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Buses as Low Carbon Mobility Solutions for Urban India: Evidence from Two Cities

Submission date: July 31, 2011

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Words: 5,083
Tables and figures: 9 (x250=2250)
Total: 7,333

ABSTRACT

Promoting the use of public transport is seen as one of the key strategies for moderating the inevitable growth of carbon emissions from urban transport in India. For the majority of Indian cities, this means promoting the use of public bus systems. However, the absence of analyses on carbon emissions savings attributable to public bus services in Indian cities is a significant gap in the literature. This paper utilizes recently available data on bus system performance, travel characteristics and emissions factors to estimate the emissions savings from public bus services in two cities – Ahmedabad and Bangalore. Three types of emissions savings estimates are calculated - past savings from increased ridership in the 5 years from 2005-2010, the current rate of savings from the newly introduced Janmarg BRTS and Big10 trunk services in Ahmedabad and Bangalore respectively, and forecasted savings for the years 2021 and 2031. All three estimates indicate that public bus services produce significant reductions in carbon emissions. The advantages of investing in bus systems over other potential strategies for reducing urban transport emissions – relatively low cost and quick implementation – suggest that they should be a high priority for both governments as well as international funding mechanisms for climate change mitigation.

INTRODUCTION

Several converging trends suggest that the contribution of urban transport to overall emissions in India is likely to increase substantially in the coming decades. The most significant of these is the increasing urbanisation of India's population, the rate of which is estimated to rise from 28% in 2001 to 40% in 2040, adding more than 300 million people to India's cities and increasing the demand for urban transport services *(1)*. The experiences of other developed and developing countries indicate that as India's populace becomes wealthier, their rate of private vehicle ownership will increase, as will their appetite for recreational and non-work trips. The increasing participation of women in the workforce will also boost overall travel activity in Indian cities and contribute to the growth in emissions.

The important role that sustainable transport interventions can play in moderating the inevitable growth of urban transport emissions is beginning to catch the attention of policymakers in India. In particular, promoting the use of public transport is seen as one of the key strategies in the effort to mitigate the growth of urban transport emissions *(2)*. And for the vast majority of Indian cities, barring the biggest metropolises where rail based mass transit systems are under development, promoting the use of public transport invariably means promoting the use of public bus services. However, despite prominent role that bus systems are likely to play in securing a low carbon urban transport future, analyses on the emissions savings from such systems in the Indian context are lacking.

Estimating emissions savings from bus-based public transport in Indian cities is important for several reasons. First, gaining an accurate understanding of the impact of public bus services on carbon emissions is essential for the proper planning of urban transport systems in the context of developing comprehensive strategies for emissions mitigation at the city level. Second, comparing the emissions reduction impacts of different methods for improving the quality and patronage of bus based public transport can help identify the relative merit and effectiveness of different innovations in bus services. Third, quantifying the emissions savings achievable by high quality bus systems can help proponents of such systems lobby for investments from governments which often have to allocate scarce resources among competing urban transport projects. Finally, from the perspective attracting investment for urban transport systems, providing concrete figures for emissions savings from bus systems can help in accessing international financial flows, particularly funding for climate change mitigation available from multilateral organizations.

Previous Studies

Previous studies on the subject of emissions from urban transport in India have approached the subject primarily from two angles: estimating present emission levels at the city level, and forecasting future emission levels given prevailing trends in travel activity and the energy use.

Reddy and Balachandra provide estimates of energy use and emissions from urban transport for 23 metropolitan cities for the period 1981-2005, utilizing various national and urban data sets on mobility patterns, fleet composition, and fuel use *(3)*. In a similar exercise, Ghate and Sundar calculate the emissions from passenger transport in 23 of 35 million plus cities in India, concluding that these cities account for one-fourth to one-third of the country's total road based passenger transport emissions *(4)*.

The majority of studies, however, focus on forecasting future emissions levels and emphasize the impacts of different future urban transport scenarios – ranging from personal vehicle ubiquity to strong public transport – on overall emissions. Rayle and Pai provide such an analysis for three Indian cities at varying stages of development – Mumbai, Ahmedabad and Surat *(5)*. Bose and Sperling use a similar set of scenarios to forecast vehicular emissions and air quality for the city of Delhi *(6)*. At the national level, Schipper et al forecast overall emissions levels from passenger transport in India using a model that links total emissions to travel activity, mode structure, energy intensity and fuel types *(7)*.

Attempts to directly calculate emissions savings at the city level from public transport services have been limited to cities outside India. Particularly relevant to this paper is the analysis by Hook et al summarizing estimates of emissions savings for Bus Rapid Transit Systems (BRTS) in three cities – Bogota, Mexico City and Jakarta *(8)*.

The lack of a systematic analysis of emissions savings from bus based public transport systems in Indian cities presents a significant gap in the literature on urban transport in developing countries. Utilizing recently available data on travel activity, bus system performance and emissions factors, this paper aims to contribute to the knowledge of emissions from urban transport in India by providing such an analysis for two cities - Ahmedabad and Bangalore.

