CO₂ Emissions from Land Transport in India: Scenarios of the Uncertain

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ABSTRACT

India is currently experiencing rapid motorization growth. The government and policy makers are catering to the growth with inadequate and unsustainable infrastructure provided as knee-jerk responses mostly geared towards the private automobile owners. With more than half the trips being served by public transport and a very high share of non-motorized transport, India is well poised for sustainable development. It is for the policy makers to recognize this and provide infrastructure to support it. Using a bottom-up approach, the paper explores four scenarios of growth namely, business as usual, energy efficiency including a large share of energy efficient small cars, two-wheeler world and sustainable urban transport with an emphasis on mass transit. These scenarios suggest different, though not mutually exclusive directions of growth that may be supported with appropriate policies. It is observed that carbon emissions are the highest in business as usual followed by energy efficiency, two wheeler world and sustainable urban transport. Assumptions applied to the scenarios include increasing the share of mini cars, improvements fuel efficiency for different types of vehicle, and reducing distances traveled for different vehicles, and these all led to a significant decrease in the carbon content of fuels. This study gives reasonable bounds to the impacts of a number of policy recommendations. More can be done, and more can be achieved to restrain the growth of emissions as both policies become emboldened and technologies improve.
INTRODUCTION
India is one of the largest economies in the world. Understanding of the country’s awakening transport activities and fuel use is imperative to predict the impact of its current motorization trends on its own transport system as well as on global carbon emissions.

With a vehicle sales boom in India touching both two wheelers and automobiles since 2000, and with the present high world oil price and concerns over CO₂ emissions, it is important to assess possible increases in fuel use and emissions, and the effect of different policies on such increases. There are many uncertainties involved in calculations of transportation emissions in India, with the lack of reliable data in absence of a central institute responsible for either the analysis of fuel use or of transportation data. Additionally, the majority of trips by Indians are on foot, by bicycles, or in two or three wheelers, with many of these trips not being recorded. Despite the uncertainties, scenarios could be created to illustrate the outcome of assumptions about different mobility and fuel-use patterns. The outcomes illustrated suggest pathways that lead to different levels of mobility and carbon emissions. Based on work undertaken by EMBARQ, the World Resources Institute Center for Sustainable Transport, this paper summarizes the results of a set of four scenarios of Indian land transportation at the national level. Further work will explore specific issues related to motorization and urban transport problems in specific cities.

INDIA MOTORIZATION TRENDS AND CHALLENGES
India’s population is projected to grow to 1.5 billion people by 2030, of which 600 million, or 40 percent, are forecast to be living in urban areas, up from 1.1 billion people and 317 million, or less than 30 percent living in cities (1). Total Gross Domestic Product (GDP) is forecast to grow to 14.1 trillion USD from 3.8 trillion USD in 2000 (in 2000 INR converted to purchasing power parity (PPP) 2000 US dollars). This growth yields a per capita GDP of almost $10,000 in 2030. As a benchmark, the Republic of Korea had the same per capita GDP in 1990 (using the same base 2000 PPP dollars). Korea by that time had achieved considerable motorization (and urban congestion) with less than 50 million people. India’s arrival at this level of urbanization and motorization, given its population, will be formidable.

Increases in car ownership, bolstered by growing auto sales driven by rising household incomes, increasing population and urbanization, all lead to higher travel demand. The number and size of urban cities have also increased increasing transport demand and distance traveled. The number of registered vehicles has grown from 37 million in 1997 to over 50 million vehicles in 2001 (2). Automobile sales have grown 30 percent within a year, with motorized two-wheelers dominating the market. Motorized two-wheelers have been the most rapidly growing type of vehicle, with about an average of 17 percent annual growth rate from 1991 to 2001, which is higher than the 15 percent annual growth rate for all types of motor vehicles (3).

With all the increases in different types of motor vehicles, there has been a gradual transformation from rail-dominated transport to road-dominated over the past few decades, where the share of railways in passenger kilometers has decreased by approximately 20 percent. Although urban road transport has increased significantly, investment in road infrastructure projects is still low (4). The lag of infrastructure investment bodes ill for booming car ownership, since available road space per car will fall. It also bodes ill for the majority of Indians on foot, pedals, buses, or even two wheelers, since their options are also constrained as individual cars slow the rest of the traffic down. Conversely, however, a thrust of investment in roads without providing dedicated space to buses and non-motorized transport would throw the present transportation system of India out of balance. Increasing congestion slows traffic and probably overall growth in vehicle use, which reduces fuel use. At the same time congestion leads to higher fuel use per km and can also lead to significantly higher emissions of local pollutants. Rapid motorization will increase regional and global air pollution, which have damaged crops, decreased energy security and created serious climate change implications. Road traffic injuries have also become a major negative impact of rapid motorization in India. Discussions on the different externalities due to pollution follow.
Traffic Congestion and Air Pollution
Since 33 percent of the total vehicles in India are within 23 metropolitan cities (5), rapid motorization is focused in urban areas, where high population density amplifies the impact of motorization. Traffic congestion is a serious consequence of motorization with average speed for motorized passenger vehicles presently ranging from 12 to 20 km per hour (6). This leads to high air pollution levels from the transport sector as discussed, with significant exposures and health impacts. The main damage from air pollution is to human health in Indian cities, which could be as high as US $191.6 million per city (7).

