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Impact of transport sustainability on air quality in Lahore, Pakistan

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Transport sustainability has direct association with improvement of urban emissions levels. Different sustainable steps like promotion of public transport, walking or the use of bicycles, reduction in the number of personal cars and improvement in speed (up to 50 km/h), fuel and model of vehicles can decrease emissions levels in the cities. In this study, emission factors of seven different vehicles have been calculated using the OSPM software. An estimated decrease of 7% in NO_x emission, 33% in CO emission and 25.8% in benzene emission has been observed with 10% reduction in the number of cars and 10 km/h gain in speed (from 40 to 50 km/h). It has also been observed that 2005 model buses using 1999 level fuel emit 1.3 times less benzene, NO_x and CO emissions compared to 2000 model buses using the quality of fuel, which was available in 1990 in Europe.

Keywords: Air quality, emission factor, fuel quality, public transport, transport sustainability.

THE world population has been increasing at a rapid rate, especially in the developing and under-developed nations. One of the main features of the developing nations is the emerging urbanization. According to the United Nations' (UN) estimates, more than 90% of the urbanization has been observed in developing nations[1]. The migration to big cities due to lack of facilities at grass-root level and small cities has created problems like dense population, traffic congestion, air pollution, poor slum conditions, health issues, etc. in big cities of developing countries. Under-developed countries are in a phase of economic development at a considerable rate. The rapid urbanization often results in enhanced ambient air pollution levels. In the coming 20 years, the urban population will be 2 billion in the developing countries, with an increasing rate of 70 million per year. The urban population will be doubled in Asia and Africa at that time. Almost 80% of the urban population of the world will be living in developing countries by 2030 (ref. 2). The results of enhanced fossil-fuel burning have also been observed at Himalayan glaciers with reduction in ice cap from 2000 to 2010 (ref. 3).

The UN has introduced 17 Sustainable Development Goals for a sustainable and peaceful world for mankind by 2030 (ref. 4). Goal 11 deals with sustainability of cities. The target 11.2 states that: 'By 2030, provide access to safe, affordable, accessible and sustainable transport systems for all, improving road safety, notably by expanding public transport, with special attention to the needs of those in vulnerable situations, women, children, persons with disabilities and older persons'[5].

Pakistan is one of the developing countries undergoing industrialization with considerable increase in motorization and energy use. The population and area of big cities in Pakistan have been increasing at a considerable rate. Lahore is the second largest city in Pakistan. In the past few years, an increase in population and car usage has been observed in Lahore. Vehicles are the main source of air pollution in urban areas and cause health impacts on road users and urban communities.

The number of vehicles has been increasing in Punjab Province and Lahore at a considerable rate. Figure 1 shows the trend of increase in the total number of vehicles, cars, motorcycles and auto rickshaws from 2006 to 2015.

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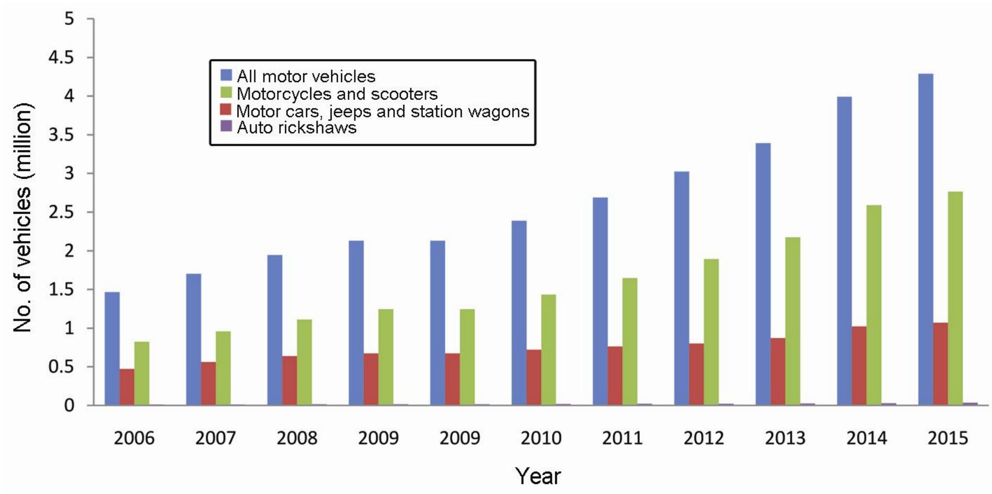

Figure 1. Trend in increase in the number of vehicles in Lahore, Pakistan.