The Role of Bus-based Public Transport in Emissions Reduction

There are three main ways in which public bus services (and public transport in general) can contribute to a reduction in carbon emissions in a given city. In the absence of adequate and good quality public transport, travel demand is met through relatively carbon intensive modes such as cars, 2-wheelers and autorickshaws. The most direct impact of a high quality public bus service, then, is to shift trips from these individual modes to a collective mode of transport that provides mobility at a lower emissions cost.

Public bus transport also requires less road space than individual transport modes on a per-capita basis. In other words, high patronage of public transport means that fewer vehicles are on the road. This has a significant impact of the levels of vehicular traffic and congestion. Thus the second major way in which public transport reduces emissions is by reducing congestion levels and the burning of fossil fuels by idling engines that are stuck in slow moving or stopped traffic.

Finally, in the longer term, public transport promotes the compact development of urban areas. This occurs in two ways. First, high use of public transport reduces the land area needed for passenger transport, such as roads and parking structures. Second, land prices tend to rise near heavily used transport nodes, as a result of which development occurs at higher densities as both residences and commercial establishments economize on space. Ultimately, compact development results in significant emissions savings as such urban forms are more conducive to non-motorized forms of travel such as walking and bicycling, reducing the absolute number of vehicular trips altogether. When people do make motorized trips, a compact urban form means that travel distances are smaller.

The analyses that follow estimate the emissions savings that result from the first and third of these effects: shifting of urban transport demand to less carbon intensive modes and promoting compact development. The impact of reducing congestion, although likely to be significant, is not considered due a lack of adequate data.

Choice of Cities

Three criteria were used in order to select the cities to be used in this analysis. First, in order to highlight the potential for well run public bus systems to mitigate carbon emissions from urban transport, the choice of cities was limited to those in which significant increases in bus system ridership have been achieved in the recent past. Second, urban public bus service providers that have implemented noteworthy service innovations were prioritized, in order to study the impact of specific interventions on emissions mitigation. Finally those cities for which a full complement of data is available, enabling a robust analysis without the necessity of overly generous assumptions, were preferred. Based on these criteria, Ahmedabad and Bangalore were chosen. What follows is a brief overview of these cities and their urban transport systems.

Ahmedabad

Ahmedabad is the largest city in the western Indian state of Gujarat. The Greater Ahmedabad metropolitan area, which includes the state capital of Gandhinagar, has an estimated 2011 population of 6.6 million, with a population density of nearly 5,000 people per square kilometer *(9)*.

Transport in Ahmedabad is dominated by 2-wheelers, which account for over 56% of all motorized trips, followed by buses, autorickshaws and cars *(10)*. The Ahmedabad Municipal Transport Service (AMTS) provides bus based public transport in the city, carrying 900,000 passengers every day on a fleet of 900 buses *(11)*. In 2009 Ahmedabad launched, 'Janmarg', India's first full-fledged Bus Rapid Transit System (BRTS). Janmarg has received widespread praise amongst users and is likely to play a significant role in promoting public transport use in the city.

Bangalore

Bangalore is the capital of Karnataka state in the south of India. It is the fifth largest city in the country, home to nearly 9.6 million people in 2011, with a population density of just under 4,400 people per square kilometer *(10)*. Bangalore in a major economic and commercial center in India and is an important hub for the Information Technology industry in India.

Public transport services in Bangalore are operated by the Bangalore Metropolitan Transport Corporation (BMTC) which operates one of the most extensive bus networks in India. With its fleet of 6122 buses, the BMTC carries 4.8 million passengers per day *(12)*. Mode share for public transport in Bangalore is high, at 49% of all motorized trips *(13)*. The majority of remaining motorized trips are by 2-Wheelers. In late 2011, the first line of Bangalore metro rail service 'Namma Metro' will be launched.

Table 1 provides an overview of the relevant city and travel characteristics for Ahmedabad and Bangalore.

TABLE 1 City and Travel Characteristics

	Ahmedabad	Bangalore
Population (millions)	6.60	9.59
Trip rate (trips per person per day)	1.16	1.28
Average trip length - motorized (km)	5.4	10.1
Mode split (% of total trips)		
Walk	37.6	34.0
Bicycle	17.6	4.5
Auto-rickshaw	8.3	4.6
Bus	8.4	30.0
Train	0;.3	0.0
Motorcycle	25.3	21.4
Private car	2.5	5.5

Sources: *(9) (10) (13)*

QUANTIFYING EMISSIONS REDUCTIONS FROM IMPROVED BUS-BASED PUBLIC TRANSPORT SYSTEMS

Three analyses are conducted to capture fully the extent of emissions mitigation offered by high quality public bus services in the selected cities. These savings estimates may be viewed as the impacts of improving bus services in the recent past, the present and the future.