Energy Use and Greenhouse Gas Emissions
Two important consequences of rapidly growing motorization are the rising oil import and the rising greenhouse gas emissions. Primary energy use for all purposes has increased in India by more than 200 percent, while the national CO\(_2\) emission has increased by more than 800 percent from 1960 to 2003 as more and more fossil fuels supplement the wide use of biomass in rural areas. As is the case in many lower income countries, the transport share of energy use or emissions in India is small but rising, as noted in the International Energy Agency’s recent World Energy Outlook (1). While the Indian government recently released its first major greenhouse gas abatement plan, little mention was made of transport (8).

Transport Development
In 1980 the average Indian moved around 1400 passenger kilometer (km) on the ground, of which 455 km was by cycle or foot, 275 passenger km by rail, 580 passenger km by bus, and less than 50 passenger km by car and 45 passenger km by two wheeler or three wheeled auto-rickshaw. By 2000 it was estimated that the total rose to nearly 3000 passenger km, with the level for bus nearly triple, that for cars quadrupled to nearly 200 passenger km, and the combined two-three wheeler mobility over 350 passenger km, almost 8 times its 1980 value (9). We should note that even the historical data used as a baseline for this work are uncertain, although both (8) and (9) have gone a long way towards reconciling various data sets.

Public transport development is one way of reducing GHG emissions, local air pollution and traffic congestion especially when other complementary transport policies are implemented. However, the existing capacity of public transport system has not been meeting the growing travel demand. Although a mix of buses, minivans, auto rickshaws, cycle rickshaws, and taxis are common in most Indian cities, buses are still the major public transport mode in India, carrying more than 90 percent of public transport passengers.

Other Studies
An early study examined automobile use and fuel consumption in the three largest countries in Asia, China, India and Indonesia (11). It provided some insights on motor vehicle use, fuel consumption and transport activity in 2020 and 2030. In a recent update, possible increases in oil demand and CO\(_2\) emissions in China were projected for 2020 (12). This study also examined a range of policies that could slow the growth in both oil use and in transport carbon emissions. That study suggested that policies aimed at sustainable urban transport would lead to as much fuel savings as policies aimed only at fuel efficiency improvements to cars.

A broader effort supported by the World Business Council for Sustainable Development (WBCSD), the Sustainable Mobility Project, covered every major region of the world and every mode of travel and freight (13). Not surprisingly, the WBCSD study foresaw a huge increase in CO2 emissions from transport unless strong measures were taken to improve vehicle efficiency, to decarbonize fuels, to reduce total travel or freight and to raise the share of activity on modes with the
lowest emissions.

The reason most foresee a big increase in CO2 emissions from transport is economic growth and subsequent motorization. Figure 1 shows trends in CO2 emissions from road transport plotted against Gross Domestic product (GDP)/capita in 2000 US dollars converted from original, real currency at purchasing power parity for selected countries. The clear increases in emissions/capita with income/capita are challenging. Trends from water born transport and air transport in particular also show similar couplings with GDP. At the same time, it is clear that at any given level of per capita GDP there is a considerable range of levels of emissions per capita. Inclusion of more countries would reinforce this finding. Still the figure suggests but does not prove that the CO2 emissions associated with future GDP development in India are not predetermined.

India is shown as a green line whose development parallels that of China for the incomes that overlap. Unfortunately, data for India for diesel used in the road sector before 1995 contain significant uses for sectors outside of transportation, and as such, scope of such historical analysis is limited. Still the trends from after that time, if they follow Korea and Japan, foretell a significant increase in emissions as India’s economy continues to grow. This study explores options India might have to change the path in emissions.

FIGURE 1 CO2 emissions per GDP per capita for ten different countries
Source: International Energy Agency authoritative emissions data base

APPROACH AND METHODOLOGY
The bottom-up model was used to build the different scenarios for this paper. This type of model takes elements of motorization, vehicle use, travel, energy intensity, and carbon content of fuels and multiplies them together to get the final results – energy use and emissions. While this approach can incur some uncertainties arising from biases of the modelers, the purpose of building a bottom-up model is to explicitly identify and quantify the key variables that combine to give total fuel use and resulting CO2 emissions levels.

