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LETTER

Air pollution co-benefits of low carbon policies in road transport: a sub-national assessment for India

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Abstract

This letter assesses low carbon scenarios for India at the subnational level in the passenger road transport sector. We estimate the future passenger mobility demand and assess the impact of carbon mitigation policies using the Asia–Pacific Integrated Assessment/Enduse models. This letter focuses on the transitions of energy and emissions of passenger transport in India in alternate scenarios i.e. the business-as-usual scenario and a low carbon scenario that aligns to the 2 °C temperature stabilization target agreed under the global climate change negotiations. The modelling results show that passenger mobility demand will rise in all sub-national regions of India in the coming few decades. However, the volume and modal structure will vary across regions. Modelling assessment results show that aligning global low carbon policies with local policies has potential to deliver significant air quality co-benefits. This analysis provides insights into the comparative dynamics of environmental policymaking at sub-national levels.

1. Introduction

Transport demand and motorization level are growing in developing countries with increasing per capita income and urbanization level. This would further aggravate the level of local air pollution, congestion and carbon emissions (Woodcock *et al* 2009, Rao *et al* 2013). Transport is the second largest source of energy related greenhouse gas (GHG) emissions in India and around 87% of the transport-related CO_2 emissions are attributable to road transport (MOEF 2010a).

Transport emissions are highly associated with the investment choices and socio-economic development patterns. Infrastructural, technological and behavioral lock-in, and path dependencies limit the substitution between modes and technologies (Schwanen *et al* 2011, Schafer and Victor 2000).Therefore, it is important to mainstream global climate policies into the national development policies for low carbon transformation especially in case of developing countries.

As India has a multi-tiered governance system, the responsibility to implement the national climate change action plans to achieve the GHG reduction target set by the central government come under the purview of state and local government. Subnational and local government actions are crucial for addressing the climate change problem as sub-national government has a better understanding of local conditions where climate uncertainties are higher compared to regional scale. However, it has been argued that climate change policies should originate from sub-national actors as they are well placed to identify innovative policy solutions accustomed to their local needs and resources (Oliveira 2009). Most of state governments have developed State Action Plans on Climate Change (SAPCC) aligning with the National Action Plans on Climate Change (NAPCC) following the guidelines given by the central government (MOEF 2010b). However the level of recognition of the climate change problem varies between states due to differing outlooks, priorities, institutional capacity and resource availability. With the increasing recognition of the climate change issue in the sub-national policies, it is important to assess techno-economic transitions and emission trajectory at the subnational level. In addition to that, sub-national analysis also helps to capture the heterogeneity that exists in terms of policies like road tax, energy prices, Motor Vehicle Act, landscape and per capita income between states in India.

Low carbon transport scenarios have either been analyzed at the national level for passenger as well as for freight transport using bottom-up energy-environment models (Dhar and Shukla 2014, Singh 2006, Garg *et al* 2006, Baidya and Borken-Kleefeld 2009). However, at the sub-national level, previous studies have only focused on the GHG emissions and air pollutant inventory development (Sahu *et al* 2014, Guttikunda and Mohan 2014, Ramachandra and Shwetmala 2009, Kurokawa *et al* 2013). The literature is short of the quantitative studies that assess the impact of low carbon transport policies at sub-national level. This study aims to fill this research gap. As local air pollutants and greenhouse gas emissions originate largely from same source, i.e. fossil fuel combustion in vehicles. Co-benefits in terms of air pollutants reduction can be realized by implementing low carbon policies. A considerable amount of literature has been published focusing on interactions and synergies that exist between air pollution reduction strategies and greenhouse gas mitigation policies (Bussolo and O'Connor 2001, Aunan *et al* 2006, Zhang *et al* 2010). While some researchers have focused on the ancillary benefits (e.g., air pollution reduction and related health benefits) that can be accrued from greenhouse gas mitigation policies (Van Vuuren *et al* 2006, Bollen *et al* 2009), others assess the climate benefits of air pollution reduction strategies (Xu 2009). However, substantial GHG reduction cannot be achieved by air pollution reduction activities itself. Hence, in this study we also assess the air quality co-benefits by implementing low carbon policies at the sub-national level.

In this study we mainly focus on the road passenger transport at the subnational level in India. We use the Asia–Pacific Integrated Assessment Model (AIM)/Enduse model, a bottom-up, technology-detailed model to assess the potential of various mitigation strategies. Service demand for various modes for each region is exogenously input into the model. Total regional road passenger transport demand is projected using logistic function using the time series panel data from 2000 to 2010. Mode wise transport demand is estimated for cars and two-wheelers separately, and the residual demand is assigned to buses.