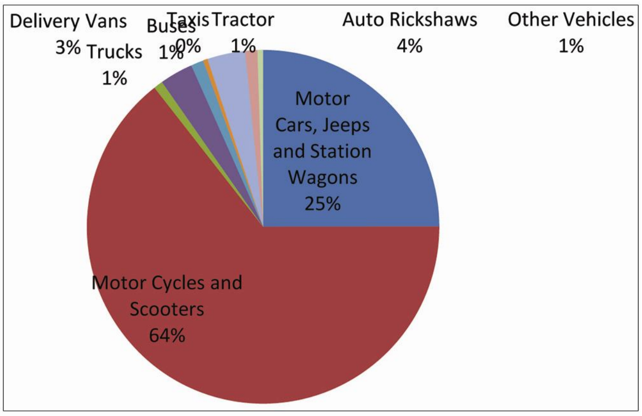

Figure 2. Percentage of registered vehicles in Lahore as on 30 June 2015.

A total number of 4,287,662 vehicles were registered in Lahore on 30 June 2015; of which 64.5% was motorcycles and 25% was cars, jeeps and station wagons (Figure 2). The overall rate of increase in the total number of vehicles, cars and motorcycles was 14.97%, 9.73% and 18.18% respectively (Table 1). Significant increase was observed in the number of motorcycles, due to their low buying and operational cost.

Each vehicle on the road using fossil fuels has been contributing to urban air pollution in the city. People are reluctant to use public transport as it is inefficient, inconvenient and time-consuming[6]. The land-use developments in Lahore city lack basic policies of transport sustainability. The level of sulphur is high in fossil fuels being used in Pakistan compared to international standards, which is the main source of SO_2 emissions in urban and industrial areas of the city[7]. The manufacturing companies are unable to introduce better engine quality and catalytic converters in the country due to poor fuel quality. People are found to use conventional lifestyle in many aspects like use of personal cars, use of conventional fuels, etc. There is need to introduce modern sustainability measures in all walks of life.

Emission of greenhouse gases is a matter of concern at the city, regional and global level. There is need for effective mitigation policies to reduce carbon emissions at these levels[8]. Use of renewable energy resources has resulted in the reduction of emission levels in the cities[9].

A long list of transport sustainability indicators may be generated with regard to environmental, social and economic domains. In this study, indicators having a direct link with environmental aspects have been selected. These include: reduction in the number of personal cars, improvement in fuel and engine quality, enhanced road width (number of lanes), signal-free tracks.

The Operational Street Pollution Model (OSPM) has been used to calculate emission factor of different vehicles. This model has already been successfully used in Stockholm, Helsinky, Copenhagon, China, USA and Vietnam[10–16]. It has also been successfully used to model NO_x emissions in Chembur (an industrialized and congested area with automobiles), Mumbai, India[17]. The OSPM software has built-in data regarding calculated emission factors of different models of vehicles. Moreover, these emission factors can also be calculated at different speeds for a given quality of fuel. In this study the emission factors of seven different classes of vehicles have been calculated considering fuel quality of the 1990 level and vehicle models of the 2000 found in Europe, at an average speed of 40 km/h. Emission factors of PM_{10}, NO_x, CO and benzene have been calculated using the OSPM software and emission factor of SO_2 has been taken from a previous study in Hanoi, Vietnam with similar conditions[2].

Five main roads of Lahore (Ferozpur road, Gulberg road, Jail road, Mall road and Multan road) were selected to study the transport sustainability indicator. Diurnal