In the basic bottom up approach, the overall mobility in passenger-km was built bottom up by mode, with load factors to translate passenger-km into vehicle km or vice versa in the case of cars. The number of vehicles in the stock of each vehicle type was estimated based on the assumed values.
in 2000 and numbers of vehicles added minus retirements since then, at five year average intervals. The increments in car ownership were driven by rising income. Next, fuel intensity for each of these increments of vehicles was assumed. The stock wide averages were taken and, together with distances, multiplied to estimate fuel use by fuel and vehicle. A similar approach was taken for other scenarios that vary by mobility, modal share, distances, fuels, or vehicles (13). The results are kept current by the modelers at the IEA who developed this global approach. By contrast, the IEA World Energy Outlook (1) and many other forecasts take a top down, aggregate approach. But this complementary approach does not permit investigation of the various components of travel, modal shift, energy intensity, and fuel mix that multiply to give total emissions.

Since there are considerable uncertainties in the data, the absolute values for fuel use or CO₂ emissions that appear in any scenario are less interesting than the differences among the scenarios. These reflect well on the differences in the assumptions. Since the differences in the assumptions can be driven by policies, they reflect opportunities for policy driven alternatives that are associated with lower or higher CO₂ emissions, i.e., opportunities for avoiding CO₂-intensive development patterns based principally around large, private automobiles.

Data Analysis
There are many difficulties with the data (13). Diesel sales to road transport are not uniquely defined before 1995 in Indian statistics. Some diesel used in road vehicles is known to be cut with cheaper kerosene, causing extra pollution. Motor vehicle registrations give the sum of all time registrations of any one vehicle, with no official adjustments for the retirement of vehicles through accidents, junking, or simply non-use. Transport experts use a thumb rule to put this factor at 33 percent, i.e., the “real” stock of vehicles is some 1/3 less than the registered number. However, the current rapid increase in car sales mean that most registered cars were bought in the last 10 years, well within the lifetime of modern cars.

The Scenarios
Some basic trends in India must be represented in all scenarios. First, population growth and continued migration to cities continue unabated according to official projections. Higher per capita GDP means higher private vehicle ownership in almost every country in the world, even if the ration of cars to GDP varies widely (14). Whether those vehicles are predominantly two or four wheeled, whether they are more or less energy efficient, and whether they are driven more or less could be studied across the scenarios.

In the baseline scenario, the penetration of vehicles by fuel will be used to estimate fuel consumption in 2000. Vehicle penetration is then projected forward by five-year intervals from 2005. Fuel intensities (fuel/vehicle-km) and distances (vehicle-km/vehicle/year) will be estimated from Indian literature and from the requirements that for recent years, the “ASIF” identity (15) is satisfied for total fuel use as the product of vehicle activity, modal structure, and fuel intensity. For projections, we vary fuel intensity using assumptions about improvements over time, as well as distances. Total passenger mobility is used to estimate modal shares in vehicle-km by assuming load factors in each kind of vehicle. For mass transit, the likely modal share in passenger-km for buses is translated into bus-km, with the load factors and seats per bus known.

Although different levels of transport activity have some impact on economic growth, growth and urbanization do not vary across the scenarios. With these parameters and assumptions, we estimated bottom up the passenger vehicle distribution and use, fuel intensities, and total fuel use for India for each five-year period from 2000 to 2030.

Business as Usual (BAU)
Car ownership is projected based on an assumption of GDP and population growth. Car ownership in 2030, per unit of GDP is the same as what Korea had when it had the same GDP/capita (early 1990s). As explained in previous work (10, 11), Korea was chosen because it lies on a trajectory of car
ownership and GDP that lies close to that of China when Korea had lower GDP/capita (in the 1980s) and Japan as Korea’s GDP grew in recent years to levels Japan saw in the 1970s. The trajectories of these two countries are assumed to define the bounds of India’s car ownership at a given per capita GDP. The number of two wheelers is assumed to rise rapidly even in this base case. Vehicle ownership and use growth will be unconstrained and no new fuel taxes are assumed. It is assumed that conventional gasoline fueled motor vehicles will still dominate the market, with compact natural gas (CNG) and diesel taking a modest but not large share.

This scenario will assume that energy, infrastructure and financial constraints do not hinder expansion of transport activities. While this may be unrealistic given the lack of good infrastructure in India, it serves as a vital check on our work and on the forecasts and scenarios of others.

Energy Efficiency (EF)
The second scenario reflects a policy focus aimed at oil saving and renewable fuels in all transport modes. In this scenario, we assume higher fuel prices and taxes that drive consumers to both smaller and more efficient cars. We assume that the outcomes include the impact of higher prices and lower fuel intensities on overall vehicle use. The Japanese level of fuel prices, approx $7USD per US Gallon in 2007, gives a rough level and is roughly double the 2007 Indian levels. Estimates of vehicle fuel economy, fuel use, and the impact of fuel prices on substitution between two wheelers and buses show a range of fuel and CO₂ savings that this path could bring about.