'Past Savings' – Emissions Reductions from Improved Bus System Ridership in the Past 5 Years

Both Ahmedabad and Bangalore have achieved considerable success in increasing ridership on their public bus transport network in past 5 years (Table 2). In both cases, these increases have been the result of significant investments resulting in an increase in service quality.

In Ahmedabad, average daily ridership has increased from approximately 349,000 passengers in 2005 to 900,000 in 2010, a 158% improvement *(11)*. Making this substantial increase even more impressive is the fact that it has occurred on the back of generally declining ridership in the previous half decade. From 2000 to 2005, average daily ridership fell by 49%, from 679,000 to 349,000. This decline was been attributed largely to the increasingly poor quality of AMTS buses, poor route planning and a complicated and expensive fare structure *(10)*. Since 2005, AMTS has embarked on a major fleet expansion and renewal program. Fleet size was increased from 540 to 900 by 2010. At the same time, a large number of old buses were scrapped and replaced with newer, higher quality buses. The route and fare structure was also reformed.

In Bangalore, BMTC ridership has been increasing steadily since 1997. The rate of increase itself began to rise in the early- to mid-2000s, when the BMTC started to implement a series of service innovations aimed at better meeting the needs of public transport consumers. Primarily this involved the differentiation of services to match the requirements of different segments of Bangalore's population. For example, the 'Vajra' service, using high-end air-conditioned Volvo buses, was introduced for the city's large population of professionals working in the IT industry. 'Atal Sarige' services with lower fares aimed at economically weaker sections of the society were also introduced. Differentiated services were also introduced for tourists, travelers to the airport and so on. In all, the BMTC currently operates 10 different types of service, each with unique branding, for various segments of the public transport market. At the same time, aggressive fleet and service level expansion has also been pursued – these supply indicators have grown by 56% and 41% respectively since 2005 *(12)*. The improvement of bus services through this program of investment and innovation has resulted in BMTC's average daily ridership increasing from 3.27 million in 2005 to 4.8 million in 2011 – a 33% increase *(12)*.

The 'past savings' calculation for both cities estimates the reduction in carbon emissions as a consequence of the substantial increases in ridership during the period 2005-2010. This is done by calculating the additional emissions that would have resulted had ridership levels stagnated at the 2005 level and the additional bus passengers traveled by cars, 2-wheelers and autorickshaws instead.

TABLE 2 Bus Service Statistics

	Ahmedabad	**Bangalore**
System Wide		
Daily Ridership (2011)	900,000	4,800,000
Daily Ridership (2005)	349,000	3,270,000
Daily Ridership CAGR (since 2005)	17.10%	6.95%
Daily Service Kilometers (Current)	93,473	1,269,091
Daily Service Kilometers (2005)	77,411	901,212
Daily Service KM CAGR (since 2005)	3.19%	5.87%
Fleet Size (Current)	900	6122
Passengers per Bus per Day	1000	784.06
Kilometers per Bus per Day	103.86	207.30
Average Trip Length	12	10.8
Recent Service Innovations		
	Janmarg BRTS	Big10
Date Introduced	Oct 2009	Feb 2009
Daily Ridership (Current)	102,182	188,761
Daily Riderhsip (Year 1 Avg)	45,919	108,570
Daily Service Kilometers (Current)	14,265	32,213
Fleet Size (Current)	56	140
Passengers per Bus per Day	1825	1348
Kilometers per Bus per Day	255	230
Average Trip Length	7.36	8.59

Sources: *(11) (12) (14) (15)*

‘Present Savings’: Emissions Reductions from Mode Shift due to Recent Innovations in Service Provision

In addition to the investments in improving general bus services mentioned above, Ahmedabad and Bangalore have also been at leading edge of public transport innovation in India, introducing first-of-their kind services in bus based public transport.

In October 2009, Ahmedabad launched Janmarg, the first full-fledged BRT system in India. Incorporating physical segregation, median stations, level boarding and a semi-closed system, the 39-km Janmarg BRTS has been hailed a ‘game changer’ for public bus services in India. After just over one year of operations, the system now serves approximately 102,000 people per day with a fleet of 56 buses *(14)*. The second phase of the BRTS network is currently under construction.

In February 2009, BMTC introduced the Big10 service in Bangalore. This consists of high frequency trunk services along 10 major arterials (later expanded to 12) connecting the city center to outlying suburbs. This direction-based service is a departure from the usual route structure linking specific Origin-Destination pairs. The Big10 service currently accommodates slightly over 180,000 passengers per day with a fleet of 140 buses *(15)*.

Surveys of Janmarg and Big10 users show that these services have contributed to a significant mode shift towards public transport in the corridors on which they operate (14, 16). The ‘present savings’ calculation estimates the reduction in carbon emissions achieved by the mode shift from private to public transport engendered by these new services. That is, given information about the fraction of users who have shifted to these services from private vehicular modes, savings are estimated by calculating the difference between the emissions produced by their use of these services and a scenario in which they continued to travel by the private modes they used before.

