IMPLICATIONS OF TRANSPORT POLICIES ON LOCAL ENVIRONMENT AND GREENHOUSE GAS SCENARIOS IN DELHI

Ranjan Kumar Bose
India
Senior Fellow, Tata Energy Research Institute, India Habitat Centre, Lodi Road, New Delhi

Daniel Sperling
USA
Director, Institute of Transportation Studies, University of California, Davis, California

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Abstract: Air quality is emerging as a principal motivation for enhancing Delhi’s transport system. In recent years, a series of initiatives have been launched in Delhi to reduce vehicular emissions. Some of these include: augment public transport; adhere to progressively stringent standards for fuels and vehicles; scrap old buses, taxis and auto-rickshaws; establish inspection and maintenance of in-use vehicles; and promote use of clean alternative fuels. Though aimed at local air pollution reduction, these initiatives have bearing on greenhouse gases (GHGs) emissions. This paper is an attempt to untangle the complexities of Delhi’s transport sector, exploring what kind of a future is likely and how it might be altered based on the current air quality improvement programs. Two scenarios are created to characterize what is likely and what is possible. One scenario (or the high-GHG scenario) representing a “business-as-usual” trajectory – is an extrapolation of observable and emerging trends in Delhi, modified to reflect existing policies and commitments. A second scenario (or the low-GHG scenario), resulting in much smaller increases in GHG emissions, is premised on strong political and institutional leadership to enhance the economic, social, and environmental performance of Delhi’s transportation system.

Following important observations stand out. First, under any plausible scenario, GHGs will soar, ranging from a doubling in the low-GHG scenario to a quadrupling of emissions in the high-GHG case from 2000 to 2020. Second, although these increases are disconcerting, they indicate that pursuit of the lower GHG path leads to far fewer emissions – and much lower transport and energy costs. Third, to improve air quality in Delhi it is not enough to introduce improved technologies and cleaner fuels, measures are required to restrain road traffic growth by better land use planning, stricter demand management, and greater use of public and non-motorized transport. These objectives can be achieved by regulatory and market based instruments, both of which require improved administrative capability.

Introduction

Delhi is a rapidly expanding megacity. Like many, it faces urban gridlock and dangerous levels of air pollution. Vehicle ownership is still a fraction that in industrialized countries, but remarkably high considering the relatively low income.

Worldwide, energy use is increasing faster in the transport sector than any other sector, and fastest of all in developing countries. From 1980 to 1997, transportation energy use and
associated greenhouse gas (GHG) emissions increased over five percent per year in Asia (excluding former Soviet Union) and 2.6 percent in Latin America, compared to one percent growth in greenhouse gases worldwide.

Delhi, India faces the same transportation, economic and environmental challenges of other megacities. Population, motor vehicles, pollution, and traffic congestion are all increasing. Air pollution levels greatly exceed national and World Health Organization health-based standards, and transportation is by far the largest source of the pollution. In the past 30 years, its population more than tripled and vehicles increased almost fifteen fold.

By 2000, Delhi had about 2.6 million motor vehicles -- 200 for every 1,000 inhabitants, a rate far higher than most cities with similar incomes. Most of these vehicles are small, inexpensive motorcycles and scooters, rather than automobiles. This proliferation of vehicles in a relatively poor city is indicative of the strong desire for personal transport – a phenomenon observed virtually everywhere. Delhi is an emerging example of how that desire can now be met with relatively low incomes.

Delhi is expected to continue growing at a rapid rate into the foreseeable future. Its population is expected to surpass 22 million by 2020, and motor vehicles, including cars, trucks, and motorized two- and three-wheelers, are expected to grow at an even faster rate. The domestic auto industry is predicting car sale increases of ten percent per year. With an extensive network of roads and increasing income, there is every reason to expect vehicle sales and use to continue on a sharp upward trajectory.

Like most megacities of the developing world, Delhi is not prepared to manage this pent-up demand. If these travel forecasts are realized, Delhi may face extreme economic and environmental consequences. Air pollution increasingly threatens human health, road traffic could worsen to the point of paralysis, large settlements of poor people on the urban periphery may become even more disenfranchised, and the cost of doing business and providing transportation infrastructure will soar -- as will greenhouse gas emissions. Rampant growth in vehicles in Delhi and throughout the developing world is overwhelming the capacity and resources of local governments. The proliferation of low-cost small scooters and motorcycles exacerbates the situation.

