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Energy demand and CO_2 emissions from urban on-road transport in Delhi: current and future projections under various policy measures

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ABSTRACT

This work presents an analysis of road transportation in Delhi region with focus on energy demand and carbon dioxide (CO_2) emissions. The study has considered five scenarios for the year 2021; one business as usual, and four future alternative scenarios, with 2007 as the reference year. The alternative scenarios have been developed by considering the introduction of six policy interventions, namely; construction of integrated mass rapid transit system (IMRTS), fixed bus speed, hike in parking fees, fuel efficiency, stringent emission norms, and increase in the occupancy of private vehicles. An integrated ***A****ctivity-****S****tructure-Energy* ***I****ntensity-****F****uel Mix* (ASIF) framework has been used to model, energy demand and CO_2 emissions. The outcome from the study shows that 2021-ALT-IV scenario gives the best-estimate results, which translated to ~32% reduction in annual energy demand than projected in 2021-BAU scenario. This reduces the daily per-capita energy requirement to 5.3 MJ in 2021-ALT-IV scenario, contributing to about 2.9 million tons of CO_2 emissions. This scenario further reduces fossil fuel demand by ~48% compared to 2021-BAU scenario; however, Delhi Metro will require a huge amount of electrical energy by the year 2021 making it inevitable to adopt cleaner electricity generation options in the near future. Therefore, the current study shows that shift to public transport use would not will merely be sufficient to reduce energy demand, oil use and carbon emissions from passenger transport in urban areas of developing countries.

1. Introduction

Almost half of the worldwide population resides in urban areas and contributes towards ~70% of the global carbon emissions (UN-Habitat, 2011). More than 60% of the universal gross domestic product (GDP) is generated by 600 cities, with major contribution from developed regions. In a recent study conducted by Dobbs et al. (2011), which shows that there will be a directional shift in economic contribution by the year 2021, with rise of 136 new cities from developing region, where 13 cities would be from India and 100 cities from China. This will increase the pace of ecosystem damage, including the uncontrolled release of anthropogenic greenhouse gas (GHG) emissions. In 2009, the World Development Report identified that cities have a unique opportunity to harness the benefits of urbanization while proactively managing its negative effects such as deteriorating environmental quality and increasing resource demand (Coulibaly et al., 2009). Urban transportation can function as the leading promoter of the new development paradigm, as it plays an integral role in shaping the economic growth, environmental health and social conditions within the region. A recent study carried out by the International Energy Agency (IEA, 2010) shows that transportation sector consumed ~62% of the global oil, which releases ~23% of carbon emissions, with ~75% contribution from road vehicles (Ribeiro et al., 2007). The rate of urbanization in emerging economies like India and China would further enhance the demand for travel, exerting a huge pressure on existing transport infrastructure and resources. Subsequently, the increase in economic growth would boost the purchasing power of individuals, thereby increasing vehicle ownership in urban areas (WEC, 2011). Thus, vehicle usage has been estimated to double globally by the year 2040 (ExxonMobil, 2013). Further, energy demand and carbon dioxide (CO_2) emissions have been expected to increase by 30% in the year 2030 (IEA, 2008). This may raise serious concerns for energy security and

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climate, especially for oil dependent countries experiencing rapid urbanization and expansion, including India (Proost and Dender, 2012). The subsequent section presents urban transportation situation in India with the case of Delhi, highlighting the problems and actions undertaken to mitigate these impacts.

