Urban air pollutants and inventory in South Asia / India

(Focus: Urban Transport Emissions Modeling)

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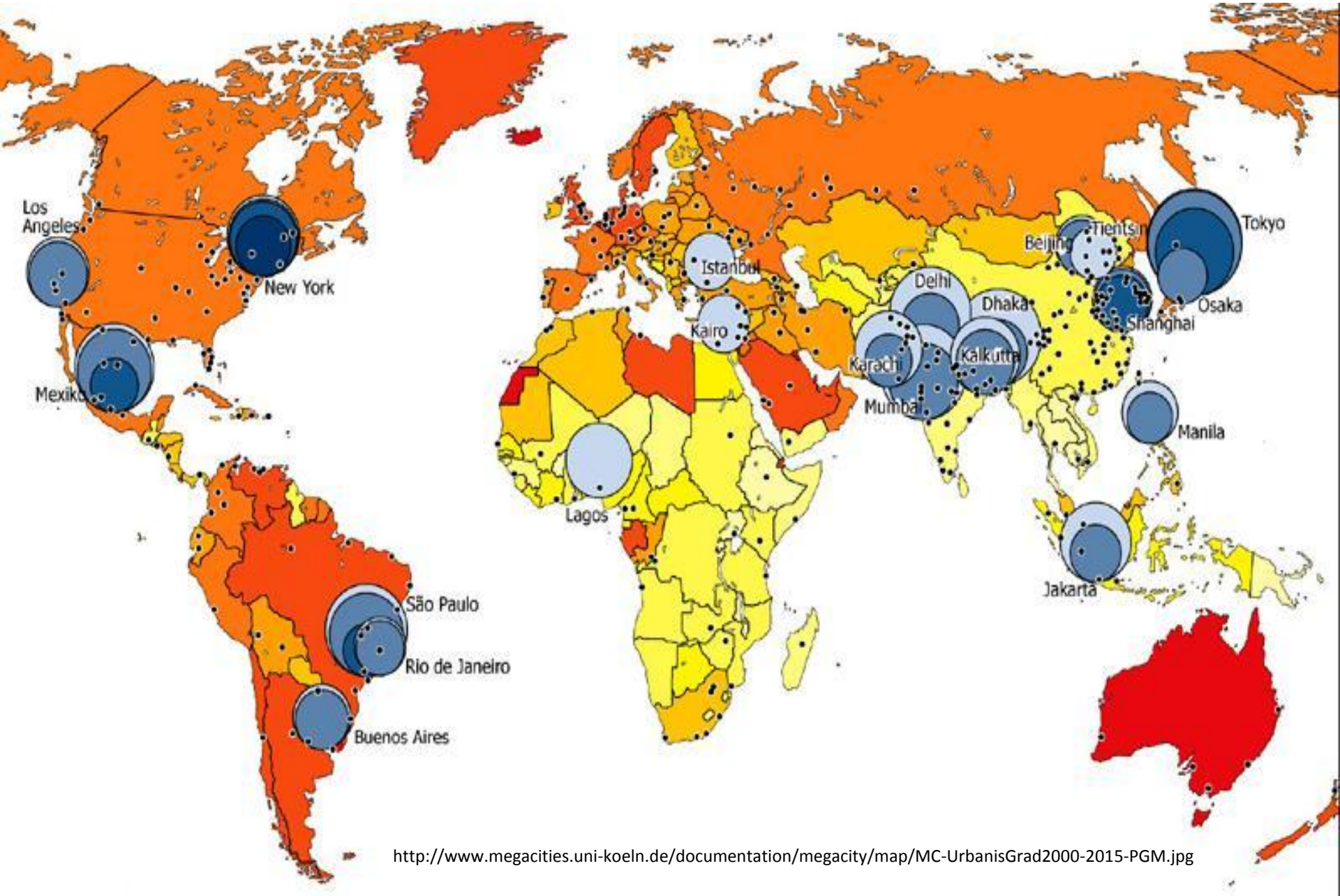
Large Urban Centers / Megacities of the world



http://www.megacities.uni-koeln.de/documentation/megacity/map/MC-UrbanisGrad2000-2015-PGM.jpg

Motivation for interest in urban centers / megacities

- The urban centers and megacities in Asia cover <2% of the land but produce 10-20% of regional trace gas emissions.

- Urban atmospheric emissions contribute to large-scale phenomena (e.g. Atmospheric Brown Cloud).

- Atmospheric chemistry models use global or regional emission inventories (EDGAR, TRACE-P);
  - ✓ often follow national approach; no detail on megacity scale,
  - ✓ no megacity level emission trends, making it difficult to capture dynamic developments in megacities.

- For a city like Delhi existing emission inventories focus on particular source (transport), problem (GHG) and only for a given year.