This paper attempts to untangle the complexities of Delhi’s transport sector to explore what is likely and how the future might be altered. The authors interviewed Indian transportation experts and political leaders, analyzed historical data, and examined a variety of policy options and strategies. They found large institutional, political, economic, and technological uncertainties, and limited knowledge of travel behaviour and preferences.

The authors created two scenarios to characterize what is likely and what is possible. One scenario – representing a “business as usual” trajectory – is an extrapolation of present trends, modified to reflect existing and likely policies and commitments. This scenario is referred to as the “High-GHG emissions” scenario. The second scenario, termed as “Low-GHG emissions” scenario, is premised on strong political and institutional leadership to enhance the economic, social, and environmental performance of Delhi’s transportation system. In this scenario car use drops, and transit and bike use increase.

Air quality programs for transport in Delhi
Air quality is emerging as a principal motivation for enhancing Delhi’s transport system. In the last two years a series of initiatives has been launched to reduce pollution. These initiatives have come out not from the legislative or executive branches of government, but the Hon’ble Supreme Court. Most of the changes the Supreme Court directives call for require a “technical fix”: altering the engine or fuel to reduce emissions, as opposed to altering traveler behaviour. The Court directives can be classified under two categories: one specifies the technology whereas the other lay down standards for fuels and emissions, leaving the choice of technology to the manufacturers. The CNG bus initiative illustrates the mandating a technology approach and imposing progressively stringent emission norms on non commercial four wheeled vehicles and scooters/motorcycles/mopeds, illustrates the standards approach (Table 1).

### Table 1. Supreme Court directives and the status of implementation in Delhi

<table>
<thead>
<tr>
<th>Technology</th>
<th>Status of Implementation as on 1 July 2001</th>
<th>Supreme Court order</th>
<th>Status of Implementation as on 31 March 2001</th>
</tr>
</thead>
<tbody>
<tr>
<td>The number of buses must increase to 10,000 by April 1, 2001 and must operate on CNG</td>
<td>About half of the required 10,000 buses are in service, with over 88% operating on diesel.</td>
<td>Non-commercial four wheeled vehicle (petrol or diesel) will be registered in the NCR only if it meets (a) Euro I equivalent norms with effect from 1st June 1999, and (b) Euro II equivalent norms from 1st April 2000.</td>
<td>Approximately 0.9 million non-commercial four wheeled vehicles are in use. 17% of these are conforming to Euro I and Euro II norms together. (Euro I 6% and Euro II 11%).</td>
</tr>
<tr>
<td>All pre-1990 taxis and autorickshaws must be replaced with new vehicles running on clean fuels by March 31, 2000</td>
<td>All pre-1990 taxis and autorickshaws have been removed by the deadline</td>
<td>All two wheelers must conform to Bharat Stage I from 1 April 2000.</td>
<td>Approximately 2 million two-wheelers are on road. 5% of these are conforming Bharat Stage I norm</td>
</tr>
<tr>
<td>Local governments must provide financial incentives to replace all post-1990 autos and taxis with new vehicles that operate on CNG or clean fuels by March 31, 2000</td>
<td>Financial incentives are being offered for new vehicles operating on CNG. 42% of the autorickshaws and 12% taxis are on CNG.</td>
<td>Introduction of low Sulphur (500 ppm maximum) diesel in the NCR from 1 April 2000</td>
<td>All petrol pumps sell only 500 ppm S diesel</td>
</tr>
<tr>
<td>All buses older than 8 years must be scrapped by April 1, 2000 unless they operate on CNG or other clean fuels. The entire city bus fleet (public and private) must be steadily converted to CNG</td>
<td>1200 CNG buses are in operation (1171 dedicated CNG buses and 29 retrofitted with CNG kit)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The Gas Authority of India must create a network of 80 CNG refueling stations by</td>
<td>73 CNG refuelling stations are open (9 mother, 17 online, 39 daughter and</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The Delhi pollution programs target conventional air pollutants -- reactive hydrocarbons, oxides of nitrogen, carbon monoxide, sulfur oxides, and particulates -- not CO$_2$, methane, and other greenhouse gases (though some regulated air pollutants have minor climate change effects). The result of these air pollution programs is likely to be a significant reduction in conventional pollution, a modest dampening of petroleum use, and only a very small reduction in greenhouse gas (GHG) emissions.