The model uses vehicle sales and fuel economy of newly-sold vehicles in each five-year period to estimate the overall fuel economy improvements over time. The scenario reflects changes to the baseline in fuel and fuel intensities only. Overall car fuel economy on road improves some 30 percent across all fuels, with mini-car fuel economy improving somewhat less. The share of low fuel mini cars rises to about 20 percent of the stock by 2030, which accounts for a further improvement in overall car fuel economy. Fuel economy of other modes improves modestly over the BAU scenario.

Clean Two and Three Wheelers, or Two Wheeler World (TWW)
The third scenario reflects a mobility scenario based on small, clean vehicles. Growth in automobile ownership is slower than in the base case or efficiency case, in part because congestion simply limits the utility of cars and boosts that of two-wheelers; growth in bus/transit use is slightly higher, reflecting the preference most have for using these modes for longer distances and using two-wheelers for shorter distances. The same idea guides three-wheeler use, which is higher in this scenario than in the previous two.

This scenario accelerates the trend towards cleaner fuels and motors in India and extends it to three-wheelers. Each new five-year increment exhibits greater energy efficiency and lower local emissions, the exact amounts differing from scenario to scenario.

The picture in Fig. 2 shows one of several neatly arranged and guarded rows of two wheelers parked at the large Karnataka bus station in Bangalore. Some of India lives in a TWW, and this world does match well with public transport on a truly mass scale.
Sustainable Urban Transport (SUT)

This scenario reflects policies aimed at truly lifting urban infrastructure constraints through demand management and installing modern mass transit as the backbone of clean mobility. Although we present national calculations, most passenger transport activity, except the majority of rail travel, is centered on cities. Hence, the impact of changes in cities will be seen in these national scenarios.

The success of mass transit depends on keeping the streets open for buses and auto-rickshaw access to bus and rail nodes. Hence, while we foresee in this scenario a large increase in passenger travel in private cars over 2000, the actual level is less than half the level in BAU and well below the level of the TWW scenario as well. The success of bus/rail transport and the relative decline of two wheelers over other scenarios help boost the role of walking and cycling. Walking and cycling are important to provide access to trunk lines of bus or rail transit.

**SCENARIO DETAILS**

Key assumptions that vary among scenarios are described in this section.

**Vehicle Ownership**

Vehicle ownership in India has been booming. Our models project the present sales forward in five year intervals. In BAU, the level of cars projected for India in 2030, 70 per 1,000 population, is somewhat lower than Korea experienced in the early 1990s, when it had the same GDP/capita as projected for India in 2030. However, Indians enjoyed some 200 two wheelers per 1000 people consistent with what is seen in many South East Asian countries today. In the EF scenario, the motorization rates are the same as in BAU. Efficiency of vehicles improved by 0.5 percent per year in BAU, but in EF this happens more quickly. We postulated fuel prices would be roughly twice what they are at present in India. The projections lead to modest savings arising from fuel economy standards relative to our base case. This reflects in part the expectation that vehicle size and power will grow somewhat, and that more expensive fuel saving technology like hybridization will not reach India on a wide scale.

The projections include penetration of “one lakh” cars, or affordable mini-cars. These have a fuel economy of at least 20 l/km (5 l/100 km). However, it would also be misleading to hail a huge increase in the number of mini-cars, which would make the average fuel economy of cars improve greatly yet raise congestion and oil use greatly because of their sheer numbers.

The TWW scenario was designed to present a contrast, as noted above. In this scenario, the number of cars only grows to slightly more than 50 per 1,000 people, but two-wheelers grow to nearly 240 per 1,000 people, and three wheelers are more ubiquitous as well. The TWW scenario is about how people move around over relatively short distances. In some countries and cities in Asia,
notably Hanoi, this level of two-wheeler motorization has been far exceeded, with two wheelers also providing informal short-distance taxi service (“Xe-om”). There are two practical reasons for the popularity of two-wheelers: the ease by which they move in congested traffic, and affordability. The picture below suggests how easy it is to acquire a two-wheeler in Pune, India, where the picture was taken. This scenario assumes that these factors lock in Indians to a two-wheeler world, something that the growing congestion and space constraints will reinforce.

Since SUT is designed to prevent the gridlock already present in India’s largest cities, there are also fewer cars than in the base case, and they are driven less than in the base case. There are more two wheelers than in the base case, but fewer than in TWW. There are more three-wheelers in this case as they provide a vital for-hire link between trunk routes of mass transit and areas farther from these routes. The big change for this scenario is enhanced Bus Rapid Transit (BRT) with exclusive rights of way, and rail connections in cities. Buses are utilized more and are larger, which reduces fuel use per passenger-km.