Some past growth statistics for megacity Delhi

Year	*Population*	*No. of vehicles*	*Road Length*	*Density*	*Density*
	(Million)	(Million)	(km)	(Veh./km)	(Veh./1000 person)
1971	4.066	0.18	8380	21.48	44.27
1981	6.22	0.521	14316	36.39	83.76
1991	9.421	1.813	21564	84.08	192.44
2000	13.783	3.457	28508	121.26	250.82
Growth					
(base yr. 1971)	x 3.39	x 19.21	x 3.402	x 5.65	x 5.67

Vehicular population in Delhi (million)							
	1971	*1985*	*1990*	*1995*	*2000*	Growth (base yr. 1971)	
Cars/jeeps	0.056	0.157	0.345	0.576	0.921		x 16.45
2-wheelers	0.093	0.579	1.113	1.618	2.231		x 23.99
3-wheelers	0.01	0.03	0.059	0.075	0.087		x 8.7
Taxi	0.004	0.009	0.009	0.013	0.018		x 4.5
Buses	0.003	0.014	0.018	0.026	0.042		x 14
Goods Veh.	0.014	0.052	0.092	0.125	0.158		x 11.29
Total	0.18	0.841	1.636	2.433	3.457		x 19.21

Major Vehicular Emissions

- Carbon Dioxide
- Carbon Monoxide (CO)
- Particulate Matter (PM)
- Nitrogen Oxides (NOx)
- Lead and Hydrocarbons (HC)
  - ✓ Precursors to Ozone

Air Toxics

- Aldehydes
  - Formaldehyde
  - Acetaldehyde
  - Others
- Benzene
- 1,3-butadiene
- Methanol
- Polycyclic organic matter (e.g. PAHs)

Vehicular Emissions and their Effects

	Health Effect					Climate Change	
Pollutant	**Direct**	**Indirect**	**Acid rain**	**Eutrophication**	**Visibility**	**Direct**	**Indirect**
CO_2						X	
CO	X						X
HC	X	X					X
NOx	X	X	X	X	X	X	
PM	X				X	X	
SOx	X		X		X		X

CO = carbon monoxide, HC = hydrocarbon, NOx = nitrogen oxides, PM = particulate matter, SO2 = sulfur oxide

Source : CPCB, 2010

Health effects associated with Vehicular Emissions

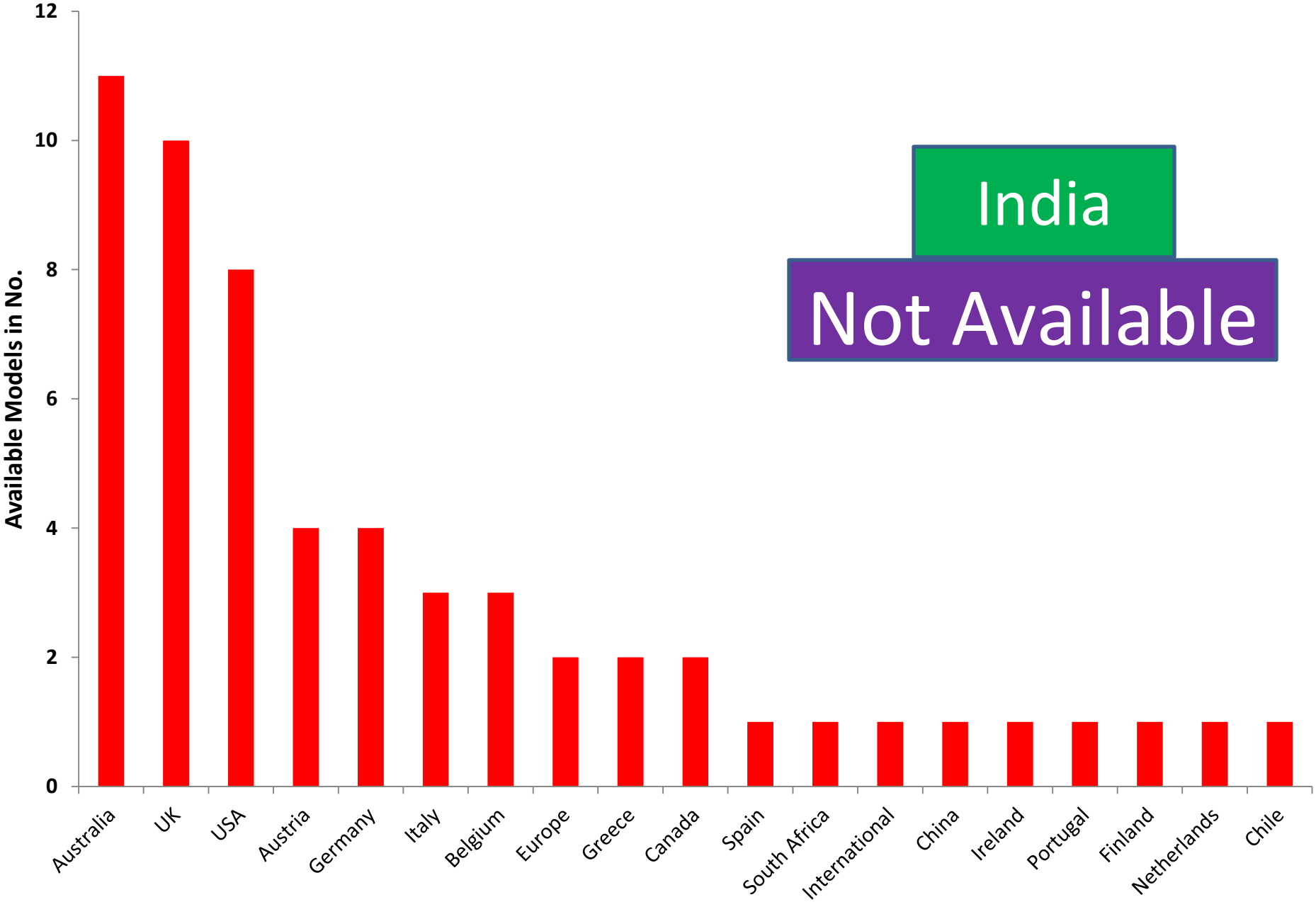
Pollutant	Effect on Human Health
Carbon Monoxide	Affects the cardio vascular system, exacerbating cardiovascular disease symptoms, may also particularly affect fetuses, sick, anemic and young children, affects nervous system impairing physical coordination, vision and judgments, creating nausea and headaches, reducing productivity and increasing personal discomfort.
Nitrogen Oxides	Increased susceptibility to infections, pulmonary diseases, impairment of lung function and eye, nose and throat irritations.
Sulphur Dioxide	Affect lung function adversely.
Particulate Matter and Respirable Particulate Matter (SPM and RSPM)	Fine particulate matter may be toxic in itself or may carry toxic (including carcinogenic) trace substance, and can alter the immune system. Fine particulates penetrate deep into the respiratory system irritating lung tissue and causing long-term disorders.
Lead	Impairs liver and kidney, causes brain damage in children resulting in lower I.Q., hyperactivity and reduced ability to concentrate.
Benzene	Both toxic and carcinogenic. Excessive incidence of leukemia (blood cancer) in high exposure areas.
Hydrocarbons	Potential to cause cancer