Even the alternative fuel directives will have little effect on GHG emissions. The primary thrust is use of natural gas fuels. Substituting natural gas for gasoline would have some benefit, but substituting natural gas for diesel fuel will generally result in an increase in greenhouse gas emissions.

The greatest GHG benefit of using natural gas results when gasoline-powered vehicles are redesigned for compressed natural gas (CNG). The benefits are substantial: a net reduction of about 20 percent per vehicle-kilometer relative to the gasoline vehicle (on a full fuel cycle basis).2 If a factory-built gasoline vehicle is later retrofitted for CNG, as opposed to being designed and manufactured for CNG, the effect is much smaller and perhaps even negative.3 Diesel engines are more problematic than gasoline engines, even if the vehicles are designed and optimized for CNG. CNG buses generate about the same GHG emissions as diesel buses, on a full energy cycle basis. Re-designing buses to run on CNG instead of diesel (which are generally dirtier with more than 500 ppm of Sulphur content) would substantially reduce air pollution, but not have any effect on GHG emissions.4

It is important to note that the public transportation system may get worse before improvements take effect. For example, the Supreme Court directive banning the use of non-CNG buses after April 2001 risks stopping some bus service. The Delhi Transport Corporation and some of its private contractors have been unable to procure CNG buses to replace the existing fleet. The Delhi government may request an extension of the deadline.

The most important implication of the Court’s intervention in transportation may be to strengthen local institutions and the resolve of local authorities to direct the transport system toward a more sustainable path. While the effect of current Court directives on greenhouse gases is minimal, they provide hope and direction for further changes to come.

Travel characteristics and vehicle ownership

PASSENGER TRAVEL

A wide variety of modes and vehicles are used for passenger travel in Indian cities. Buses account for about half of all passenger travel. But this share is dropping and expected to continue dropping into the foreseeable future. The planned rapid transit system, using rail and dedicated busways (road lanes dedicated to buses), is expected to temporarily slow the drop in transit share, but the overall trend for mass transit is downward.

The Delhi experience with personal vehicles is instructive. It is the third largest city in India, but has more total vehicles and more vehicles per capita than any other. Indeed, its vehicle ownership rate approaches that of many affluent OECD cities. As of 1993, 81 percent of households owned a vehicle, though only 13 percent owned cars.5 Most vehicle-owning households possessed small scooters and motorcycles. Motorized two- and three-wheelers
represent two-thirds of the total vehicle fleet in Delhi, have maintained that share for over a decade, and are expected to maintain that share into the foreseeable future.

This high level of vehicle ownership is an important phenomenon that bears examination because it illustrates that personal vehicles can play a large role in urban transport at very low-income levels. About 2/3 of these vehicles is low-powered, small mopeds, scooters and motorcycles, with engine sizes of 50-150 cc. They cost only about $400 to $1200. Used two-wheelers (and many used cars) cost even less. While not comfortable or reliable, they do provide convenient inexpensive travel. The Delhi experience demonstrates that personal vehicles can play a large role in urban transport at very low-income levels.

The entire vehicle fleet, motorized and non-motorized, is growing rapidly. From 1975 to 1998, the car population increased from about 68,000 to almost 800,000, and the motorized two-wheelers from about 100,000 to almost 2 million. With continued income growth, the motor vehicle population is expected to continue expanding at a high rate (see Table 2). The number of bicycles and cycle rickshaws is also very large and increasing, though the number is unknown since many owners do not comply with the requirement for annual registration. It is estimated by the authors that as many as 300,000 cycle rickshaws currently travel on Delhi roads.