In this study, two scenarios i.e. business-as-usual and low carbon are developed for this modelling assessment. The 'business-as-usual' scenario envisages continuation of current trends energy and transport policies The low carbon scenario assumes various mitigation strategies like improving vehicle efficiency and imposition of carbon tax pegged with 2 degree temperature stabilization target.

Section 2 describes study area and presents the methodology of estimating future road transport passenger demand. We discuss the results related to the impact of various low transport carbon policies on GHG emissions as well as on air pollutants in section 3 followed by in depth discussion related to policy insights that can be obtained from the modelling assessment at the sub-national level.

2. Methods

2.1. Study area and data

For this analysis, we redefine 29 states and 7 Union territories into 18 region (figure 1). We combine the new states that are born out of socio-political reasons, back with the original states due to data limitations. For instance, Chhattisgarh state which was formed in 2000 by detaching 16 districts from Madhya Pradesh is combined back with Madhya Pradesh for this analysis. In addition to that, union territories i.e. Daman and Diu, Lakshadweep, Dadra and Nagar Haveli, Goa, Pondicherry are combined as one region and 8 north-eastern states, i.e. Assam, Nagaland, Mizoram, Meghalaya, Tripura, Sikkim, Arunachal Pradesh and Manipur, as one region. Since New Delhi is the capital of India and also highly urbanized, we consider it as a separate region.

All the vehicle and socio economic data i.e. GPD and population are collected at the state level. GDP and population data at the state level are taken from the statistics released by Ministry of Statistics and Programme Implementation. Vehicle data is taken from the 'Road Transport Yearbook' (Ministry of Road Transport and Highways 2006–2011) and the Indiastat database. Factors like income, urbanization and population are primarily driving mobility demand. It can be seen from figure 1 that disparities in terms of GDP per capita exist between regions. Although the average car ownership level of India is quite low compared to developed countries like the US and Japan, in economically advanced regions like Gujarat, Tamil Nadu, Delhi and Maharashtra it is higher than the national average. India has a high two wheeler ownership level that varies across regions, and can be observed in figure 1.

2.2. Socio-economic assumptions

2.2.1. Population

First, India's population growth rate up to 2050 is calculated based on projected population in the medium scenario of the UN. Then, regional population from the benchmark year (2010) is calculated taking the same share as per the 2011 census. Maximum and minimum regional population growth rate are calculated for the benchmark year.