**Mobility**

Measured in passenger-km per capita, mobility rises from around 2800 pass-km in 2000 to over 8300 passenger km in BAU. Table 1 gives the growth, which parallels what has happened in other Asian countries as incomes grew, motorization took off, and urbanization continued its increase.

<table>
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<th>Mode</th>
<th>2000</th>
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<th>FE</th>
<th>TWW</th>
<th>SUT</th>
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<td>1794</td>
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<td>534</td>
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<tr>
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<td>8339</td>
<td>7957</td>
<td>9221</td>
</tr>
</tbody>
</table>

**Vehicle Use**

Vehicle use in the scenarios reflects the differences in driving factors. Car utilization is highest in BAU and lowest in SUT, with TWW in the intermediate level. Motorcycles are driven the farthest in BAU, and about the same in SUT and TWW, although the much higher numbers in TWW mean the share of total mobility provided by motorcycles in that scenario is highest of all. Because of their high
numbers, two-wheelers dominate total vehicle kilometers traveled (VKT) on the roads in India in all scenarios. Figure 3 depicts the comparative vehicle use in all scenarios.

![Vehicle use by vehicle type in the three scenarios, 2000, 2015, and 2030](image)

**FIGURE 3 Vehicle use by vehicle type in the three scenarios, 2000, 2015, and 2030**

The results of these scenarios leave Indians much more mobile in 2030 than today. Average travel in 2000 was put at slightly under 3,000 km/capita. This rises to over 8,000 km/capita in the first two cases, slightly less in TWW and over 9,000 km/capita in SUT. In every case automobile mobility rises the most in relative terms, from a very low level. But while two wheelers lead in their scenario, buses and rail are the dominant form of mobility in SUT.

In TWW, car travel is significantly lower than in BAU, but two-wheeler mobility is slightly higher as is bus use. Two wheeler travel is lower in SUT because of buses and transit covering longer distances effectively, but still serves a key role in shorter trips. Car travel is lower in TWW and lowest in SUT, because cars are more difficult to use.

**Fuel Intensities**

Fuel intensities transform vehicle or passenger activity into fuel use. The values reflect both realistic values for present conditions as well as possible improvements in vehicles as newer and more efficient models come on stream and cleaner fuels permit more advanced engines. However, the rise in automobile power or weight that many other countries experience as automobile ownership matures has not been considered. This is in part because India will be entering a phase of motorization where cars coming into the stock will be principally for middle class families who can afford smaller cars (16). Note that the actual on-road fuel intensity of all cars is the product of the weighted average of each of these intensities, the numbers of each car and the distances each car drives.

For 2000 we assumed gasoline cars achieved 10.9 kilometers per liter (km/l). Indian traffic, rising to 12.35 km/l in BAU, and 14 km/l in EF, TWW, and SUT scenarios. Diesel cars achieved
about 25% better fuel economy on a volumetric basis. Mini-cars introduced in the fuel efficiency scenario achieved 20 km/liter (about 45 MPG in US Terms) in 2005 and almost 25 km/l by 2030. That Tata Motors has announced the introduction of the Nano mini-car was no surprise, but its claimed test fuel economy is even better than these “on road” values we assumed. Two wheelers average about 65 km/l in 2005, rising about 10% in BAU and 25% in EF.

As the most energy-intensive mode, fuel use for cars dominates the BAU and EE scenarios, and still represents the largest single modal share in TTW. Only in SUT does their share fall below that of buses, which provide more than four times the total mobility as cars do in SUT.

**Fuel Mix**
The assumed values for fuel mix were varied based on important trends in India, namely the appearance of CNG cars, three-wheelers, and buses. CNG gains as much as a quarter of the total fuel used by buses in 2020, for example. Diesel cars have made some headway in recent years and power all the large cars in our scenarios. Behind some of these trends is the low price of CNG or diesel, or incentives for three-wheelers to convert to CNG. CNG has lower GHG emissions than gasoline and is about even with diesel, depending on the exact measurement of various parts of the full fuel cycles. These choices do not influence the overall results for CO2 greatly but they do have an impact on the kinds of local pollutants, particularly particulate matter. We assume that the quality of diesel used in India improves markedly, so that beyond 2020 all diesel is ultra-low sulfur of less than 30 PPM. Indeed, without cleaner fuels for all vehicles, people waiting for buses will be exposed to high levels of emissions as they wait, as well as when they ride. This is important for raising the image of buses (and three wheelers) as clean and sustainable.