Table 2. Motor vehicles in use in Delhi, 1990-2020 (thousands)

<table>
<thead>
<tr>
<th>Year</th>
<th>Scooters and motorcycles</th>
<th>Cars/jeeps</th>
<th>Auto rickshaws</th>
<th>Taxis</th>
<th>Buses</th>
<th>Freight</th>
<th>All motor vehicles</th>
</tr>
</thead>
<tbody>
<tr>
<td>1971</td>
<td>93</td>
<td>57</td>
<td>10</td>
<td>4</td>
<td>3</td>
<td>14</td>
<td>180</td>
</tr>
<tr>
<td>1980</td>
<td>334</td>
<td>117</td>
<td>20</td>
<td>6</td>
<td>8</td>
<td>36</td>
<td>521</td>
</tr>
<tr>
<td>1990</td>
<td>1077</td>
<td>327</td>
<td>45</td>
<td>5</td>
<td>11</td>
<td>82</td>
<td>1547</td>
</tr>
<tr>
<td>2000</td>
<td>1568</td>
<td>852</td>
<td>45</td>
<td>8</td>
<td>18</td>
<td>94</td>
<td>2584</td>
</tr>
<tr>
<td>2010</td>
<td>2958</td>
<td>1472</td>
<td>103</td>
<td>14</td>
<td>39</td>
<td>223</td>
<td>4809</td>
</tr>
<tr>
<td>2020</td>
<td>6849</td>
<td>2760</td>
<td>209</td>
<td>28</td>
<td>73</td>
<td>420</td>
<td>10339</td>
</tr>
</tbody>
</table>

Note: Historical data are from Delhi Statistical Handbook and Transport Department, Delhi. Except for 1971 and 1980, they have been revised downward to reflect scrappage of vehicles over time. There are no registration data for 1971 and 1980 to estimate attrition. Projections are by Bose and Nesamani (2000).

Buses form the backbone of the transport system in Delhi. As a generalization, buses are the most economically and environmentally efficient means of providing transport services to most people. In Delhi, buses constitute less than one percent of the vehicle fleet, but serve about half of all travel demand.

Since 1992, Delhi has turned increasingly to the private sector to help expand and improve bus service. This decision was a response to the widely acknowledged shortcomings of public bus service, including escalating costs, poor maintenance, high labor costs, an aging bus fleet, and erratic service.

Bus service was expanded in 1996 by adding more buses, with buses per route increasing from 0.8 to 1.7. The regular fixed-route bus system now comprises about 4,000 privately operated buses and 3,760 publicly operated buses. It is complemented by 5,000 private charter buses that provide point-to-point service during peak hours to subscribers who pay a monthly fee for a guaranteed seat.

Public buses provide a low level of service and comfort, with passengers often traveling on footboards and bus roofs. Large-scale privatization has increased capacity but buses continue...
to be overcrowded and poorly maintained. Even though buses carry half of all passenger travel, they receive no preferential treatment in terms of dedicated lanes or traffic management.

The low quality of service is due in large part to the extreme poverty of so many riders. Many Delhi residents cannot afford to pay even the low subsidized fares. Consider that a single one-way bus fare for people living on the outskirts of the city is $0.20-$0.25 (Rs.8 to Rs.10), depending on the number of transfers. For the poorest 28 percent of households with monthly incomes of less than Rs.2,000 (about US $40), a single worker would spend 25 percent or more of their entire monthly income on daily round trip bus fare. For those with incomes much less than Rs 2,000, the already-low bus fare is prohibitively expensive.\(^8\)

One market response, at the bottom of the service scale, is privately operated, small, indigenously designed three- and four-wheel vehicles (sometimes referred to as jeeps) with 8-12 seats. These vehicles comprise an estimated 3 percent of the total vehicle fleet.\(^9\) They operate without a schedule and sometimes without a fixed route. This service is mostly provided by the informal sector. Operators are required to register with the Transport Authority, which requires meters to measure distance and fares, but many are known to evade these requirements.\(^10\)

An upper end market response is the chartered buses mentioned above. These private buses provide point-to-point service to individual subscribers, schools, and companies and are playing an expanding role in Delhi.\(^11\) They accounted for 4 percent of total bus trips in 1982, increasing to 11 percent in 1997. The average monthly income of charter bus commuters is Rs.7717 per month, which is roughly the wealthiest 15 percent of the population (more than 50 percent higher than the average for all Delhi residents). These buses are in many ways in direct competition with personal vehicles. To the extent the service is high quality and not too expensive, many travelers prefer it to personal vehicles. Indeed, 43 percent of the charter bus commuter’s own two-wheelers and 11 percent own cars. Clearly, charter buses are in many cases replacing the use, and perhaps even purchase, of private vehicles.