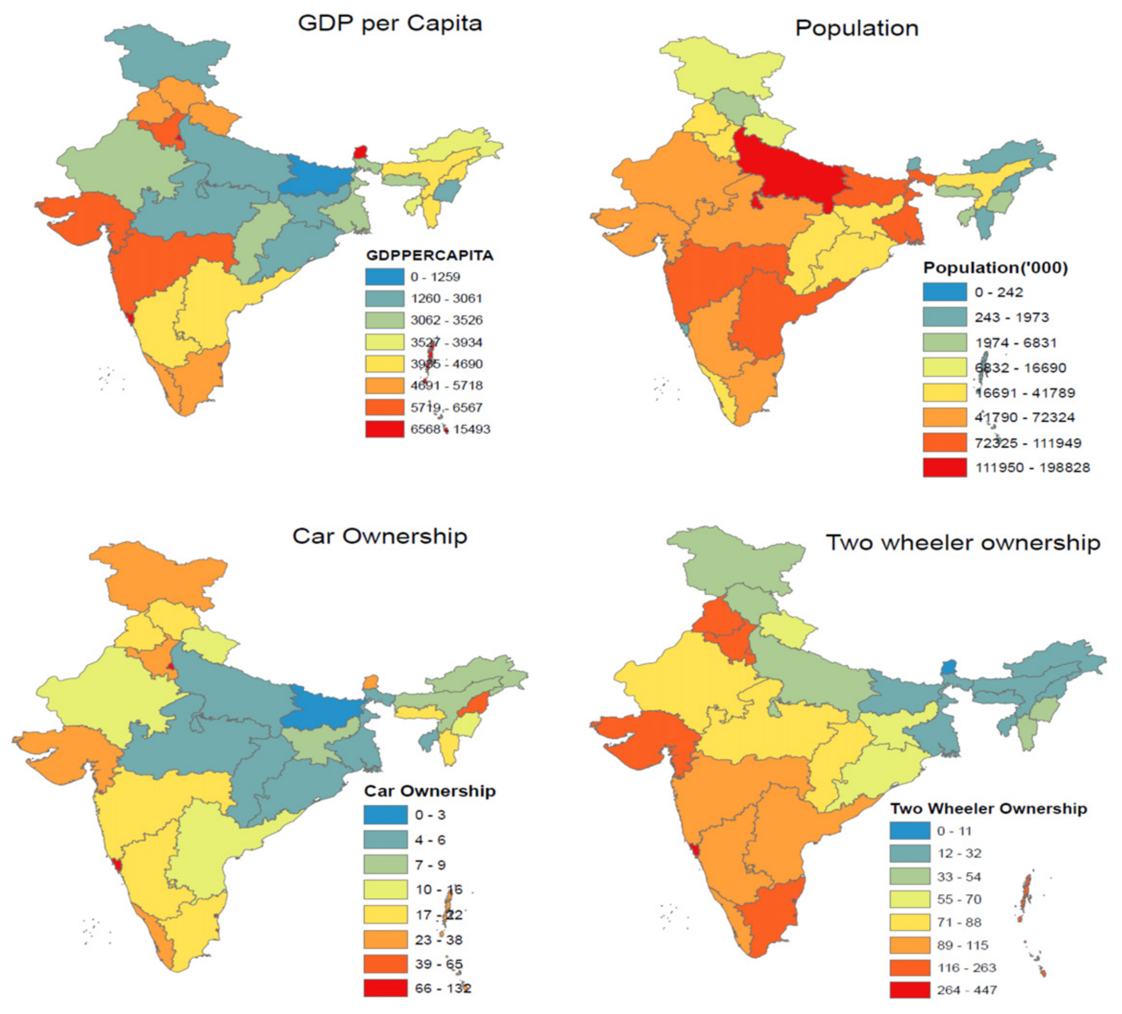

Figure 1. GDP per capita (a), population (b), car ownership per 1000 persons (c), and two wheeler ownership per 1000 persons (d) in 2010 in 18 regions.

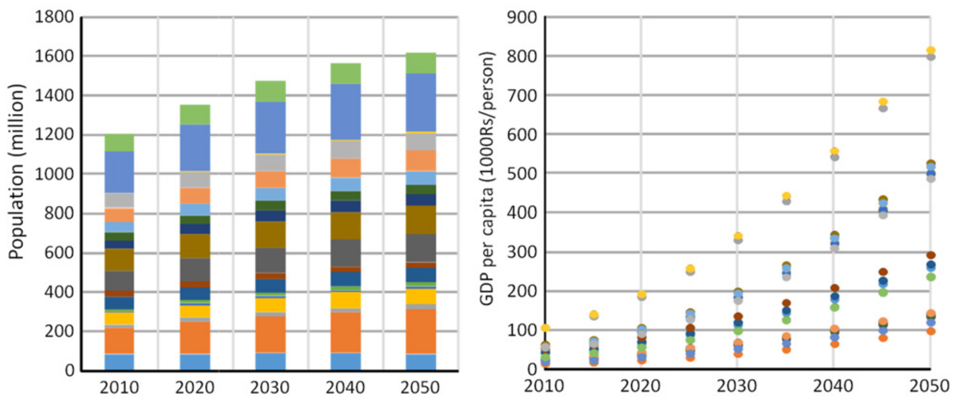

Figure 2. Disaggregated socio-economic parameters.

The national population is disaggregated at the regional level based on equation (1) assuming distance between the national average rate and maximum growth rate does not change in future. Regional population is calculated using equation (2). To keep the total population consistent with the national population projection done by the UN the regional population is adjusted to the country population (equation (3))

$$X_{t,r\in(X_{t0,r}>X_{t0,avg})} = X_{t,avg} + (X_{t,max} - X_{t,avg}) \times \frac{X_{t0,r} - X_{t0,avg}}{X_{t0,max} - X_{t0,avg}}$$

$$X_{t,r\in(X_{t0,r}\leqslant X_{t0,avg})} = X_{t,avg} - (X_{t,avg} - X_{t,min}) \times \frac{X_{t0,avg} - X_{t0,r}}{X_{t0,avg} - X_{t0,min}}$$

$$X_{t,r\in(X_{t0,r}>X_{t0,avg})} = X_{t,avg} + (X_{t,max} - X_{t,avg}) \times \frac{X_{t0,r} - X_{t0,avg}}{X_{t0,max} - X_{t0,avg}}$$

$$X_{t,r\in(X_{t0,r}\leqslant X_{t0,avg})} = X_{t,avg} - (X_{t,avg} - X_{t,min}) \times \frac{X_{t0,avg} - X_{t0,r}}{X_{t0,avg} - X_{t0,min}} \quad (1)$$

$X_{t,r}$ population change in year t and region r

$X_{t,avg}$ national average of population change in year t from medium variant scenario of UN