Source : CPCB, 2010

Emission inventories are important for assessing and simulating air quality and to evaluate policy decisions in air quality management.

Emission models can be used in the context of Decision Support Systems (DSS) to provide the analyst and the decision maker with quantitative estimates, trends, and insight on the policies simulated.

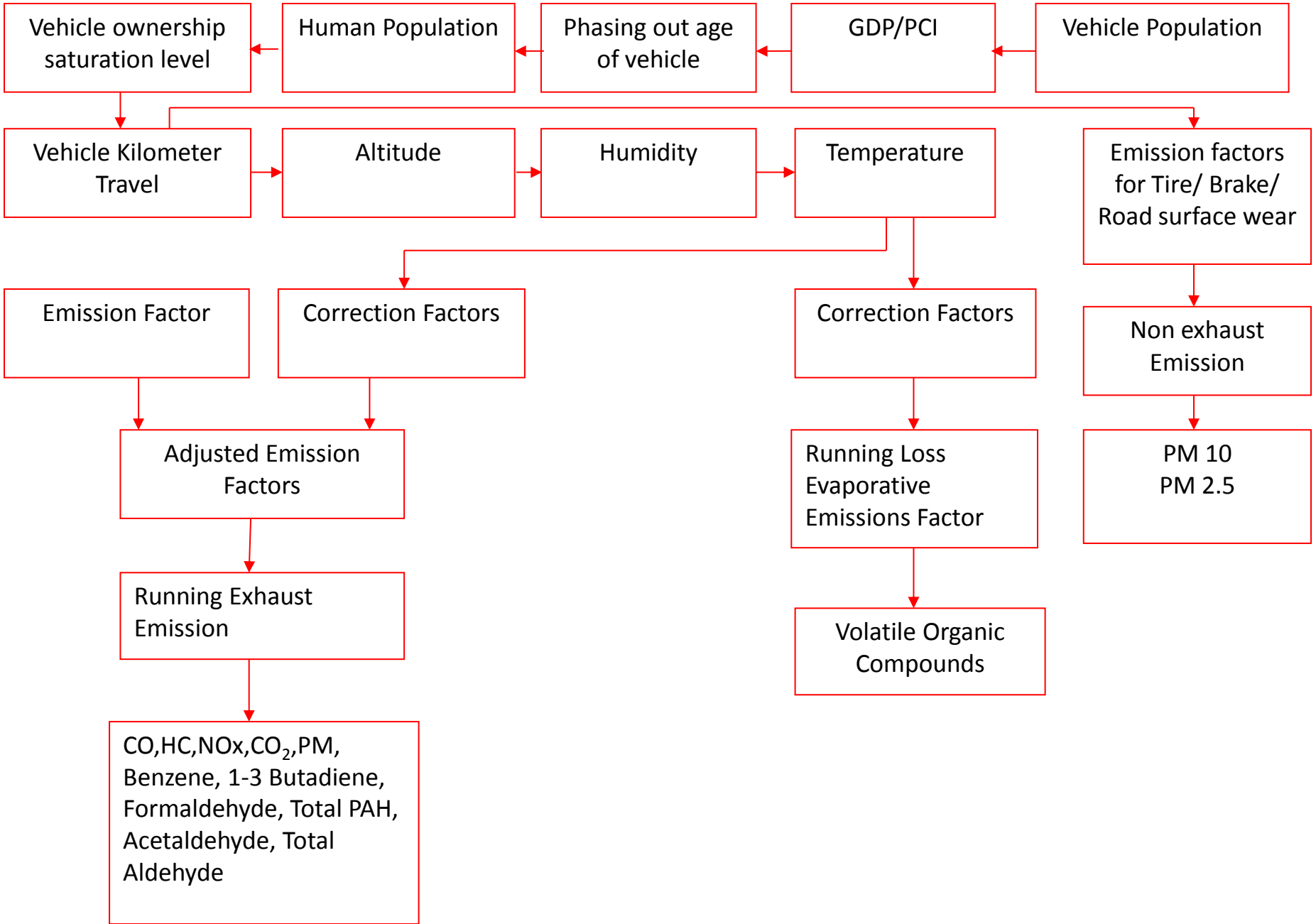
Available Vehicle emissions models in various countries