Despite these expanded transit services, at both the lower and upper end of the market, overall transit use continues to lose market share. Buses accounted for 57 percent of total passenger kilometers in 1990, dropping to about 49 percent in 2000 (see Table 3). This drop is largely due to increased use of motorized personal vehicles in upper income households, mostly two-wheelers but also cars, and the expanding population of very poor immigrants who cannot afford to ride the bus.

**Table 3. Historical and forecasted travel demand in Delhi, 1990-2020, billion passenger kilometers (motorized travel only)**

<table>
<thead>
<tr>
<th>Year</th>
<th>Two-wheelers</th>
<th>Cars &amp; jeeps</th>
<th>Auto rickshaws</th>
<th>Taxis</th>
<th>Buses</th>
<th>Rail Transit</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1990</td>
<td>8.0</td>
<td>8.6</td>
<td>3.4</td>
<td>0.3</td>
<td>27.2</td>
<td>0.0</td>
<td>47.5</td>
</tr>
<tr>
<td></td>
<td>(17)</td>
<td>(18)</td>
<td>(7)</td>
<td>(&lt;1)</td>
<td>(57)</td>
<td>(-)</td>
<td>(100)</td>
</tr>
<tr>
<td>2000</td>
<td>14.8</td>
<td>29.0</td>
<td>3.5</td>
<td>0.4</td>
<td>46.8</td>
<td>0.0</td>
<td>94.4</td>
</tr>
<tr>
<td></td>
<td>(16)</td>
<td>(31)</td>
<td>(4)</td>
<td>(&lt;1)</td>
<td>(49)</td>
<td>(-)</td>
<td>(100)</td>
</tr>
<tr>
<td>2010</td>
<td>33.8</td>
<td>61.6</td>
<td>7.6</td>
<td>0.6</td>
<td>105.0</td>
<td>10.4</td>
<td>219.1</td>
</tr>
<tr>
<td></td>
<td>(15)</td>
<td>(28)</td>
<td>(3)</td>
<td>(&lt;1)</td>
<td>(48)</td>
<td>(5)</td>
<td>(100)</td>
</tr>
<tr>
<td>2020</td>
<td>102.6</td>
<td>153.3</td>
<td>15.8</td>
<td>1.3</td>
<td>220.0</td>
<td>10.4</td>
<td>503.4</td>
</tr>
<tr>
<td></td>
<td>(20)</td>
<td>(30)</td>
<td>(3)</td>
<td>(&lt;1)</td>
<td>(44)</td>
<td>(2)</td>
<td>(100)</td>
</tr>
</tbody>
</table>

Note: Figures in parentheses are percentages.
Source: Bose and Nesamani, 2000.\(^6\)
FREIGHT

The movement of goods is key to the economic growth of a city. It is a highly decentralized business activity; consequently data are sparse and understanding of freight activity is lacking outside the industry. What is known is that intra-city movement of freight is almost entirely by truck, and increasing at a rapid rate. The volume of goods is forecast to increase five-fold from 2000 to 2020 (see Table 4), and the number of freight vehicles more than four times (Table 2).

Goods are carried by a variety of truck types, from small three-wheelers for local deliveries to large tractor-trailers. Freight vehicles are estimated to constitute only about 3 percent of all vehicles, but this statistic is distorted downward by the large number of two-wheelers in the passenger vehicle population. Freight vehicles outnumber buses five to one, and use about 11 percent of the transport energy consumed in Delhi.

<table>
<thead>
<tr>
<th>Year</th>
<th>Freight Movement</th>
</tr>
</thead>
<tbody>
<tr>
<td>1990</td>
<td>0.52</td>
</tr>
<tr>
<td>2000</td>
<td>0.66</td>
</tr>
<tr>
<td>2010</td>
<td>1.73</td>
</tr>
<tr>
<td>2020</td>
<td>3.62</td>
</tr>
</tbody>
</table>

Source: Bose and Nesamani 2000.6

GHG scenarios for the Future

HIGH-GHG EMISSIONS

This scenario is an extrapolation of observable and emerging trends. Neither major new policy initiatives nor public investments are incorporated, beyond what are already programmed. Past economic trends, rates of technological change, and behavioral patterns are assumed to continue into the future. A gradual shift toward personal vehicle travel increases. That, combined with a variety of other factors, including an expansive road network, results in a fourfold increase in greenhouse gas emissions from the transport sector.