$X_{t,max}$ assumed maximum value of population change in year t

$X_{t,min}$ assumed minimum value of population change in year t

$t0$ benchmark year

$$\mathrm{POP}_{t,r} = \mathrm{POP}_{t-1}{}^{*}X_{t,r} \quad (2)$$

$\mathrm{POP}_{t,r}$ population in region r in year t

$$\mathrm{POPN}_{t,r} = \mathrm{POP0}_t{}^{*} \frac{\mathrm{POP}_{t,r}}{\Sigma_r \mathrm{POP}_{t,r}} \quad (3)$$

$\mathrm{POPN}_{t,r}$ adjusted population in year t and region r

$\mathrm{POP0}_t$ national population in year t based on UN projection

POPt, r population in region r in year t

2.2.2. GDP per capita

Transport demand is primarily driven by the population and income. GDP per capita is used as a proxy for the income. The future GDP per capita is projected assuming the hypothesis of growth convergence within states (Gunji and Nikaido 2010, Cherodian and Thirwall 2013, Bandyopadhyay 2003, 2006). The regions are categorized into three clubs excluding the union territories and national capital, and GDP per capita convergence happens within this club in the year 2100. The long term projection of GDP per capita for each region is calculated using logistic regression based on the historical panel data between 2000 and 2010. Since New Delhi is an urbanized region and the tertiary sector dominates the economy, and the Union territories had a share of only 0.3% of the total of India's population in 2010, GDP per capita is calculated separately for these two regions (figure 2).

2.3. Future service demand estimation

Empirical evidence shows that the per capita passenger demand increases with increase in income then tends to peak in the saturated growth phase (Singh 2006, Scafer and Victor 2000). Therefore total road passenger demand is estimated using the logistic function for each of the 18 regions. Mode wise transport demand is estimated for cars and two-wheelers separately and the remaining demand is allocated to buses. The car and two wheeler demand is calculated by multiplying the vehicle population by occupancy and average distance travelled by the vehicle annually (equation (4))

$$\text{transport demand}_{m,r,t} = \mathrm{OW}_{t,m,r} \times \mathrm{POP}_{t,r} \times \mathrm{AADT}_{t,} \times \text{occupancy}_{t}, \quad (4)$$

OW no. of vehicles/1000 people in time t in each mode m in region r

POP population in year t in region r

ADDT average annual distance travelled in region r

Several studies have used sigmoid-shape function aligning with the principle of the product life cycle and diffusion theory to predict the car ownership growth in developed and developing countries (Button *et al* 1993, Dargay *et al* 2007, Singh 2006, Metz 2010, Wu *et al* 2012). The car ownership rate is primarily driven by income. It can be represented in the logistic or Gompertz functions. We consider the Gompertz function to estimate the regional car ownership per 1000 people as shown in equation (5)

$$C_{r,t} = C^{*} \times e^{\alpha e^{\beta \mathrm{GDDPC}_{r,t}}}, \quad (5)$$

where

$C_{r,t}$ the number of cars per 1000 people in region r in year t

C^{*} saturation value

$\mathrm{GDPPC}_{r,t}$ GDP per capita in region r in the year t

α, β parameters that influence the shape of the S-curve

We conduct the linear regression analysis by taking the logarithmic transformation of equation (5) along with considering a dummy for each region in order to control the effect of heterogeneity between different regions using the panel time series data (2000–2010).

Nishitateno and Burke (2014) investigate the relationship between the two wheeler ownership and income. They show the existence of an inverted U-shaped curve based on the empirical data that means two wheeler ownership level rises with an increase in income and, after reaching a peak, declines with further increase in per capita income. We use a quadratic function to estimate the two wheeler ownership per 1000 people for each region as shown in equation (6) using GDP per capita as an explanatory variable

$$\log\,(\text{TWPC})_{r,t} == a + b1^{*}\log\,\text{GDPPC}_{r,t} + \text{b2}^{*}\log(\text{GDDPC})^{2}_{r,t} + b_j{}^{*}D_r + \varepsilon_i, \quad (6)$$

where

$\text{TWPC}_{r,t}$ two wheelers per 1000 people in region i in year t

$\text{GDPPC}_{r,t}$ GDP per capita in region i in the year t

D_r dummy variable for region

The value of the parameters, like occupancy and annual distance travelled for the base year, is taken based on the literature review mentioned in the supplementary material available at stacks.iop.org/ERL/10/085006/mmedia for the base year (table S4). Mode-wise transport demand is exogenously provided into the AIM/Enduse optimization model.

2.3.1. AIM/Enduse

AIM/Enduse model is a technology detailed recursive optimization model which selects the optimal set of technologies at the minimum total system cost approach, subject to several constraints like operating capacity, service demand etc (Kainuma *et al* 2003, Hanaoka and Kainuma 2012). A detailed description regarding model formulation and constraints is provided in Hanaoka *et al* (2015). The study considers the time span of 40 years starting from 2010 up to 2050. The technology details like lifetime and vehicle efficiency are provided in the supplementary material (tables S1, 2, 3, 6).