Table 1. Rate of increase in vehicles in Lahore, Pakistan

Year	Number ratio of increase (%)	All motor vehicles	Motor cars, jeeps and station wagons	Motorcycles and scooters	Trucks	Delivery vans	Buses	Taxis	Auto rickshaws	Tractor	Other vehicles
2006	No.	1,464,344	473,311	822,264	11,439	33,243	27,792	10,586	58,024	26,540	1145
2007	No.	1,703,007	561,500	957,939	14,146	37,036	31,365	11,660	59,627	28,415	1319
	Rate of increase	16.3	18.6	16.5	23.7	11.4	12.9	10.2	2.8	7.1	15.2
2008	No.	1,944,709	637,787	1,110,218	15,999	40,133	32,518	11,771	66,246	28,575	1462
	Rate of increase	14.2	13.6	15.9	13.1	8.4	3.7	1	11.1	0.6	10.8
2009	No.	2,129,990	673,449	1,245,389	17,029	42,315	33,335	11,771	74,259	30,757	1686
	Rate of increase	9.5	5.6	12.2	6.4	5.4	2.5	0.0	12.1	7.6	15.3
2010	No.	2,387,993	722,012	1,432,639	18,683	45,094	34,132	11,789	87,541	34,220	1883
	Rate of increase	12.1	7.2	15.0	9.7	6.6	2.4	0.2	17.9	11.3	11.7
2011	No.	2,687,987	764,265	1,647,842	20,806	48,046	35,345	11,867	102,029	37,305	20,482
	Rate of increase	12.6	5.9	15	11.4	6.6	3.6	0.7	16.6	9	987.7
2012	No.	3,022,126	801,403	1,894,324	22,772	78,621	36,841	14,766	113,007	39,551	20,841
	Rate of increase	12.4	4.9	15	9.5	63.6	4.2	24.4	10.8	6	1.8
2013	No.	3,391,268	871,244	2,172,760	24,683	81,922	40,485	15,146	222,517	42,191	20,320
	Rate of increase	12.2	8.7	14.7	8.4	4.2	9.9	2.6	96.9	6.7	–2.5
2014	No.	3,991,517	1,023,110	2,588,254	27,344	86,753	43,972	15,247	139,927	45,971	20,939
	Rate of increase	17.7	17.4	19.1	10.8	5.9	8.6	0.7	–37.1	9	3.1
2015	No.	4,287,662	1,070,243	2,763,872	36,265	130,344	50,519	17,404	149,562	47,356	22,097
	Rate of increase	7.4	4.6	6.8	32.6	50.3	14.9	14.2	6.9	3.0	5.5
Average rate of increase		12.72	12.7	9.6	14.5	14.0	18.0	7.0	6.0	15.3	6.7
Vehicles registered during 2016		1,694,580	1,694,580	120,577	1,458,603	–	–	–	–	–	–

Source, Additional Director General, Excise & Taxation, Punjab, Lahore, Pakistan.

Table 2. Average diurnal traffic at five selected roads of Lahore as on May 2016

Vehicle	Ferozpur road	Gulberg road	Jail road	Mall road	Multan road
Motorcycle	59,214	22,212	24,642	32,084	40,994
Car	26,169	13,740	19,101	20,531	19,777
Van	2469	1185	1288	1506	1709
Minibus	2432	1019	1081	1325	1871
Bus	441	146	119	190	186
Truck	803	249	309	259	547
Auto rickshaw	10,830	4522	4765	4703	8331

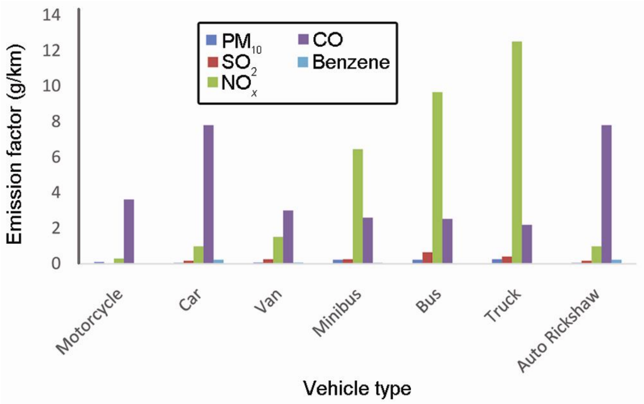

Figure 3. Calculated emission factors of different classes of vehicles in Lahore.

(24 h) traffic pattern was studied on these five roads. Traffic count was performed by a team of three persons during May 2016 on working days. A movie camera was used to record the number of vehicles on a single point on each road. Traffic count was performed on 9, 10, 11, 12 and 17 May 2016, for Ferozpur road, Gulberg road, Jail road, Mall road and Multan road respectively.

More number of lanes and low adjacent building heights help reduce vehicular exhaust emissions. The impact of road width on emissions levels has been discussed according to semi-empirical urban street (SEUS) model design.

The signal-free tracks having underpasses and overhead bridges, help reduce congestion and improve vehicle speed as well. The reduction in emission levels of vehicles for an optimum increase in speed has been calculated and drawn using the OSPM software.