PRIMARY LIMITATIONS OF AVAILABLE MODELS

- All of these models have been developed in advanced countries, where exhaustive dataset are available.
- Due to much difference in technology, infrastructure, driving cycles etc., in the developed countries and that of a developing country like India, application of these models in Indian context may give erroneous results.
- Although International Vehicle Emission (IVE) model is specially designed for developing countries like India, but again it is similar to the U.S. and European models in complexity and input data requirements. It is very difficult to compile such dataset in India.
- Emission factor or basic rate of emissions of all models are the US and European based, which enhance the error in estimated emissions for India.
- Most of the models are not able to give output for more than one year.
- Most of model require experimental data, which is not possible for Indian conditions
- Most of the model are region specific

MODEL DESIGN



RUNNING EXHAUST EMISSIONS

Emission Factor

Adjusted EF

$$E_{api} = EF_{pi} \times C_{tpi} \times C_{hpi} \times C_{api}$$

$$E_{tpi} = P_i \times E_{api} \times V_i \times D_{ti}$$

Vehicle Population

Distance Travel

Traveling Days

Temperature

$$C_{TG} = \left[\left(\frac{C_{tHigh}}{C_{tLow}}\right)^{\frac{1}{(tHigh-tLow)}} - 1\right] \times 100$$

$$C_T = C_{tLow} \times (1 + C_{TG})^{(tT-4)}$$

Humidity

$$C_{hG} = \left[\left(\frac{C_{h80\%}}{C_{h20\%}}\right)^{\frac{1}{(80-20)}} - 1\right] \times 100$$

$$C_h = C_{h20\%} \times (1 + C_{hG})^{(h-20)}$$

Altitude

$$C_{AG} = \left[\left(\frac{C_{a1700m}}{C_{a950m}}\right)^{\frac{1}{(1700-950)}} - 1\right] \times 100$$

$$C_a = C_{a950m} \times (1 + C_{AG})^{(a-950)}$$

Vehicle Population

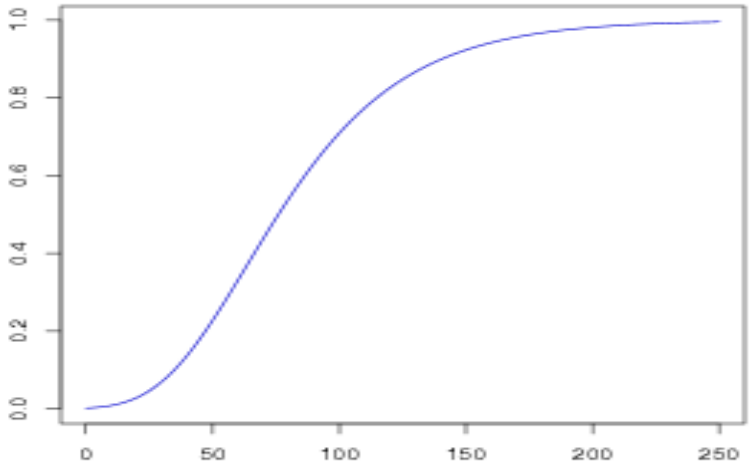
BASE LINE METHODOLOGY

Present and Past Registered Vehicles

$$x_{Pi} = \left[\left(\frac{RPi_{Final}}{RPi_{Initial\ Pi}} \right)^{\frac{1}{t}} - 1 \right] \times 100 \quad (1)$$

$$RPi_{Final} = RPi_{Initial\ Pi} \times (1 + x_{pi})^{t} \quad (2)$$

$$O_{Rpi} = RP_{Ci} - RP_{(C-Z)i} \quad (3)$$



Vehicle Population Projection

GDP/PCI

$$V_{pt} = \lambda e^{\alpha e^{\beta G}} \quad (4)$$

Saturation Level

$$\alpha = \frac{n(\sum GP_{it}) - (\sum G)(\sum P_{it})}{n(\sum (G^2) - (\sum G)^2} \quad (5)$$

$$\beta = \frac{(\sum P_{it})(\sum (G^2)) - (\sum x)(\sum GP_{it})}{n(\sum (G^2) - (\sum G)^2} \quad (6)$$