**THE RESULTS FOR CO2 EMISSIONS**
Total CO2 emissions are calculated in a straightforward matter from fuel use. The contribution from electricity is counted at the average ratio of emissions to kilowatt-hour (kWh) delivered to the Indian economy (1). In every case the conversion from fuel to CO2 is done using Intergovernmental Panel on Climate Change (IPCC) coefficients. Diesel has higher GHG per unit of energy than gasoline, but diesel light-duty vehicles are more efficient than their gasoline counterparts, so the two effects more or less cancel. In calculating the emissions from CNG, we have taken into account only the direct emissions from combustion, but not the indirect emissions or leakage of natural gas used in pipeline pumping and compression where vehicles are filled. A full fuel cycle analysis might add 10-15 percent overheads to the emissions from oil and 15-20 percent to those of natural gas.

The results for CO2 emissions by mode are shown in Figure 4. The most striking element of these scenarios is the huge rise in total emissions in all of them. Our assumptions were conservative -- numbers of vehicles, distances, fuel economy, and modal shares are well within the experience of Asian countries and even to some extent OECD countries. But even with conservative assumptions on car ownership and use, this mode drives total energy demand and emissions.
What propels this growth in CO\textsubscript{2} is the assumption that India will continue to motorize from a low level of 2000. Exactly how much of that growth continues on two wheelers or continues to shift to cars is what the scenarios capture. And how much the real fuel intensity of vehicle use can be pushed down illustrates the real potential for near term improvements in vehicles and fuels.

The greatest uncertainties in these scenarios arise from a combination of the number of vehicles and the distance traveled per vehicle. Lacking a great technological breakthrough, on-road fuel intensities are not likely to fall by more than 25-30 percent over their estimated values for 2000, which is reflected in our work.

We could represent more extreme variation by several ways. On the high fuel use/emissions side of BAU, we could assume that vehicles grow in size, weight and power and that cities sprawl. This would reduce the share and probably absolute use of collective transport and two wheelers. This scenario would illustrate how more car-km and higher fuel/km together might boost fuel use by 30 percent and CO\textsubscript{2} emissions as well. On the other hand, the factor of around 8 increases between 2000 and 2030 represents one doubling of fuel use and CO\textsubscript{2} emissions from land passenger transport in each of the three decades covered. For the purpose of this paper, the present BAU illustrates a high enough future.

We could also raise the share of mini cars, accelerate the possible improvements in fuel efficiency of each type of vehicle, and reduce distances traveled in these vehicles considerably in the appropriate scenario, reduce the carbon content of fuels and the role of cars in TWW. This might reduce total emissions in 2030 to 250-300 million tonnes of CO\textsubscript{2} in Fuel Efficiency, somewhat less in TWW, and close to 200 million tonnes in SUT. In short, the overall range of both calculated scenarios as well as those noted here range from roughly 10 times the emissions of 2000 to only four times those emissions. The difference arise more from variation in modal shares and distances than from differences in the energy use per vehicle-km of any individual mode.

What could drive a wedge between the high and the low? From a national perspective, concerns about rising oil imports and the health impacts of air pollution have aroused attention in India. Higher fuel prices particularly for diesel, CNG, and LPG, and taxes to reflect the various costs and externalities associated with fuel use are one important policy package. Charging directly for kilometer run is another, as is charging electronically for using congested roads or entering congested parts of cities. This paper will mention highlights that present opportunities for CO\textsubscript{2} mitigation in the following section.
Expanding mass transit would help maintain the high share of bus and rail in India. However, this is only effective if policies that restrain cars use, including those not mentioned above, be implemented.

Similarly, reducing the CO\textsubscript{2} content of fuels has been elusive. While sugar-based ethanol in Brazil has been successful up to a point limited by how much can be grown and how much can be sold, few other bio-fuels or other alternatives have proven to be both truly low in CO\textsubscript{2} per unit of actual energy delivered when the entire fuel cycle is considered and at the same time available in significant quantities to bear even ten percent of expected fuel demand. Lacking strong evidence that India is on its way to a low-carbon fuel, we have not included this option in the calculations for CO\textsubscript{2} emissions. But the approach to calculating CO\textsubscript{2} in these scenarios permits us to make such adjustments if we find evidence of “significant” quantities of bio fuels that can make an impact on India.

**OPPORTUNITIES FOR CO\textsubscript{2} MITIGATION**

The scenarios we have created illustrate alternatives and opportunities. Here we discuss the key issues for each scenario, then present the opportunities for pushing one or another through policies and technological development.

**Business as Usual**

The base case, built on simple relationships of motorization and GDP per capita, may be overly optimistic and pessimistic at the same time. The scenario is “pessimistic” because it does not assume the lowering of prices that come with familiarization of technology. India’s auto industry went from a largely closed domestic industry based on decades old designs and technologies to one with Indian and world-class companies both partnering and competing. Similar changes could drive down the price of cars while driving their quality up. The same is true of the now ubiquitous two wheelers. So we have been pessimistic on the level of car ownership India could afford at a given income in 2030.