2.3.2. Scenario description

We consider two scenarios i.e. 'business-as-usual' and 'low carbon' to assess the impact of low carbon policies. The 'business-as-usual' scenario presumes continuation of current energy and transport related government policies. Specific actions like tightening the efficiency standards in accordance with the 'Auto Fuel Policy and Vision 2025', penetration of low carbon technologies and fuel corresponding to the 'National Mission for Electric Mobility' and 'National Policy on Biofuel' are included in this scenario. The socio-economic assumptions like GDP and population are the same for both scenarios. The projections related to population growth rate and level of urbanization at the national level closely follow the median demographic projections made by the UN in both scenarios. The low carbon scenario assumes implementation of various mitigation strategies, like improving vehicle efficiency and implementation of carbon tax aligned with the 2 degree temperature stabilization target. The assumptions related to technology related efficiency improvement in both the scenarios are mentioned in table S6. Carbon price trajectory is assumed to be same as the Copenhagen pathway mentioned in Lucas *et al* (2013) derived from a global modelling exercise using the global climate policy FAIR model. Carbon price increases from \$13.9 tonne^{-1} of CO_2 in 2020 to \$195 tonne^{-1} of CO_2 in 2050 (table S5). In the low carbon scenario, strong efforts will be made at the global level for the innovation and deployment of the advanced low carbon technologies. Large-scale deployment would decline the cost of the advanced vehicle technologies in the LCS scenario.

3. Results

3.1. Transport service demand

Figure 3 shows the road transport demand in six socio-economically different regions of India. The regions are diverse in term of economic status. Gujarat and Maharashtra are comparatively more industrialized and economically advanced regions. Bihar and West Bengal have a lower income and Andhra Pradesh and Karnataka lie between these two categories. All states have rising income and population until 2050, and these two drivers cause secular rise in the road passenger transport demand in all the regions. The rate of growth of population and income decline earlier in high income regions and hence the growth of passenger transport demand in these regions gradually begins to saturate by the year 2050 (figure 3). The share of cars rises early in the high income states, like Maharashtra and Gujarat, compared to the low income states. In high and medium-income states, the share of two wheelers at first increases with rising income, and then declines in later periods when cars begin higher penetration. However, the share of two wheelers is higher in the medium-income states, e.g. Andhra Pradesh, compared to the high-income states, which corresponds to the trend of transition from two wheelers to cars with rising income.

3.2. Carbon intensity

The carbon intensity (CO_2 emission per sqkm) across 18 sub regions in the BaU and LCS scenario is shown in figure 4. On the relative scale, the major hotspots in 2010 were Kerala in the south and West Bengal in the east, and industrialized states like Gujarat and Maharashtra in the west. The red spots in figure 4 correspond to urbanized union-territories governed by the central government. Going into the future, the carbon intensity of industrialized regions like Gujarat, West Bengal and Maharashtra continue to rise under the BaU scenario. In the LCS scenario, all regions have significantly lower carbon intensity compared to that