$$SS = \sum_{i=1}^{n} (Pit - Pitfit)^2 \quad (7)$$

Model wise calculation

$$P_{imy} = P_{if-}P_{ip}$$

$$\%RP_{iy} = \frac{RP_{iy}}{RP_{icy} \times 100}$$

$$P_{i=} \frac{P_{icy} * \%RP_{iy}}{100}$$

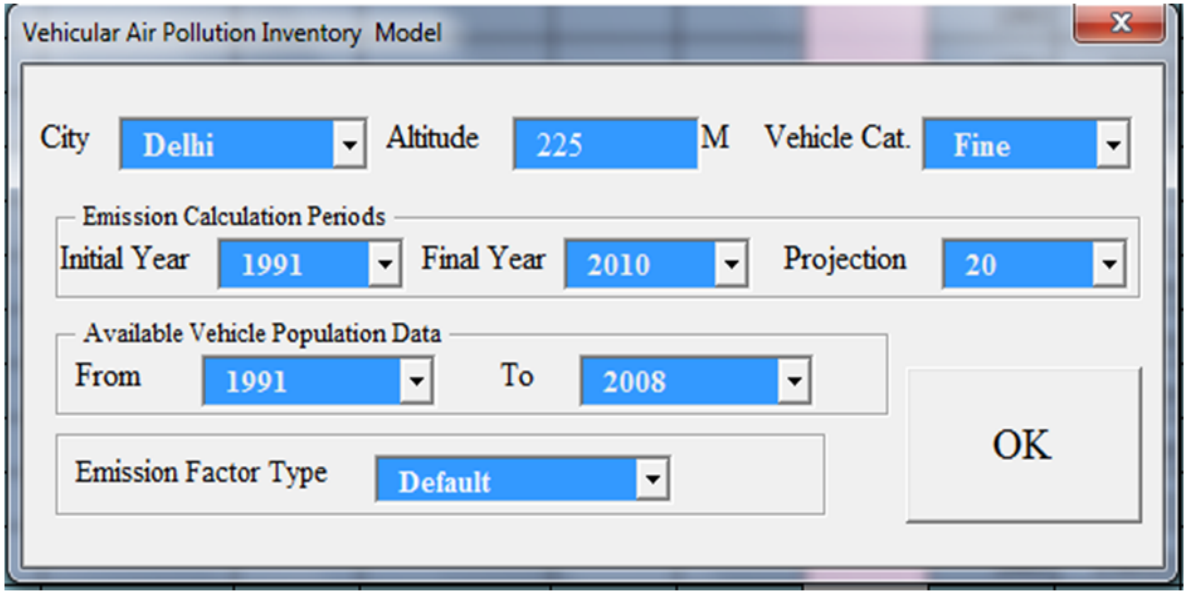
Evaporative Emissions