Government plays a passive role in this scenario. Gradual introduction of the proposed rapid transit initiative continues in this scenario, but slower than currently planned and with less-than-projected ridership. Compliance with past Supreme Court directives is also delayed. Bus transit increases its share of travel somewhat from 2000 to 2010, mostly in response to Supreme Court directives to increase the bus fleet and bus service, and then drops sharply to a combined bus-rail market share of 39 percent in 2020. Cars increase market share from 30 percent of travel in 2000, to 34 percent in 2020, though 8 percent are minicars (less than 0.5 ton with engines smaller than 660 cc). Scooters and motorcycles increase from 16 to 24 percent and many of the newer cars and buses operate on natural gas and diesel fuel.

The basic elements of this scenario closely follow the forecasts developed by Bose and Nesamani and reported as “baseline forecasts”.6 Total motorized passenger travel increases over...
five folds from 94 billion person kilometers in 2000 to 503 in 2020 (see Table 3). Non-motorized travel also increases, but at a slower rate, almost tripling, from 9 to 25 billion kilometers.

The mode share, load factor, and energy use factors were converted into greenhouse gas estimates by Dr. Mark Delucchi of UC Davis. Dr Delucchi calculated fuel cycle CO$_2$-equivalent measures for each scenario. He adapted a detailed model developed earlier for OECD countries, and widely used by governments and companies in those countries. High GHG emissions scenario results in more than a fourfold increase in transport-related greenhouse gas emissions between 2000 and 2020 (Figure 1).

In summary, this scenario is one of rapid expansion in vehicles, energy use, and greenhouse gas emissions. It approximates a business-as-usual trajectory, implying that it is not an upper bound. GHG emissions could plausibly grow even faster – if per capita income grows faster than 4.3 and 5.4 percent during each of the next two decades, and if population grows faster than 3.2 and 1.6 percent during those decades.

Is this scenario sustainable? Probably yes for the next two decades. On the one hand, air pollution could be controlled through regulations and technical fixes required by the Supreme Court. Most of the cost would be borne by vehicle manufacturers, but this cost would be modest since the technologies are being developed elsewhere and widely disseminated. This element of the scenario is plausible, even likely.

Other elements are more problematic and troubling. Traffic congestion would increase as more people travel in personal vehicles. Deterioration of traffic flow could continue for some time, since Delhi benefits from an expansive road system already in place. Small fixes such as improved signalization and widening of bottlenecked roads is possible, and would help defer...
major initiatives and a sense of urgency. With more people driving, the political constituency for better roads would strengthen, and the constituency for transit would weaken. At some point, traffic congestion would become stifling, and the disenfranchisement of the very poor too severe and extensive. But that might not be for two decades. By that time, the economic and environmental consequences of this scenario would also be severe: high levels of traffic congestion would require large investments in road infrastructure, requiring more land, causing more noise, and generating more greenhouse gases.

This scenario is plausible, if not likely. However, if allowed to evolve without increasingly strong adjustments, it would eventually arrive at a worrisome, even catastrophic situation – economically, environmentally, and socially.

**LOW-GHG EMISSIONS**

This second scenario is premised on strong local leadership dedicated to restraining vehicle use and creating transportation system and transportation services that are economically, environmentally and socially sustainable for the long term. It reflects what is possible if ambitious initiatives are mounted to reduce vehicle and energy use (and therefore GHG emissions). It results in substantial increases in greenhouse gases – about a doubling from 2000 to 2020 – but only about half that generated in the business-as-usual scenario (see Figure 1).

In this scenario, conventional-sized cars drop from 30 to 19 percent of motorized travel between 2000 and 2020, and transit increases its share from 49 to 53 percent. Scooters and mini-cars account for most of the remaining motorized travel, and bicycling becomes more important, especially for the poor. Even with this aggressive shift toward more environmentally benign transportation, greenhouse gas emissions more than double in the twenty-year period.

The low-GHG scenario does not require revolutionary change. Many opportunities to slow the growth in vehicle use, pollution, greenhouse gases, and traffic congestion are at hand – at modest cost. To realize these opportunities, however, vision, leadership, and political must be brought to bear. At present, air pollution is the principal motivator for action in Delhi (though it may in part be a proxy for traffic congestion). Leadership is not coming from the executive or legislative arms of government, however, but from the Supreme Court.