Diurnal traffic was calculated on the five selected roads in Lahore. The average speed remained around 40 km/h on Ferozpur road, Mall road and Multan road. The average speed on Jail road and Gulberg road was around 50 km/h. The economical and capacity-building factors in developing countries are hurdles in conducting such studies[18]. Figure 3 provides the emission factors of seven different classes of vehicles.

There are a large number of personal cars on the road due to lack/less use of public transport by the upper and middle class of the city. The use of personal cars can be reduced to a considerable number through introduction of better and efficient public transport. Table 2 provides the details of observed diurnal traffic at the five selected roads.

Table 3 shows the calculated emission levels (due to cars) of selected pollutants for each kilometre at an average speed of 40 km/h in the five different roads. A possible decrease in the emission levels with decrease in number of cars and improvement in speed (from 40 to 50 km/h) has also been indicated.

PM_{10} and SO_2 emission factors remain almost the same with gain in speed of vehicles (from 40 to 50 km/h). An estimated decrease of 7% in NO_x emission, 33% in CO emission and 25.8% in benzene emission has been observed with 10% reduction in the number of cars and 10 km/h gain in speed (from 40 to 50 km/h). Similarly, 17.5%, 40.7 and 34% decrease has been observed in NO_x, CO and benzene emissions respectively, with 20% decrease in the number of cars and 10 km/h gain in speed (from 40 to 50 km/h) (Table 3).

Transport-related environmental pollution can also be reduced by introducing several innovations in vehicle design and fuel quality. Air quality is directly related to fuel consumption. In 2009, Pakistan had opted Euro II standards for vehicles, i.e. Pak II. The fuel quality in Pakistan is almost that of the 1990 level found in Europe. The benzene content (about 3.7%–5%) in petrol used in Pakistan is very high[19]. Similarly, the concentration of sulphur is considerably high in diesel (0.5%–1%) and furnace oil (1%–3.5%) compared to international standards[20]. Consumption of fossil fuels has been increasing at the rate of about 6% per annum. Half of the petroleum products is being used by the transport sector in Pakistan. Some South Asian countries have minimized the sulphur content in diesel to 0.035% and furnace oil to 0.5% (ref. 20). In India, a number of green policies were introduced in Delhi, under the direction of the Supreme Court of India. The content of sulphur in diesel (1%) and petrol (0.2%) was minimized to 0.05% from 1996 to 2001. The commercial vehicles were converted to CNG and 15-year-old automobiles were banned in Delhi[21]. Later, 10-year-old diesel vehicles were banned in India according to NGT Rule, 2015. A high level of fuel quality is required to achieve Euro standards in Pakistan.

Table 3. Possible decrease in car emission levels on five different roads

	Street	Emission kg/km				
		PM_{10}	SO_2	NO_x	CO	Benzene
Emissions generated by cars per km at an average speed of 40 km/h	Ferozepur Road	2.617	4.449	25.646	204.093	6.124
	Gulberg Road	1.374	2.336	13.465	107.159	3.215
	Jail Road	1.910	3.247	18.719	148.971	4.470
	Mall Road	2.053	3.490	20.121	160.123	4.804
	Multan Road	1.978	3.362	19.381	154.241	4.628
With 10% decrease in the number of cars and gain in speed (at 50 km/h)	Ferozepur Road	2.355	4.004	23.811	136.250	4.546
	Gulberg Road	1.237	2.102	12.502	71.538	2.387
	Jail Road	1.719	2.923	17.380	99.451	3.318
	Mall Road	1.848	3.141	18.681	106.896	3.566
	Multan Road	1.780	3.026	17.995	102.969	3.435
With 20% decrease in the number of cars and gain in speed (at 50 km/h)	Ferozepur Road	2.094	3.559	21.166	121.111	4.041
	Gulberg Road	1.099	1.869	11.113	63.589	2.121
	Jail Road	1.528	2.598	15.449	88.401	2.949
	Mall Road	1.642	2.792	16.606	95.019	3.170
	Multan Road	1.582	2.690	15.996	91.528	3.054

The decrease in sulphur content in petrol, diesel and furnace oil, and benzene content in petrol can improve the emission factor of different vehicles. Vehicles can achieve better Euro standards with provision of better fuel quality and use of catalytic converters. It must be made mandatory for luxury vehicles to be equipped with catalytic converters and pay tax on certain roads. However, catalytic converters can only be used in vehicles with provision of very low sulphur content (0.05% or less)[20].