$$E_{api} = EF_{pi} \times C_{tpi} \times C_{api}$$

Non Exhaust Emissions

$$E_{tpi} = P_i \times E_{pi} \times V_i \times D_{ti}$$

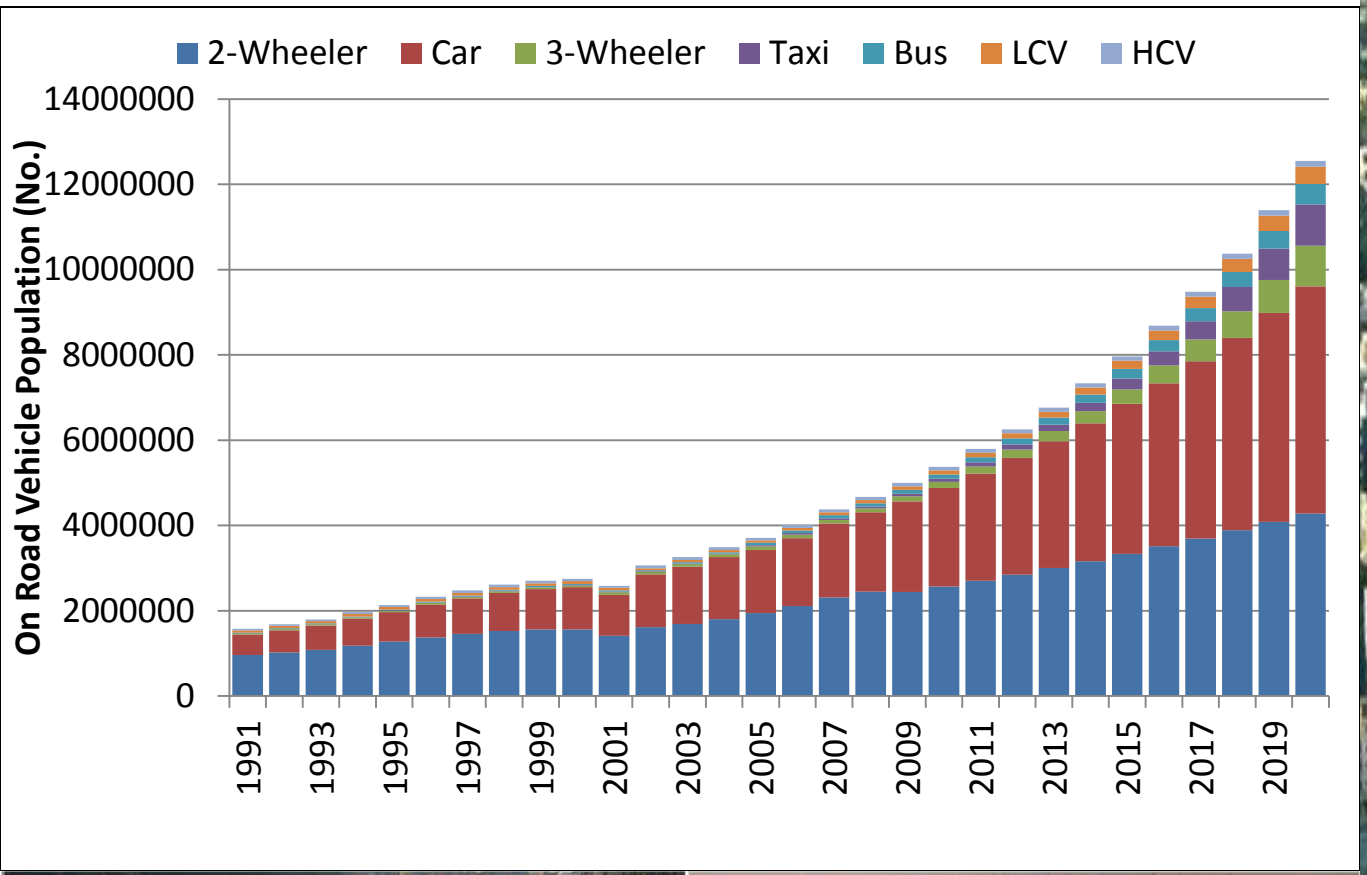
Window of VAPIM



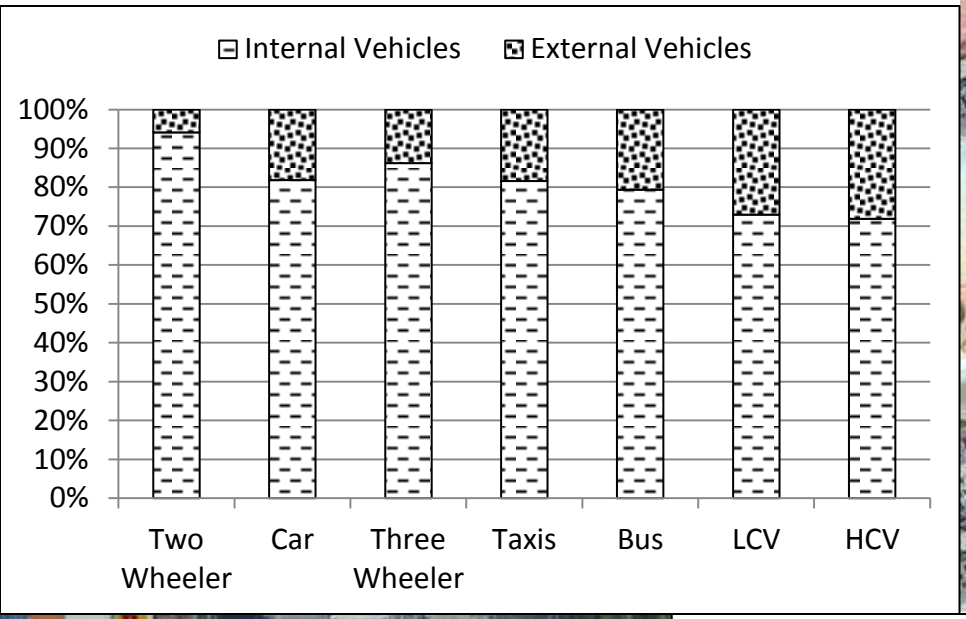
Exhaust Emissions from On-Road vehicles in megacity Delhi (1991-2010)