‘Future Savings’: Potential Savings From Improved Bus Services Over The Next Two Decades

The final analysis presented in this paper aims to estimate the magnitude of potential savings in future transport related emissions that can be achieved by investing in and improving the quality of bus services in Ahmedabad and Bangalore. The savings in emissions are calculated by comparing two urban transport trajectories for the cities that result, respectively, from failing to adequately improve the public transport system and making timely and ample investments in high-quality bus based public transport.

In the first scenario, termed ‘Automobility’, the city does not invest in public transport infrastructure and services. As a result the majority of travel demand is met through the increasing use of private motor vehicles. Mode shares for bus transport fall. The dependence on motor vehicles also means that urban growth occurs at lower than present densities, resulting in sprawl and a greatly expanded urban footprint. This in turn increases trip lengths and therefore emissions. In the converse scenario, termed ‘Sustainable Transport’, the city invests heavily in developing high quality bus systems, ensuring that public transport carries the majority of trips in the metropolitan region. The high use of public transport also promotes compact urban development, allowing growth to occur at existing densities and moderating the spatial expansion of the city

By forecasting travel activity for these two scenarios, total emissions from passenger transport are calculated for two time points, 2021 and 2031. Comparing total emissions from the

Sustainable Transport and Automobility scenarios will provide an estimate of the potential savings in overall emissions that promoting high quality bus –based public transport can make possible.

METHODOLOGY

Many methodologies are available for the calculation of emissions savings from public transport systems *(17)*. Based on the data requirements for the different methodologies, this paper applies the American Public Transportation Association's recommended practice for quantifying greenhouse gas emissions from public transport systems *(18)*. This methodology involves five main steps. First, passenger kilometers on the bus service are calculated using ridership number and average trip length as inputs. Second, bus passenger kilometers are apportioned to the various other motorized travel modes since, in the absence of bus services, passengers would use one of these modes to satisfy their travel needs. The specific allocation of bus passenger kilometers to the various other motorized modes is based on the calculation of 'mode shift factors' – defined for a particular mode as the proportion of displaced bus passenger kilometers that are transferred to it. These mode shift factors in turn are based either on stated preference surveys of bus users or by assuming that the existing mode share structure is maintained (that is, bus passenger kilometers are apportioned in the exact proportion of existing non-bus motorized mode share). For this analysis, both of these methods are used. For the 'past' scenario, mode shift factors are derived from existing mode share structure. For the 'present' scenario, data from stated preference surveys were used *(14, 16)*. Third, the additional passenger kilometers for the various modes are converted into vehicle kilometers based on average vehicle occupancy rates for each mode. Fourth, emissions factors are applied to vehicle kilometers for each mode and added to find total emissions. Finally, net savings are calculated by subtracting the emissions produced by the operation of the bus service itself. Figure 1 provides a overview of this methodology.

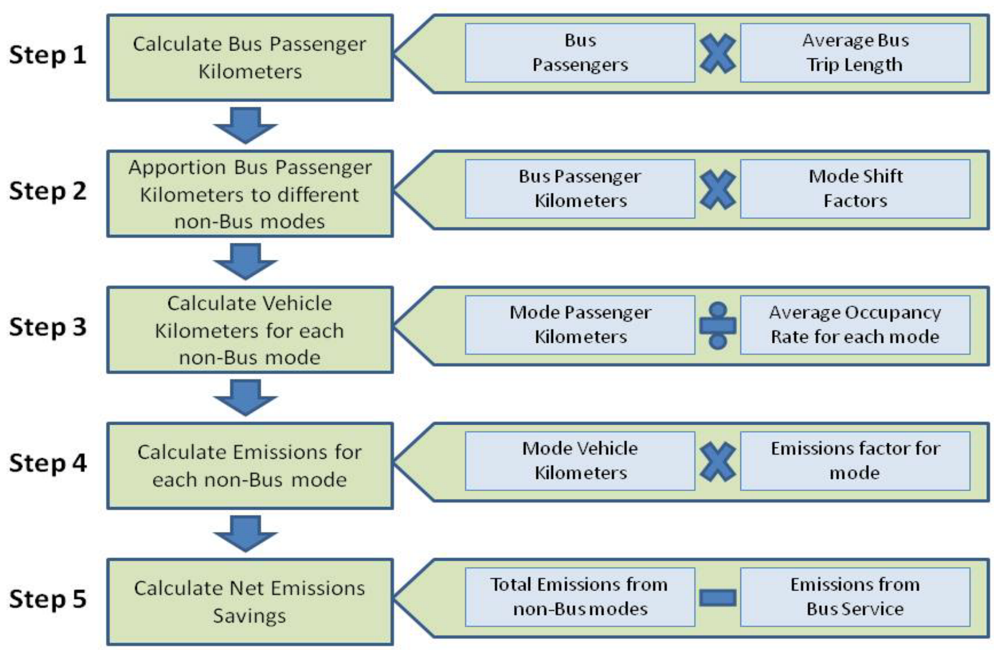

FIGURE 1 Methodology for estimating emissions reductions from Public Bus Transport