The emission factors of SO_2 and benzene depend upon their concentration in fuels. Therefore, these emission factors can be improved through provision of better quality fuel with low benzene and sulphur content. The emission factors of CO, NO_x and PM can be improved through improved engine technology and the use of catalytic converters.

Figure 4 shows a comparison of emission factors of vehicles with different models and fuel quality. The results reveal a considerable reduction in emission factor with improvement in model and fuel quality. It has been observed that category I buses (2005 model, 1999 level fuel) have 1.3 times less benzene, NO_x and CO emissions compared to category II buses (2000 model, 1990 level fuel). Category I trucks have 1.3 times less benzene and 1.4 times less NO_x and CO emission compared to category II trucks. Category I cars have 8.4, 1.5 and 1.4 times less benzene, NO_x and CO emission respectively, compared to category II cars. Category I vans have comparable reduction in emissions like category I cars. Category 1 minibuses have comparable reduction in emissions like trucks and buses. It is possible for a developing country like Pakistan to opt for fuel quality level of 1999 and 2005 model standard vehicles of Europe.

Road width has a direct impact on traffic-produced turbulence. The SEUS model has been designed using the formula describing inverse relation between emission concentration and road width

$$C \propto 1/W,$$

$$C = E\,\mu s^{-1}\,W^{-1} + Cb, \quad (1)$$

where E is the emission rate per length, C the model concentration of pollutant in the street, μs the dispersion velocity, W the street width and Cb is background concentration[22]. Therefore, road width has a direct impact on reduction of air pollution on roads. Also, roads with more number of lanes, green belts, greater speed of vehicles and low adjacent building heights have low concentration of pollutants. The pollution levels are low at Gulberg road compared to Mall road, Multan road and Ferozpur road due to greater width, higher speed of vehicles and signal-free factors in the former.

A reduction in most of the pollutants has been observed with increase in speed to an optimum level. However, NO_x emissions increase with increase in speed for diesel vehicles. The congestion and low speed of vehicles result in enhanced levels of pollutants[23]. In Lahore, most of the personal cars and all motorcycles use petrol as fuel. Only the loader trucks and most buses use diesel as fuel. Therefore, increase in speed to an optimum level of 40–50 km/h results in decrease in urban emissions. Moreover, with provision of signal-free tracks, congestion, number of cold starts and fuel usage are found to decrease. Figure 5 shows the trend of vehicular exhaust pollutants for Euro II gasoline cars (cylinder capacity, cc: <1.41) generated by OSPM.

Urban air pollution has negative correlation with transport sustainability measures. Road width, better fuel quality, advance engine type, signal-free roads, mix developments and use of electronic technologies are