At the same time we may be optimistic about the levels of individual motorization Indian cities and mega-cities can tolerate. The rapid decay of transport in most other larger Asian cities, whether the streets are dominated by cars, two-wheelers, minibuses and auto-rickshaws or large buses does not bode well for high individual vehicle use in 2030 in Indian cities. With the lack of space to drive vehicles and the lack of space to park them it is unclear whether India can hold so many individual motor vehicles if they appear as rapidly as they appeared in China or Korea.

The huge run up in fuel, whether oil or CNG or another fuel implied by the level of CO\textsubscript{2} emissions in Figure 4 underlies the importance of finding ways of restraint. Our suggestion is that policies should be aimed at deviating from the BAU scenario and making the most of one or more of the other scenarios.

**Energy Efficiency**

Whether through fuel efficiency standards or another mechanism including voluntary agreements, the playing field for production, purchase, and use of motor vehicles must be tilted in a way that prioritizes fuel savings over larger and more powerful vehicles year on year.

The Indian auto industry understands the importance of restraining the growth in fuel use. Whether standards alone are the best approach, they have been adopted in many countries as both a real mechanism for change/restraint and as a symbol as well (17).

To achieve maximum CO\textsubscript{2} mitigation through this scenario, necessary policy actions would involve more rapid introduction of cleaner fuel to allow better engines to penetrate sooner. It also calls for early development and adoption of a low carbon fuel. As noted elsewhere (e.g. 1), nowhere but in Brazil have biofuels with low carbon content appeared at a price comparable to world oil prices and in quantities able to displace a sizeable percent of fossil fuel use. There is further need for early adoption of voluntary targets or mandatory fuel efficiency standards agreed by the automobile industry, the government and the consumers alike, with a fuel and vehicle taxation policy that would
support reaching these targets. There is also a pressing need for an early introduction of small hybrid cars to create a low-cost efficiency market and for improved traffic controls and road surfaces to allow traffic to flow more smoothly.

**Two-Three Wheelers: The Two Wheeler World (TWW)**

This vast popularity of two wheelers in Hanoi and many other large cities in Asia raise the issue of whether these could be the basis for a long-term sustainable transport system. The fuel use per passenger-km of two-wheelers is low, but the present fleet in India is a huge contributor to air pollution and accidents. The air pollution factor could diminish, as the majority become those using more efficient four-stroke engines. If local emission standards are stronger and fuel quality improved problems experienced with previous populations of these light vehicles will not be as severe as today. The safety factor can only come from greater education and enforcement. To achieve this scenario policy should guide the development in the following directions.

While the two-wheeler emissions have reduced to a large extent compared to the recent past emission levels would have to fall further. Recent work converting three wheelers to CNG or LPG should be highlighted to show the advantages or disadvantages of these fuels against gasoline in four stroke motors. Safety would have to be improved through training, enforcement, and above all measures to lower two wheeler speeds. The Partnership for Sustainable Urban Transport in Asia (PSUTA) (17) found that the majority of two wheeler fatalities and most serious accidents take place in regions of urban areas where traffic is thinner and speeds higher. Parking and other facilities must be better organized to both increase security and save space. The sale of electric bikes may be promoted with special attention being paid to the storage and disposal of the batteries. The lot of autorickshaw (three wheeler) drivers and related six-seater operators has to be better defined and improved. Designated waiting space should be provided, particularly at interchanges with major rail and bus nodes.

**Sustainable Urban Transport (SUT)**

This scenario is about how Indian stakeholders choose to shape their cities. We presume that Indian cities can follow patterns based on corridors of homes, jobs and services clustered around mass transit of BRT, metro, and rail, with organized large feeder services as well as three-wheelers (and private two wheelers) connecting these corridors to more dispersed areas. But this outcome, which avoids much of the congestion and time waste already plaguing India’s major cities, will not happen without a very careful approach taken by national and local authorities as well as private stakeholders.

To achieve this scenario public transport must be a priority. Priority to collective transport must mean restraint of private vehicle use through means such as congestion pricing, parking charges that reflect the scarcity of land or cost of building parking facilities, parking enforcement, enforcement of bus only or two wheeler/cycling lanes to stop invasion by other modes. The policymakers must further support stepped up demonstration as is now underway at a modest scale of BRT and other affordable fast transport concepts. Expensive metros may be called for in the densest districts, but only when strong measures are undertaken to reduce surface private traffic and to create high-density residential, commercial, and service opportunities and other large-scale developments around the metro stations and nodes. Finally there must be provision of better two wheeler parking and three-wheeler interchange facilities at all major bus and rail/metro stations, along with well defined bus platforms and other features encouraging bus use.