For the estimation of potential future emissions savings, the 'ASIF' equation for calculating total emissions is used. In this methodology total emissions are a function of total travel activity ('A'), mode structure of travel ('S'), the fuel intensity of each mode ('I') and carbon content of the fuel choice ('F') *(19)*. Forecasting total emissions thus involves a bottom up calculation using observed current population, trips rates, travel distances, mode shares, vehicle occupancy rates and vehicle emissions factors. Figure 2 provides a graphical representation of the ASIF equation. Reasonable assumptions about the evolution of these factors are then applied to forecast their values for 2021 and 2031 for each city, following the method laid out in Rayle and Pai *(5)*. For both the automobility and sustainable transport scenarios, forecasted population, per capita trip rates, and vehicle emission factors remain the same. In Ahmedabad, public transport remains the domain of the bus. In Bangalore, the soon to be launched metro rail service contributes to the growing mode share of public transport in the sustainable transport scenario.

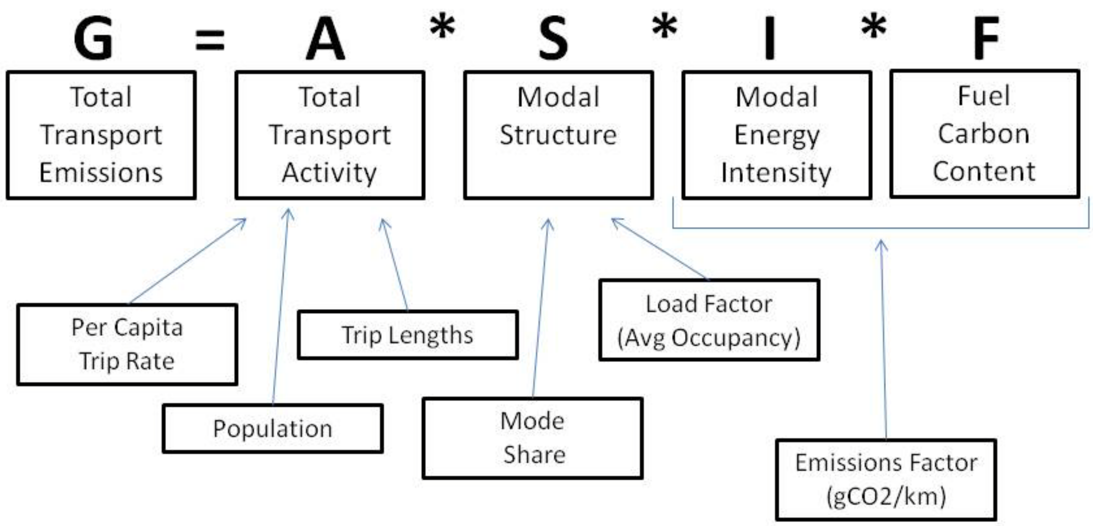

FIGURE 2 'ASIF' equation for measuring total transport emissions and factors that influence its components. Source: *(19)*

Data Sources

Data on ridership and service kilometers for public bus services in Ahmedabad and Bangalore were obtained directly from the service providers, AMTS and BMTC respectively *(11, 12)*. Travel characteristics including mode share, trip length and vehicle occupancy for Ahmedabad are taken from a city-wide travel survey conducted in 2003 and cited in the main design document for the Janmarg BRTS *(10)*. For Bangalore, travel characteristics were obtained from a travel behavior study of the Bangalore Metropolitan Region conducted in 2010 *(13)*. Demographic data were obtained from the 2011 Census *(9)*. Emissions factors for Indian vehicles are sourced from a comprehensive study conducted by the Automotive Research Association of India (ARAI) in 2008 *(20)*. This study developed emissions factors for a wide variety of vehicles, of different types, vintages and engine technologies. These data sources fully specified the inputs required for the calculation of ‘past’ and ‘present’ emissions savings.

These same data sources also served as the baseline for the estimation of ‘future’ emissions savings. Developing these estimates requires the forecasting of several travel characteristics that form inputs into the model that calculates total travel activity. This necessarily requires some assumptions to be made regarding the evolution of these travel characteristics over time. The following section explains the key assumptions that were made for this analysis.

Key Assumptions

Demographics

The population of both Ahmedabad and Bangalore are expected to grow, albeit at a slower rate than in previous decades. Reduced migration and lower fertility rates are assumed to account for this slow down in population growth. Population figures for 2021 and 2031 are derived from the observed trend in decadal growth rates for these cities. These rates are assumed to fall in each subsequent decade.