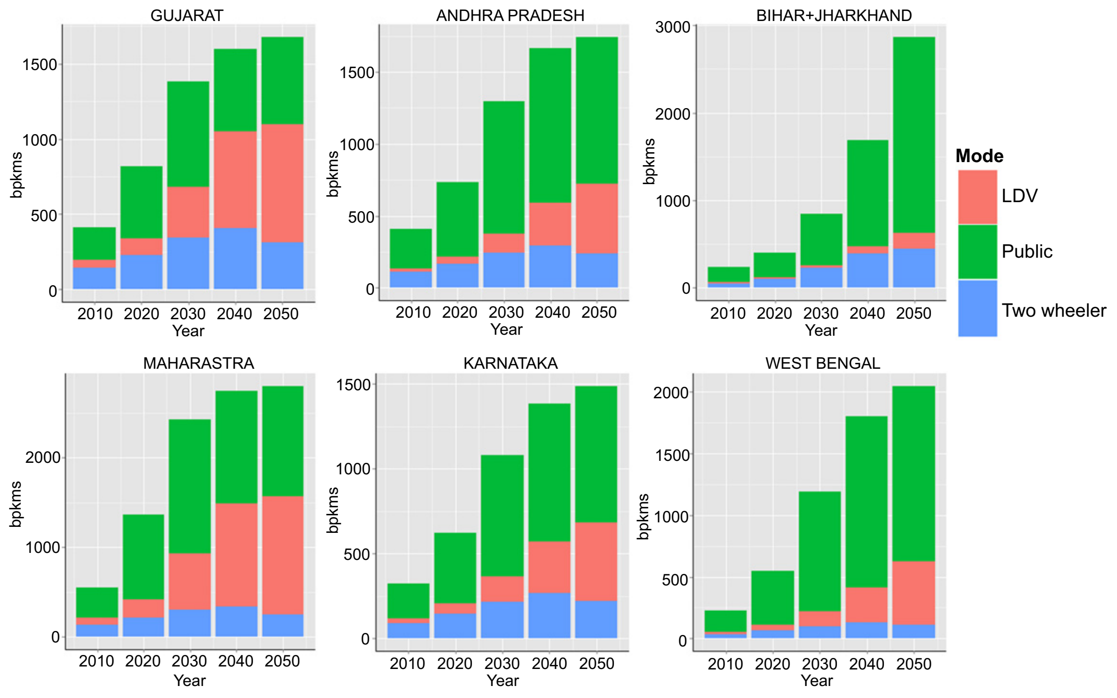

Figure 3. Transport demand in representative regions.

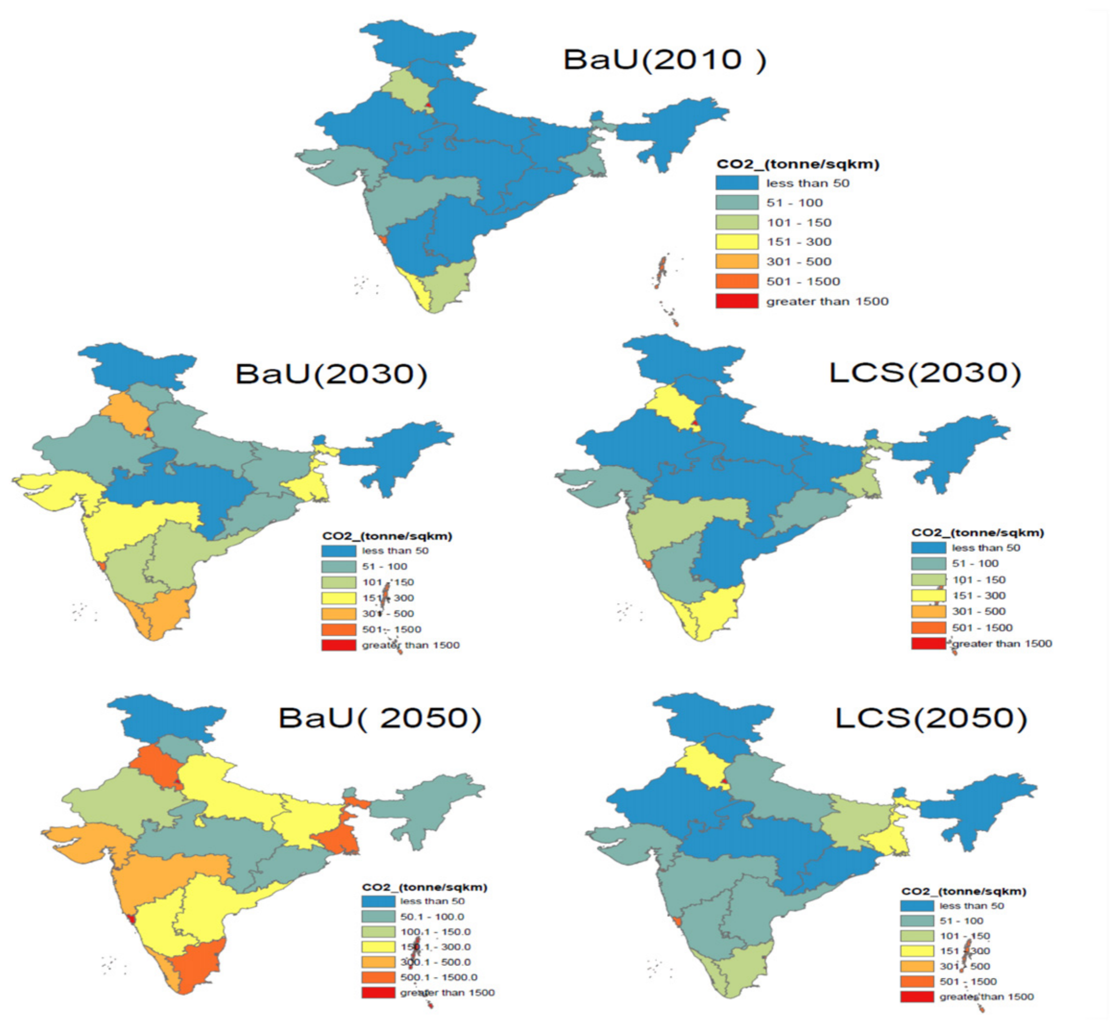

Figure 4 Carbon intensity across 18 sub regions (tonnes sqkm^{-1}).