Currently the Jawaharlal Nehru-National Urban Renewal Mission activities in India have earmarked substantial funds for development of integrated urban transport strategies. Some cities, notably Ahmedabad, Pune, Indore, Bangalore and Jaipur have expressed interest in BRT and in some cases metro or rail systems. A multi-modal long-term approach that analyzes options is needed to make this scenario successful not a string of project-by-project feasibility studies. Coupled to that must be an intensive campaign to gather data and measurements on vehicles and personal movements.

We have not treated land us changes in any analytical framework in this work. At the same
time we acknowledge that the patterns of daily travel in Indian cities that rely mostly on non-
motorized transport or public transit depend on land use patterns of relatively high density with a
mixture of uses, patterns that are observably changing in Indian cities. Recent modelling work
focused on Bangalore (18) confirm, however that a strategy of urban development focusing on high
density with transit corridors would lead to both shorter journeys and a lower share of travel in
individual, carbon intensive modes than greater sprawl, which in turn implies lower CO2 emissions
than present trends would indicate. Clearly “Sustainable Urban Transit”, while necessary, is not
sufficient to limit the growth in CO2 emissions from transport. Urban form and land uses must evolve
away from sprawl towards maintaining the present high densities and mixed uses while still
providing ample connectivity within and between metro regions. Figure 2, from the two-wheelers
parking at Bangalore’s main bus station suggests that in a well organized city, good interchange
between urban and long-distance buses on the one hand and individual transport (two wheelers) on
the other is possible. Exactly how land use needs to be shaped by authorities and land markets alike
will depend on each region, but something has to control sprawl.

CONCLUSIONS
Demand for motorized mobility in India will grow, raising fuel use and carbon dioxide emissions. But
by how much depends on many factors. We have used scenarios depicting 2030 to demonstrate that a
relatively wide range of future levels of CO2 are feasible as India approaches the GDP per capita of
Korea in the early 1990s. Concerted efforts to reduce oil consumption, reduce congestion and
improve urban access/mobility are the driving factors that would lead likely to the outcomes depicted
in the least CO2-intensive scenario, which is roughly 75 percent of the highest scenario.

In short, efforts to save oil and CO2 emissions should build upon important needs to improve
accessibility in Indian cities. Focusing on energy efficiency alone does produce a notable savings in
oil and in CO2 emissions. Favoring two wheelers in crowded cities where cars are ineffective and
more highly taxed reduces fuel use even further with some increase in access. But only a world where
cities are designed for mass transit and access can all Indians be assured of mobility. Figure 5 reminds
the reader that there is money for private vehicles in India, but no money for sidewalks, which were
not present in the part of Pune where this picture was taken. With poor sidewalks and clouds of air
pollution from all types of vehicles, walking and cycling is both unsafe and unhealthy, which leads to
greater demand for individual motorized transportation, which makes it even more difficult for
walkers and cyclists, as well as for those waiting at bus stops for buses stuck in traffic. In short,
Figure 5 is a symbol of the vicious circle by which the rise of uncontrolled private transportation
drives away all the alternatives.

FIGURE 5 Two-wheeler loans but no sidewalks in Pune. Photo taken by Lee Schipper, EMBARQ

These scenarios are by their nature normative, not predictive. Their value is in the ranges of
outcomes they illustrated. Equally important, they alert various officials, experts, and stakeholders in
government, the private sector, and civil society as to what is at stake in different paths of land transportation in India. Experience with numerous other developed and developing countries show that policies can influence vehicle ownership and characteristics, vehicle use, fuel efficiency and total fuel use. All of these factors have a profound multiplicative effect on CO₂ emissions through affecting choice and use of technology, i.e., behavior. Additionally, other policies can affect the CO₂ content of fuels, and therefore also affect emissions, although these were not studied closely in this work. It is clear that both national and local Indian authorities, as well as private companies, NGOs, and bi- and multilateral agencies and banks can assist the Indian government with the diagnoses, cure, prognosis, and evaluation related to the chain from vehicles through mobility and ultimately CO₂ emissions. This study gives reasonable bounds to the impacts of a number of suggestions herein. More can be done, and more can be achieved to restrain the growth of transport problems that lead to high fuel use and CO₂ emissions as both policies become emboldened and technologies improve. As policies and technologies appear, this same approach can be used to model their range of outcomes.

Finally, land-based mobility in India in our 2030 scenarios, lying between 8300 pass-km/capita and 9200 pass-km, is comparable to 1980 levels of Japan (7000 pass-km) but below much of northern Europe (around 10 000 pass-km) or the US (17000 pass-km), values that are roughly 30% higher in 2005 (19) and updates from national sources). India’s per capita GDP as projected for 2030 is below the values these regions had in 1980, so our projections may appear high, but India has far more two-wheelers now than these other countries ever had. Still, the levels of mobility India reaches – or rather the access to jobs, services, shopping, free time and above all each other – will depend not simply on income or the number of cars but the way cities and the countryside develop and how far Indians need to move during their lives.

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