Population Density and Urban footprint

Population growth in both cities will inevitably lead to an expansion of their urban areas. This is because growth at higher than current densities is assumed to be both unfeasible and undesirable. However the density at which growth occurs is different for each scenario. In the automobility scenario, the reliance on car travel promotes low density growth concentrated in the urban periphery. As a result, growth is accompanied by sprawl and occurs at lower than present densities. It is assumed that this pattern of growth results in a metropolitan area with 80% the current density in 2021, and 60% the current density in 2031. In the sustainable transport scenario, high quality public transport promotes compact development and growth takes place at existing densities.

Trip Length

For both Ahmedabad and Bangalore, historical data for the evolution of trip lengths is scarce. Extrapolating trip lengths for the future from such limited data is undesirable. Instead, future trip lengths are forecast by exploiting an observed relationship between city form and existing trip lengths. The metropolitan areas of both Ahmedabad and Bangalore are roughly circular in shape. It is therefore assumed that the observed ratio of trip lengths (for each mode) to the radius of a circle encompassing an area equivalent to that of the metropolitan region remains constant. That is, future trip lengths grow in proportion to the increasing spatial dimensions of the city. Trip lengths for each mode in the Automobility scenario, which exhibits low density growth and thus more sprawl, are therefore higher than those for the Sustainable Transport scenario.

Trip Rate

Historical time-series data on trip rates is also limited for both cities. Forecasting future per capita trip rates from such scarce data is likely to be inaccurate. Given the observed positive correlation between income and trip rates, it is assumed that the increase in trip rates follows the trend exhibited in cities around the world for which more data is available. For cities in developed countries, per capita trip rates have stabilized at between 2 and 3 trips per day *(21, 22,* *23)*. Since the trip rates for both Ahmedabad (1.16) and Bangalore (1.28) are at relatively similar levels at present, it is assumed that trip rates for both cities will rise to 2 in 2021 and 3 in 2031.

Mode Shares

Future mode shares for each city are forecast taking current observed mode shares as a starting point and differ depending on the scenario. In the Automobility scenario, mode shares for cars increase, whereas that of buses decreases from present rates. Conversely, bus mode share in the Sustainable Transport scenario increases, whereas the mode share of individual transport collectively decreases. Mode shares for 2-wheelers and autorickshaws decrease in both scenarios, albeit at a slower rate in the case of Automobility. This is because rising incomes are likely to ensure that private motor vehicle travel in the future is predominantly car-based. In Bangalore, the soon to be opened metro system also contributes to the mode share of public transport. Projected ridership from the metro project plan is used to forecast the mode share of the metro system *(24)*.

Table 3 shows the evolution of the travel characteristics used in this model through 2031.

TABLE 3 City Size and Travel Activity – Current and Forecast

Ahmedabad

	Current	Automobility		Sustainable Transport	
	2011	2021	2031	2021	2031
City Characteristics					
Population (millions)	6.60	7.93	9.11	7.93	9.11
Density (people/sq. km.)	4966	3973	2980	4966	4966
City Size (sq. km.)	1330	1995	3059	1596	1835
Per Capita Trip Rate	1.16	2	3	2	3
Mode Share (% of total trips)[a]					
Bus	8.4	8.0	7.00	15.00	30.00
Train	0.3	1.0	1.00	2.00	3.00
Car	2.5	16.0	30.00	7.00	10.00
2-W	25.3	28.0	29.0	22.0	15.0
Autorickshaw	8.3	9.0	8.0	8.0	8.0
Avg Trip Length (km)[a]					
Bus	12.0	15.7	18.2	13.1	14.1
Train	36.8	45.1	55.8	40.3	43.2
Car	11.2	13.7	17.0	12.3	13.2
2-W	6.8	8.3	10.3	7.4	8.0
Autorickshaw	5.2	6.4	7.9	5.7	6.2

Bangalore

	Current	Automobility		Sustainable Transport	
	2011	2021	2031	2021	2031
City characteristics					
Population (millions)	9.59	12.95	16.83	12.95	16.83
Density (people/sq. km.)	4378	3502	2627	4378	4378
City Size (sq. km.)	2190	3696	6406	2957	3844
Per Capita Trip Rate	1.28	2	3	2	3
Mode Share (% of total trips)[b]					
Bus	30.0	25.0	20.0	35.0	45.0
Train	0.0	6.0	5.0	6.0	5.0
Car	5.5	18.0	40.0	7.0	11.0
2-W	21.4	18.0	15.0	14.0	12.0
Autorickshaw	4.6	4.0	4.0	4.0	4.0
Avg Trip Length (km)[b]					
Bus	10.8	14.0	18.5	12.5	14.3
Train	7.0	9.1	12.0	8.1	9.3
Car	10.3	13.4	17.6	11.9	13.6
2-W	8.0	10.4	13.7	9.3	10.6
Autorickshaw	5.9	7.7	10.1	6.9	7.8

Notes: [a]2003 figures [b]2010 figures
Sources: *(9) (10) (13)*

Emission Factors

It is expected that, due to improvements in internal combustion engine technology, emissions factors for all modes will gradually decrease through 2031. India does not currently have a vehicle emissions policy regulating fuel efficiency. However, standards for other criteria pollutants do exist are generally observed to follow Euro emissions standards with a five year time lag *(25)*. This trend represents an annual rate of improvement of 2.1%, and is applied to emissions from both passenger vehicles and buses. Emissions factors for 2-wheelers and autorickshaws, which are already relatively low, are expected to improve by 1.5% a year. The emissions factor for trains is expected to approach those of rail systems in advanced Asian cities *(26)*. Table 4 shows current emissions factors and the change in their values through 2031.