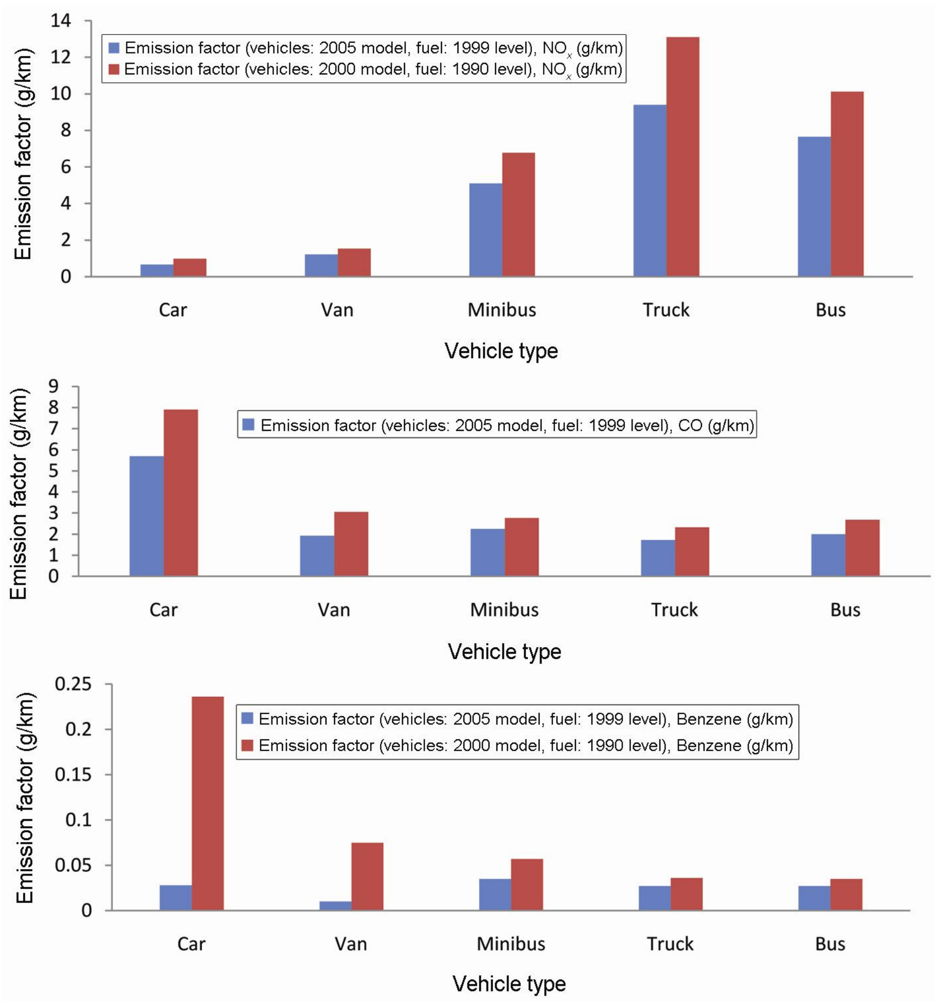

Figure 4. Comparison of emission factors of vehicles with different models and fuel quality which was in 1990 and in 1999 in Europe at an average speed of 40 km/h.

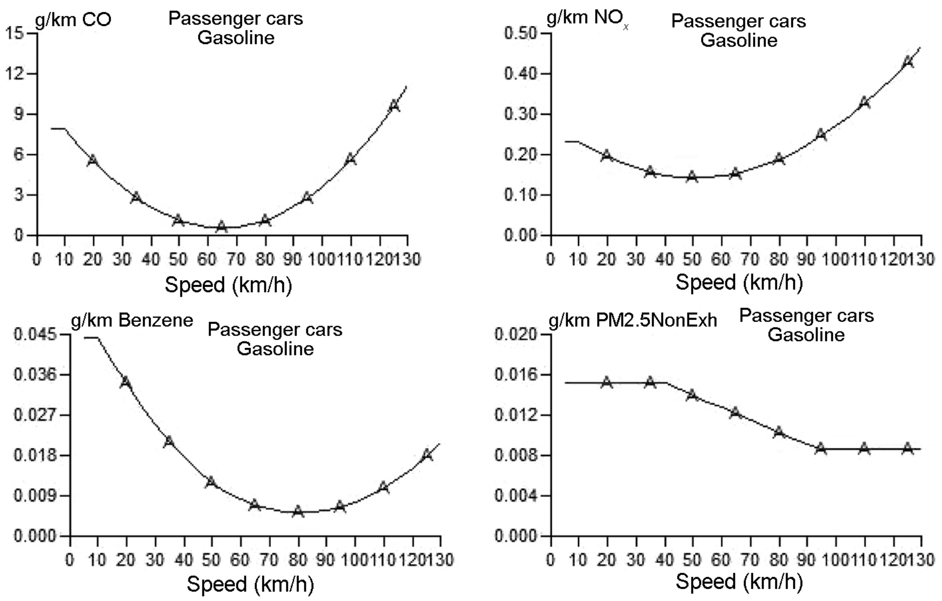

Figure 5. Vehicular exhaust emissions versus speed. NonExh, Non exhaust emissions.

found to have a positive impact on improvement of air quality. It has been observed that 2005 model buses using 1999 level fuel, emit 1.3 times less NO_x, benzene and CO emissions compared to 2000 model buses with 1990 level fuel (found in Europe). Similarly, 2005 model with 1999 level fuel emit 8.4, 1.5 and 1.4 times less benzene, NO_x and CO emission respectively, compared to 2000 model cars with 1990 level fuel (found in Europe).

Reduction in the number of cars can also improve the speed of vehicles, which can result in reduction of emissions, especially CO and benzene. It has been found that 20% decrease in the number of cars and 10 km/h gain in speed can reduce CO and benzene emissions to 40.7% and 34% respectively. Very little change has been observed for emission factors of NO_x, SO_2 and PM_{10} with gain in speed from 40 to 50 km/h.

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