A large variety of still other initiatives are also at hand that could shift Delhi to a more sustainable path. Low-cost, incremental strategies and investments include building and maintaining sidewalks, separating slow moving vehicles (bicycles and cycle rickshaws) from motorized vehicles, enhancing the quality and range of transit services, eliminating inefficient and very polluting two-stroke engines in scooters and motorcycles, using cleaner low-carbon natural gas fuels, enhancing rapid transit, and discouraging the use of private vehicles in densely populated areas. These efforts would provide dramatic improvements in traffic flow, pollution, energy use, greenhouse gas emissions, and overall system costs.

More fundamental system and technology changes could have even deeper, long-term impacts. These include restructuring land development patterns to reduce the demand for transport, accelerated introduction of very efficient advanced vehicle technologies, and use of information and communication technologies to facilitate new, more efficient forms of transportation and vehicle ownership patterns that leapfrog today’s car-centric land-use patterns. A wide variety of policy instruments and investments could be used to support these incremental and transforming initiatives.
Emissions loading of local pollutants under GHG scenarios

The first author of the paper has adapted a computerized software known as LEAP (long-range energy alternatives planning) to develop an urban transport model for analyzing emissions loading of the criteria pollutant (CO, HC, NOx, and SO2) under the two GHG scenarios described above. LEAP is developed by the Stockholm Environment Institute, Boston.

The LEAP model is run separately for High-GHG and Low-GHG scenarios to get the estimated energy and emission results from the transport sector in Delhi until 2020. The database and assumptions used to run the model is given in another published paper by the author. The model results are depicted in Figure 2 for energy demand, Figure 3 for emissions of local pollutants namely, CO, HC+NOx, and SO2. Petrol consumption increases four-fold in the high-GHG scenario, and diesel 3.8 fold. Although CNG cars, taxis, and buses have been introduced in Delhi, their scale of operation is rather limited. CNG accounts for about 4% of total transport energy demand in 2005, increasing to 12.5% in 2020. CO2 emissions increase at the rate of 6.6% per year, amounting to a 3.6-fold increase between 2000 and 2020.

Figures 2 and 3 reveal that the net effect of the Low-GHG scenario is a large increase in energy demand and emissions of CO, HC+NOx, and SO2, but considerably less than in the High-GHG case. Energy demand drops sharply in Low-GHG case and much of the demand shifts to CNG. Total energy demand is 23% less in the Low-GHG scenario than in the High-GHG scenario, with CNG 25% lower, petrol 56% lower, and diesel 10% lower. Similarly, CO2 emissions (reduced by half in the Low-GHG compared to BL in 2020) increase 2.2 times over 2000 levels in the Low-GHG case, considerably less than the 3.6-fold increase of the High-GHG scenario.

In both the scenarios, while the current emissions loading in Delhi is showing an upward trend but it is likely to show a declining trend in total emissions only beyond 2004. By 2004 the gains from newer and cleaner vehicles, which currently form only 10% of the fleet (i.e. 0.3 million vehicles) will be large enough to offset the losses from old and poorly maintained...
vehicles (see Figure 3). This is due to the introduction of progressively stringent emission standards on new vehicles, along with matching fuel quality standards as per the plans and programmes of the government and auto industry. Beyond 2010, the emission loading of CO and HC+NO$_x$ is expected to rise under the High-GHG scenario. In the Low-GHG case, emissions of these pollutants is also expected to increase though marginally beyond 2010 whereas, SO$_2$ emissions is expected to decline till 2020 in both the scenarios. In 2020, total HC+NO$_x$ emission is 60 % less in the Low-GHG scenario than in the High-GHG case. Similarly, emissions of CO and SO$_2$ in 2020 are 43 and 47 % less in Low-GHG scenario respectively.

**Figure 3. Emissions loading of regulated pollutants**
**Conclusion**

Two important observations stand out. First, under any plausible scenario, greenhouse gases will soar, ranging from a doubling to a quadrupling of emissions. Second, even though these increases may be disconcerting, they indicate that pursuit of the lower greenhouse gas path leads to far fewer emissions – and much lower transport and energy costs.