TABLE 4 Emissions Factors for Indian Vehicles– Current and Forecast through 2031

	gCO2 / KM		
	2011[a]	**2021**	**2031**
2-Wheeler (2-Stroke)	37.7	32.5	28.0
2-Wheeler (4-Stroke)	43.8	37.8	32.5
Autorickshaw (Petrol 2-Stroke)	62.8	54.1	46.6
Autorickshaw (Petrol 4-Stroke)	73.8	63.6	54.8
Autorickshaw (CNG)	67.7	58.3	50.3
Autorickshaw (LPG)	61.4	52.9	45.6
Car (Petrol)	142.2	115.5	93.8
Car (Diesel)	182.3	148.1	120.3
Bus (Diesel)	602.2	489.2	397.4
Bus (CNG)	806.5	655.2	532.2
Train (Commuter)	1063	860.98	696
Train (Metro)	1541	1246.9	1008

Notes: [a]Values for 2011 are assumed to be the same as 2007, the year of the source.
Sources: *(20) (25) (26)*

Two other model inputs – vehicle occupancy rates by mode and fleet composition by fuel type – are assumed to remain constant at current levels.

RESULTS

Investing in bus systems have resulted in significant reductions in carbon emissions for both Ahmedabad and Bangalore. By investing in new buses, moderately expanding service levels and rationalizing its route and fare structure, Ahmedabad has managed to save over 70,000 tons of CO2 emissions per year on average over the last five years. Similarly, improved bus services in Bangalore have saved an average of just over 59,000 tons of CO2 per year since 2005. These are significant sums – comparable to the estimated annual savings from the Transmilenio BRT system in Bogota, Colombia *(8)*. Table 5 shows the year by year savings in emissions for the period 2005-2010

Despite adding nearly twice as many additional passengers as Ahmedabad, emissions reductions in Bangalore have been lower. A comparison of service indicators reveals why this is so, and also speaks to the effectiveness of the different strategies adopted by the two cities to improve bus services. In Bangalore, the service levels have increased dramatically, by 49% over 2005 levels. By comparison, service kilometers in Ahmedabad increased by only 24%. This suggests that while Bangalore's supply driven strategy has been effective at attracting travelers to the public bus system, Ahmedabad's strategy of fleet renewal and route rationalization has been even more effective. However, the significant swing in passenger numbers in Ahmedabad from 2000 also suggests that there was a high pent up demand for public transport which the new initiatives helped serve, rather than attracting marginal consumers as in the case of Bangalore. Nevertheless, given that Bangalore's BMTC currently operates in excess of 2600 routes, the experience of Ahmedabad suggests that a similar route rationalization strategy in Bangalore can continue to serve the current numbers while reducing service kilometers and thus emissions even further

TABLE 5 Emissions Reductions from Increases in Bus Ridership, 2005-2010

Ahmedabad						
	2006	2007	2008	2009	2010	Total
Additional Passengers (Average Daily)	230,000	397,000	495,000	471,000	552,000	-
Additional Service (km, Average Daily)	10,661	29,044	24,994	26,552	18,866	-
Displaced Emissions (Tons CO2/Year)	40,297	69,640	86,859	82,642	96,874	376,311
Addition Service Emissions (Tons CO2/Year)	2,343	6,382	5,492	5,834	4,145	24,196
Net Emissions Reduction (Tons CO2/Year)	37,955	63,258	81,367	76,808	92,728	352,115
Bangalore						
	2006	2007	2008	2009	2010	Total
Additional Passengers (Average Daily)	271,000	568,000	652,000	820,000	1,043,000	-
Additional Service (km, Average Daily)	51,781	98,630	217,260	298,082	395,616	
Displaced Emissions (Tons CO2/Year)	42,732	89,563	102,809	129,299	164,462	528,866
Addition Service Emissions (Tons CO2/Year)	11,378	21,672	47,739	65,498	86,929	233,215
Net Emissions Reduction (Tons CO2/Year)	31,354	67,891	55,070	63,802	77,534	295,651

TABLE 6 Emissions Reductions from Recent Innovations in Bus Services

	Ahmedabad	Bangalore
Service Name	Janmarg BRTS	Big10 Services
Ridership (Average Daily)		
Year 1 of Operation	45,919	108,570
Year 2 of Operation[a]	-	164,571
Current	102,182	188,761
Mode Shift (%)		
Car	4.21%	1%
Autorickshaw	26.58%	3%
2-Wheeler	16.66%	9%
Emissions Savings (Tons CO2/Year)		
Year 1 of Operation	2,035	2,011
Year 2 of Operation[a]	-	3,048
Annual Savings at Current Ridership rates	5,130	3,496

Notes: [a]Janmarg has only been in operation for 14 months.