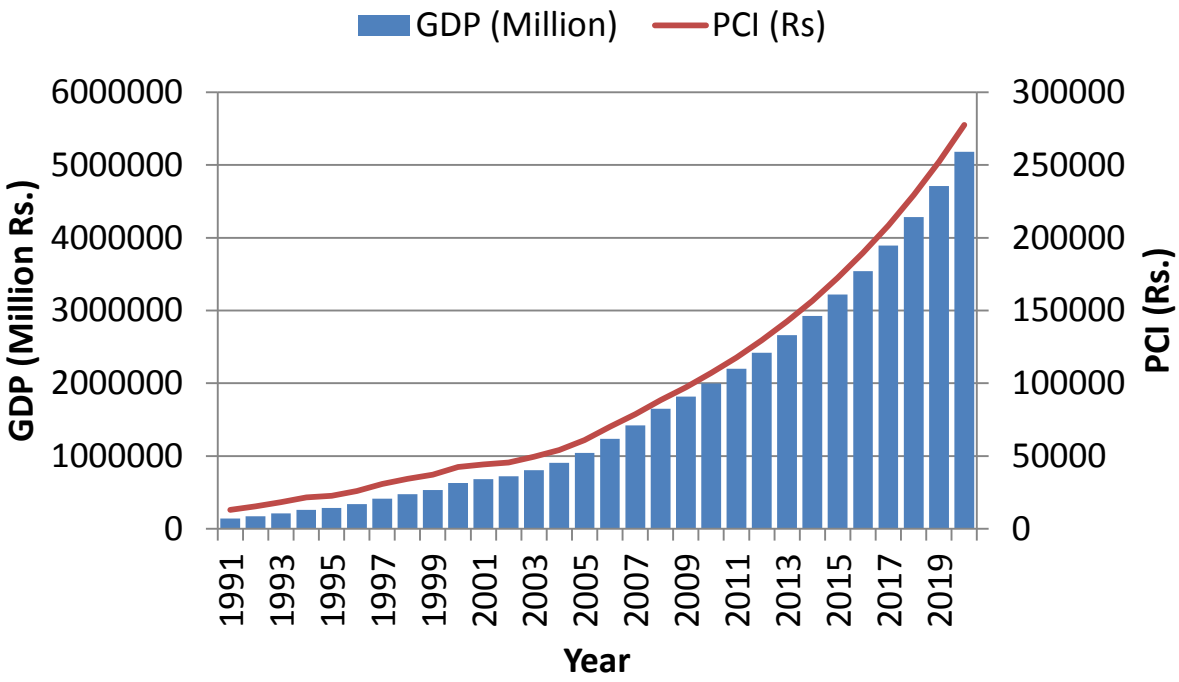
Input Parameters

Vehicle Population



Internal and External Vehicle In Delhi





Average Service Life of vehicles in Delhi

Life	2-Wheeler	3-Wheeler	car	Taxis	MUV	Trucks	Buses
Mittal and Sharma, 2003)	15	10	20	10	15	15	8
CRRI, 2002	17	12	17	17	17	17	17
TII, 2006						10	
Bose, 2006	15		15				
Roychowdhury, 2001		15					
Kokaz et. al, 2001	15	10	25	15		12	8

Vehicle Kilometers Travel

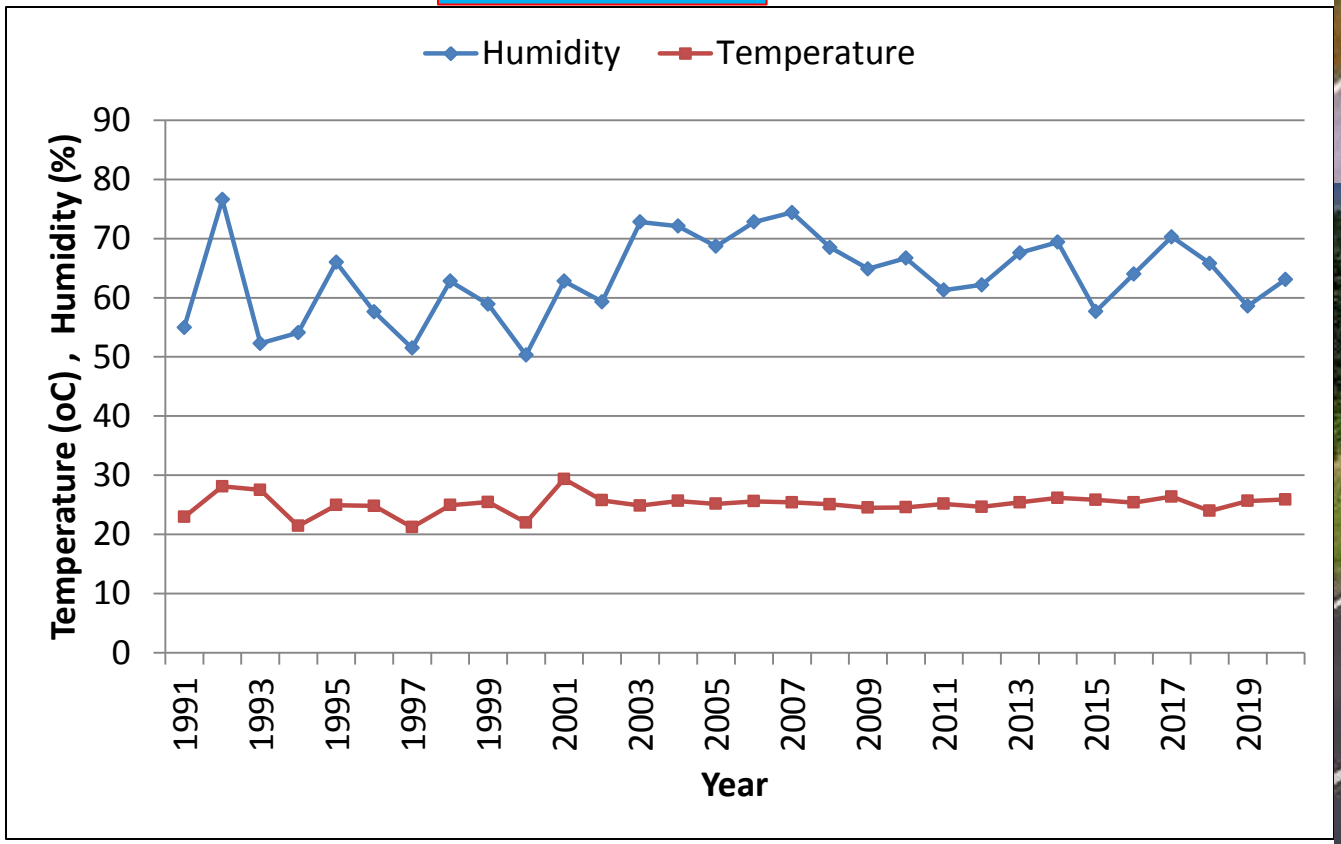
Vehicle type	VKT (km/day)
2 wheelers	27
3 wheelers	110
Passenger cars	41
Taxis	82
Multi utility vehicles	101
Buses	164
LCV	110
HCV	82
External Vehicle	
Buses	50
LCV	50

