (CNG) for public transport vehicles. A schematic diagram showing the chronological order of road transport related measures in Delhi is shown in Fig. 1 and that of emission standards for different vehicle types is shown in Fig. 2. Since most of the factors such as pollution control measures, changing fuel share, and growth of fleet act simultaneously, independent effects of each of these are not known. Further, from a multi-pollutant perspective, the effects of these factors are not unidirectional.