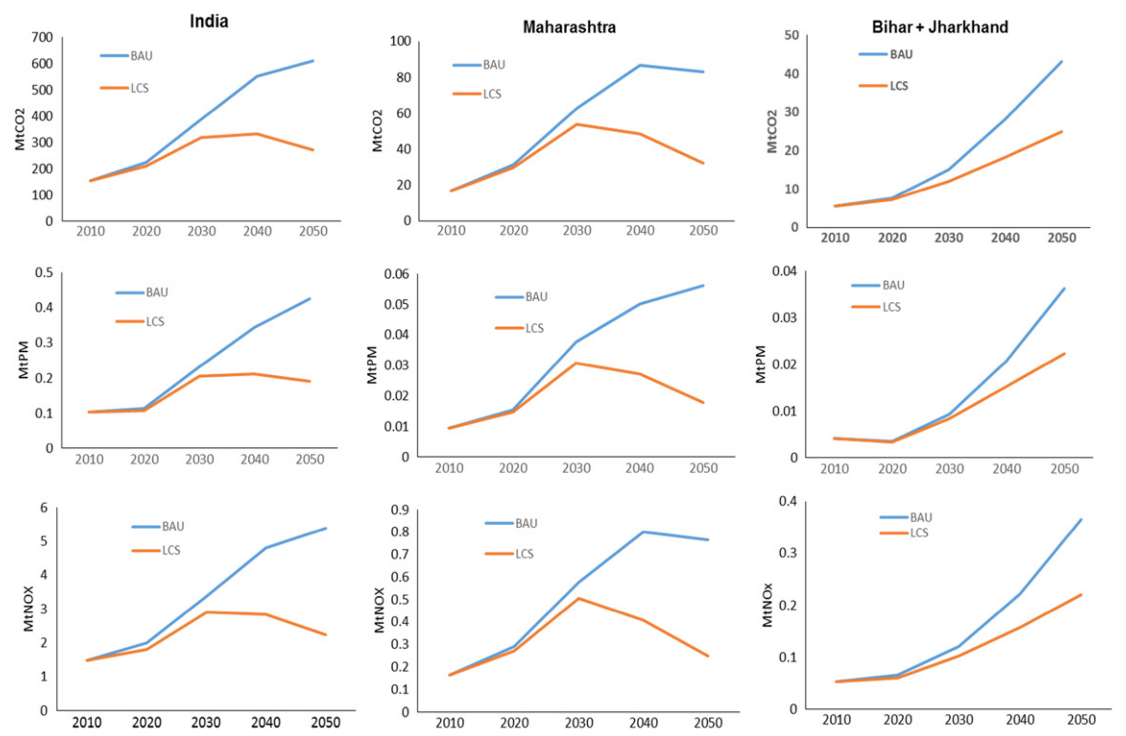

Figure 5. Emissions from the road passenger transport sector.

in the BaU. In some regions, e.g. Kerala, which was a hot spot in 2010, the intensity under LCS scenario even declines significantly over the time. Assessment of scenarios shows that the low carbon policies cause secular reduction in the CO_2 emission intensity in all regions; however the extent of reduction would depend on the regional specificities hence the importance of disaggregated regional assessments.

3.3. Air pollution co-benefits

In the BaU scenario, national level CO_2 emissions from the road passenger transport sector grow to 609 Mt CO_2, nearly a four-fold rise from 2010 to 2050. Figure 5 shows the CO_2 and air pollutants (NOx, PM) emissions in the two scenarios. In the LCS scenario, not only the CO_2 emissions but also the emissions of local air pollutants (NOx and PM) decline in all the regions. Whereas the extent of emissions reduction varies across regions, the reduction of SOx emissions in LCS is insignificant.

In the LCS scenario, CO_2 emissions peak in 2040 and thereafter decline at the national level. However, in the high income regions like Maharashtra, the peaking of CO_2 emissions happens before 2040 in the low carbon scenario whereas in low income regions like Bihar and Jharkhand, CO_2 emissions continue to grow but at the slower pace in LCS scenario.

In the case of local air pollution, the emission embedded in electricity is not considered in this study as the location of electricity generation plants differ from electricity consumption. Under the low carbon scenario, though, the share of electricity generated from the low carbon sources like renewables and nuclear increases due to implementation of the carbon tax. It is evident from figure 4 that there are significant air quality co-benefits, in terms NOx and PM emission reductions, which can be realized by implementing low-carbon policies. Compared to low-income regions, the co-benefits in terms of air pollutant emissions reduction is higher in high income regions like Maharashtra in the low carbon scenario due to the higher level of transport electrification in these states. The penetration of advanced low-carbon technologies is higher in high-income states in the low carbon scenario.