Table 6 shows that recent innovations in both cities, Janmarg in Ahmedabad and Big10 services in Bangalore, have also been effective at reducing carbon emissions. Both of these new services have managed to effect mode shift from individual to public transport modes, resulting in lower emissions. At current ridership rates, the Janmarg BRTS results in savings of 5,130 tons of CO2 per year, and Big10 services save 3,496 tons of CO2 per year.

Comparing emissions savings from Janmarg and Big10, the difference in scale of the reductions achieved again points to the relative effectiveness of the different approaches for improving services. In particular, the mode shifts achieved by Janmarg are dramatically higher than those of the Big10 service. This is not entirely surprising – with the full BRT treatment of segregated lanes, level boarding and priority at junctions, Janmarg is able to offer a very high quality public transport experience. The fact that mode shift has occurred at all suggests that the trunk services offered by Big10 are an improvement on regular BMTC services along the same corridor. Nevertheless, without any sort of bus priority, Big10 buses are still stuck in the same traffic as other buses. Ultimately, cities seeking to achieve significant mode shifts in favor of public transport will need to invest in the infrastructure and bus priority measures that move performance levels towards those seen in BRT systems.

TABLE 7 Emissions Savings Forecast

		Total Emissions (million Tons CO2/Year)	
		Ahmedabad	Bangalore
2011	Current	0.34	0.74
2021	Automobility	2.01	2.86
	Sustainable	1.06	.1.60
	Savings	47.15%	43.91%
2031	Automobility	3.98	10.90
	Sustainable	1.44	3.96
	Savings	63.94%	63.63%

The final analysis presented in this paper points to the major long term reductions in carbon emissions that can be achieved if Indian cities make a concerted effort to promote sustainable transport and work to prevent the unchecked rise of motorization and private vehicle use. The results of the ‘future’ savings forecast show that by 2040, cities like Ahmedabad and Bangalore can potentially reduce transport emissions by nearly 2/3[rds] if timely investments in high quality public transport are made (Table 7). The size of these investments will be substantial. Assuming that current rates of passengers per bus per day remain constant, serving the number of trips forecast for public bus systems in the Sustainable Transport scenario will require a fleet of nearly 30,000 buses for Bangalore and 5500 buses in Ahmedabad. These numbers represent a 5- and 6- fold expansion of existing fleets for these cities, respectively.

CONCLUSIONS

The analysis presented in this paper shows that well performing and high quality urban bus systems can achieve significant emissions reductions at the city level. Improving the quality and level of service of bus-based public transport is thus is an important weapon in the emissions reduction arsenal for cities in India. The strategy of improving bus services also has some significant advantages over other strategies for moderating emissions from urban transport. Most of these other strategies – a compact, mixed use development paradigm that promotes the use of non-motorized transport and avoids the need for motorized trips, building rail based mass transit, improving the energy efficiency of existing technologies and systems – are interventions that are both very expensive and require long gestation periods before any benefits are seen. By comparison, improving bus services by, for example, expanding and upgrading the bus fleet and rationalizing and improving route planning can be achieved at relatively low costs. Shorter timelines for implementation also mean that the benefits of these investments can be realized sooner. This suggests that, while ultimately a combination of many different interventions will be required to achieve maximum reductions in urban transport emissions, improving the quality and reach of bus systems are a ‘quick win’ and should be the highest priority for city governments and agencies.

From the international perspective of climate change mitigation, it is interesting to note that the emissions impacts of public bus systems mean that programs to invest in and improve the quality of such systems exhibit many of the characteristics of Nationally Appropriate

Mitigation Actions (NAMAs). NAMAs are broadly defined as actions that developing countries voluntarily undertake that significantly reduce emissions. In particular, city and state governments in India that are searching for alternative sources of funding and support for upgrading their urban transport networks would benefit from framing investments in bus systems as NAMAs and seeking the appropriate international support for implementing such programs. Conversely, given the scope for reducing urban transport emissions by investing in bus systems, international multilateral agencies involved in climate change mitigation should develop urban transport specific funding mechanisms to support and promote the implementation of such transport related NAMAs in developing countries.

ACKNOWLEDGMENTS

Research for this paper was conducted at EMBARQ India – The WRI Center for Sustainable Transport, and was made possible by funding from the British High Commission's "Strategic Programme Fund – Low Carbon, High Growth" grant program.

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