1.1. Urban transport in Delhi

Since independence, the capital of India, Delhi has been struggling to solve the issues of rapid urbanization and excessive motorization (Mehta, 2009). Like many other urban regions in Asia, Delhi is experiencing considerable growth due to migration and growth in population. In the period 1990–2010, the population growth in Delhi befell predominantly in the city fringe districts, while the growth has relatively stabilized in the central core. It has been observed that due to its strategic location in context to being a political, economic and commercial center, it attracts an enormous influx of people, promoting faster growth, resulting in massive demand for passenger transport (Ahmad et al., 2013). It is expected that due to the demographic marginalization and urban sprawl, the distance traveled would further increase, resulting in high reliance on personal vehicles. Currently, the vehicle fleet of Delhi has increased to 7.69 million by the year 2011, with nearly 299 two-wheelers and 162 cars for every 1000 people (MoRTH, 2011). Sovacool and Brown (2010) have reported that transport sector in Delhi contributes ~66% of the total carbon emission, the highest among the top 12 megacities of the world. Increase in per-capita income (~0.2 million rupees per annum in 2012–2013) has augmented the purchasing power of individuals, thereby adding more vehicles on-road. This would result in increased congestion, vehicular pollution and Metropolitan stress; adding to the complexities of urban life (Tiwari, 2011; Jain and Khare, 2010, 2008). The regulatory authorities in Delhi acknowledge that urban air pollution is a potential health hazard, where, passenger transport is a major contributor. Various effective actions have been taken to reduce these impacts of motorization, especially in-terms of air pollution as reported by Jain et al. (2014) (details are provided in Supplementary Information; SI, Section A, Table A1). Some of the significant ones include an introduction of stringent fuel emission standards like Bharat Stage IV (BS-IV) in 2010 for vehicle types, mandatory use of compressed natural gas (CNG) in public transport and light-duty vehicles (LDV) since 2001–2006, gradual removal of two-stroke vehicle by 2006, and an elimination of polluting vehicles older than 15-years of age, etc. (Kumar et al., 2013). The construction of the integrated mass rapid transit system (IMRTS) was rolled out in 2002, for fulfilling the growing travel needs from Delhi and its national capital region. These initiatives have shown optimistic results in terms of improving urban air quality in Delhi region (Goel and Gupta, 2013; Kumar et al., 2013), with a marginal impact on CO_2 emission reductions. Further, Doll and Balaban (2013) have also studied the environmental co-benefits from transport sector in Delhi. They have observed that integration of all modes of public transport system along with increased parking fees, restricting parking space for private vehicles would increase the environmental co-benefits from transport sector. However, the impact of urban transport on climate remains unrecognized (Moriarty and Honnery, 2008), thereby lacking actions aimed at curbing the growth of city transport based carbon emissions. This makes it necessary to look for an integrated approach that would address the issues of air quality and carbon emission.

1.2. Measures to mitigate carbon emission issues

There are many studies conducted in past which talk about carbon emission measures in transport sector e.g., Proost and Dender (2012) have identified and appraised various policy measures to address the issues related to transportation energy and GHG emissions. They have categorized these policy responses as; tax (carbon or fuel), credit exchange or trade (emission trading system), fuel efficiency standard, alternative fuels or technologies, modal shift and land-use regulation (aiming at limiting sprawl). Atabani et al. (2012) have carried out a study on fuel economy standards for passenger cars in Indonesia. They have reported that implementation of fuel economy standards would result into fuel saving of 32 billion liters and reduction of 1.46 million ton CO_2 emissions. Lucas and Pangbourne (2014) have reported that the equity of carbon mitigation policies for transport in Scotland is urgently needed to mitigate the climate change impacts which are missing links in the present scenario while taking informed decisions. Kay et al. (2014) have reported that pricing policies, along with low carbon technologies, increases in the carbon efficiency of medium and heavy-duty vehicles, renewable fuels, and land use and transit measures are required to reduce the carbon emissions from transport sector. Many studies, for instance, Silitonga et al. (2012) for ASEAN countries, Lindsey et al. (2011) for Chicago, NRC (2011) for United States, and Huizenga et al. (2006) for Asia, have outlined the potential benefits from these policies in controlling energy demand and CO_2 emission for urban areas. However, a few studies have extended this idea to the city transport situation in Delhi region. Hickman et al. (2011) have considered several policy measures for predicting the urban transport and CO_2 emission in the year 2030 for Delhi region. Other studies like Singh and Sharma (2012), Baidya and Borken-Kleefeld (2009), and Badami and Haider (2007) have evaluated only the current situation in Delhi using available mobility data. It is implicit that these studies have been useful in assessing the impacts of urban transport on growing energy demand and CO_2 emissions (D'Angiola et al., 2010; Reynolds and Broderick, 2000). Nonetheless, these emission quantification methodologies can have limitations, (as suggested by Sturm et al., 1996) e.g., missing and/or incomplete information on engine technology, vintage and mileage while computing the overall impact of on-road vehicles, etc. This will result in higher uncertainty, especially for future predictions and policy formulations. Lee and van de Meene (2013) have found that increase in integration of energy efficient modes of transport will result in increase in the climate co-benefits in the country. Further, Verma et al. (2011) identifies that accuracy of the transport planning process can be enhanced by inclusion of vehicle classification information, collected through stated response studies and activity-based demand assessment studies in urban areas.

Therefore, the present study has adopted urban travel demand and vehicle classification approaches for estimating annual energy demand and CO_2 emissions for current and future years (as suggested by Progiou and Ziomas, 2011). It accounts for impacts of passenger vehicles, including private (cars and two-wheelers) and public (auto-rickshaw,[1] bus and Delhi Metro), in the year 2007 and 2021. Further, a number of policy interventions such as source emission norms, modal shift, new engine technology, speed regulation and hike in parking fee of private vehicles (as suggested by Doll and Balaban, 2013) have been considered for assessing the effect of passenger vehicle use on energy demand and CO_2 emissions in the study region.

2. Description of modeling and future scenario design

This section describes the methodology of data collection and assessment for analyzing the impact of various policy interventions

[1] The paper uses auto for auto-rickshaw.