4. Discussion and conclusions

India is an emerging economy undergoing multiple socio-economic transitions—urbanization, industrialization, income and population. These transitions intimately govern the dynamics of the transport sector. In the case of India, there is considerable diversity in these dynamics at the sub-national (state) level. This letter focuses on the transitions of energy and emissions of passenger transport in India under a business-as-usual future and a low carbon future that aligns to the 2 °C temperature stabilization target agreed under the global climate change negotiations. Typically, the scenario assessments are carried out at national level. The key contribution of the letter is the assessment of air pollution related co-benefits delivered by the carbon mitigation policies at sub-national level in India. The analysis therefore provided insights into the comparative dynamics of environmental policymaking at sub-national levels. This beyond, the letter narrows the focus further on the emissions from passenger transport, since these are central to the urban air quality debate in India. The analytical framework aligns the global and local environmental policymaking following the co-benefits approach which is aimed to delivers multiple dividends. The modeling assessment spans the period until 2050. This permits the analysis of the multiple transitions which occur over the long-term due to the inertia of transport, energy and related infrastructure systems.

The energy consumption and emissions result from several endogenous and policy driven technological changes like vehicle efficiency improvements, low or zero carbon fuels, and alternate vehicle technologies such as electric vehicles. Typically, the global policy aimed at achieving the global climate change stabilization target is viewed as a burden on the national economy. The analysis in this letter reverses the perspective and focuses an attention on the contribution of carbon mitigation policy to the air quality. The results of the analysis show that reduction in a low carbon scenario with early deployment of advanced vehicles not only helps to reduce CO_2, but also helps to address the local pollution issue. The difference in the SOx emissions level in the two scenarios is not significant. Roll out of the stringent norms in accordance with the latest auto fuel policy in the BaU scenario itself will substantially bring down the SOx emissions from mobile sources.

Previous studies have also investigated the links and disjoints between local pollutants and CO_2 policies (Shukla *et al* 1999, Garg *et al* 2003, Shukla *et al* 2008). It has been shown that air pollution control policies have lesser residual impact on the CO_2 emission compared to what the low carbon policies have on the local air pollutants (Pandey and Shukla 2002).

The sub-national level analysis of the passenger transport demand shows that the ownership of two-wheelers will rise in the middle-income regions over the coming decades. The electric two-wheelers thus appear as a low carbon alternative to the gasoline powered two-wheelers in the carbon mitigation scenario wherein the electricity is significantly decarbonized. The low carbon modeling assessments (Shukla and Chaturvedi 2012) show that renewable electricity generation capacity will be a sizable fraction of the total generation capacity under long-term low carbon scenarios. In such scenarios, the intermittency of renewable technologies is ameliorated by load management interventions like storage technologies and smart grids to ensure stability and reliability of the grid. The letter in fact points to the complementarity between the large scale grid integration of renewable technologies and electric vehicles. The batteries in electric vehicles provide a storage capacity which can enable integration of renewable technologies with the grid by balancing the generation and load timing (Lund and Kempton 2008). The sub-national analysis brings the infrastructure focus on to the state governments who have key role in provisioning supporting infrastructure like charging stations and dedicated lanes in order which can facilitate segregation of electric two-wheeler for safety as well as efficiency motives.

The key conclusions from the study are as follows.

1. Demand for passenger mobility will rise, driven by rising income, urbanization and population, in all sub-national regions of India in the coming decades, but the volume and modal mix shall vary across regions.
2. The ownership of two wheelers will rise in the middle-income regions over two to three decades and then decline with rising income.
3. Due to regional socio-economic differences, emissions intensity varies across states. Hence, the assessment at sub-national level is important.
4. Implementation of low carbon policies would deliver significant air quality co-benefits.

The potential benefits, though, would not accrue automatically but shall require alignment of global to sub-national policy signals. The study therefore points to: (i) the need for understanding the present diversity of transport dynamics at subnational level in India, (ii) projecting these dynamics into the future using sound methodologies, and (iii) crafting policies at sub-national levels that deliver air quality co-benefits of implementing the global carbon mitigation in India. This study focuses solely on the passenger road transport sector at the sub-national level. Evidently, sizable co-benefits could be expected by further downscaling the assessment to city level, including design of urban form. Besides, enlarging the study to include freight transport can also demonstrate additional co-benefits from low carbon policies. Overall, the letter demonstrates the use of bottom-up methodology that delineates the package of policies and measures that maximize the sum of global carbon mitigation benefits and local air quality co-benefits, and therefore align the interests of global and local policymakers.

Acknowledgments

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