The low-GHG scenario does not require revolutionary change. Many opportunities to slow the growth in vehicle use, pollution, greenhouse gases, and traffic congestion are at hand – at modest cost. To realize these opportunities, however, vision, leadership, and political must be brought to bear. Currently, air pollution is the principal motivator for action in Delhi (though it may in part be a proxy for traffic congestion). Leadership is not coming from the executive or legislative arms of government, but from the Supreme Court of India. In the past few years, the Court has dictated a series of programs to sharply reduce air pollutant emissions from vehicles, and requirements that vehicles use clean alternative fuels. Though aimed at local air pollution reduction, many of these initiatives also restrain vehicle growth and greenhouse gas emissions.

Many other initiatives are also available to shift Delhi to a more sustainable path. Low-cost, incremental strategies and investments include the following:

- building and maintaining sidewalks,
- separating slow moving vehicles (bicycles and cycle rickshaws) from motorized vehicles,
- enhancing the quality and range of transit services,
- eliminating inefficient and very polluting two-stroke engines in scooters and motorcycles,
- using cleaner low-carbon natural gas fuels,
- enhancing rapid transit, and
- discouraging the use of private vehicles in densely populated areas.

These efforts would provide dramatic improvements in traffic flow, pollution, energy use, greenhouse gas emissions, and overall system costs. More fundamental system and technology changes could have even deeper, long-term impacts. These include the following:

- restructuring land development patterns to reduce the demand for transport,
- accelerating the introduction of very efficient advanced vehicle technologies, and
- using information and communication technologies to facilitate new, more efficient forms of transportation and vehicle ownership patterns.

A wide variety of policy instruments and investments could be used to support these incremental and transforming initiatives.

In the end, it must be recognized that all people desire greater access to goods and services, and greater comfort and convenience in accessing them. The challenge facing Delhi and other expanding megacities is to balance the personal transport desires of the more affluent with the minimal mobility needs of the very poor.

In summary, greenhouse gases associated with transportation will increase dramatically in Delhi in the coming decades, but much can be done now to slow that growth, often at little cost. It is no exaggeration to say that the environmental and economic consequences of inaction...
could be disastrous. The difference between a doubling and quadrupling of greenhouse gas emissions from the transportation sector over 20 years is huge, especially because the higher 2020 emission levels would serve as the basis for further growth. Strong leadership is needed. The good news is that many of the actions described in this paper respond to a variety of compelling social, economic, and environmental goals and not just reductions in greenhouse gases.

Notes and references

1 Majority of this paper is adapted from the report titled “Transportation in Developing Countries: Greenhouse Gas Scenarios for Delhi, India”, jointly authored by Ranjan Kumar Bose and Daniel Sperling. The full report was published and brought out in July 2001 by the Pew Center on Global Climate Change, Washington, DC, 43 pp.

2 All greenhouse gas emissions analyses presented in this report were conducted by Dr. Mark Delucchi based on an adaptation of his greenhouse gas model. For documentation of the model see the report cited in reference 1.

3 Post-factory retrofits are problematic for several reasons: the quality of the conversion is usually mixed, in part because mechanics are not expert on all engine types; not all mechanics are well qualified; and an engine system optimized for one kind of fuel is being converted to run (sub-optimally) on a very different fuel. With the advent of electronic controls, the challenge is even greater.

4 CNG has very high octane (and therefore is well suited to spark-ignited gasoline engines), but has very low cetane, a key attribute for fuels burned in diesel engines. Because diesel engines are also inherently more energy efficient than gasoline engines, CNG is relatively less attractive in diesel-like engines from an energy efficiency (and therefore GHG) perspective.


7 In addition, there are another 5,000 or so school and tourist buses.

8 Source of ridership income is IITD, Household Travel Surveys in Delhi, Operations Research Group, September 1994, pp. 6-7.


10 These vehicles are assembled locally. In many Indian cities (not Delhi), these vehicles do not have closed cabins and use inexpensive one-cylinder diesel engines, many designed for agricultural purposes. They are generally highly polluting, inefficient and noisy, and not designed for transport use. These vehicles do not adhere to safety and emission standards and very little effort has been made to improve them. The government of Delhi recently issued norms restricting the age of vehicles that can be used or sold new for commercially registered vehicles, but enforcement is spotty and unregistered vehicles are beyond the purview of even spotty enforcement. The worst of these vehicles do not operate in Delhi.


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13 Stockholm Environment Institute, 1993. Long range energy alternatives planning system: overview for version 94.0. Boston, Massachusetts, USA.