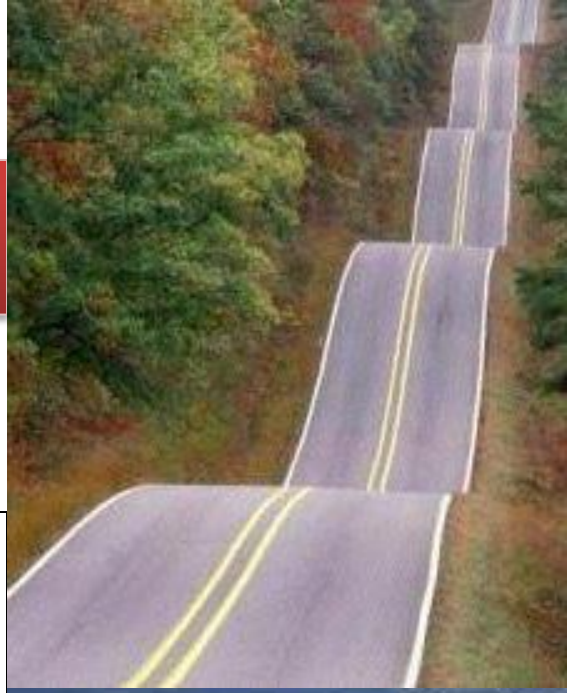
Vehicle Population Saturation Level

	2-Wheeler	3-Wheeler	Passenger car	Taxis	Buses	LCV	HCV
Per 1000	200	330	200	200	20	20	20

Altitude, Temperature, Humidity

Altitude 225 m



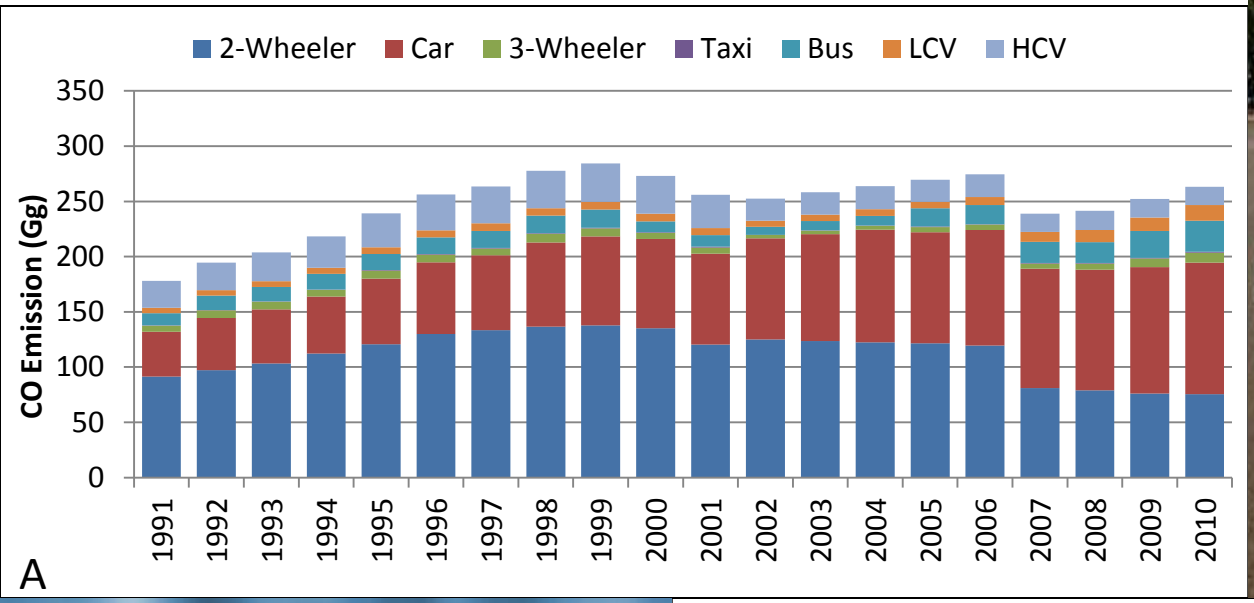


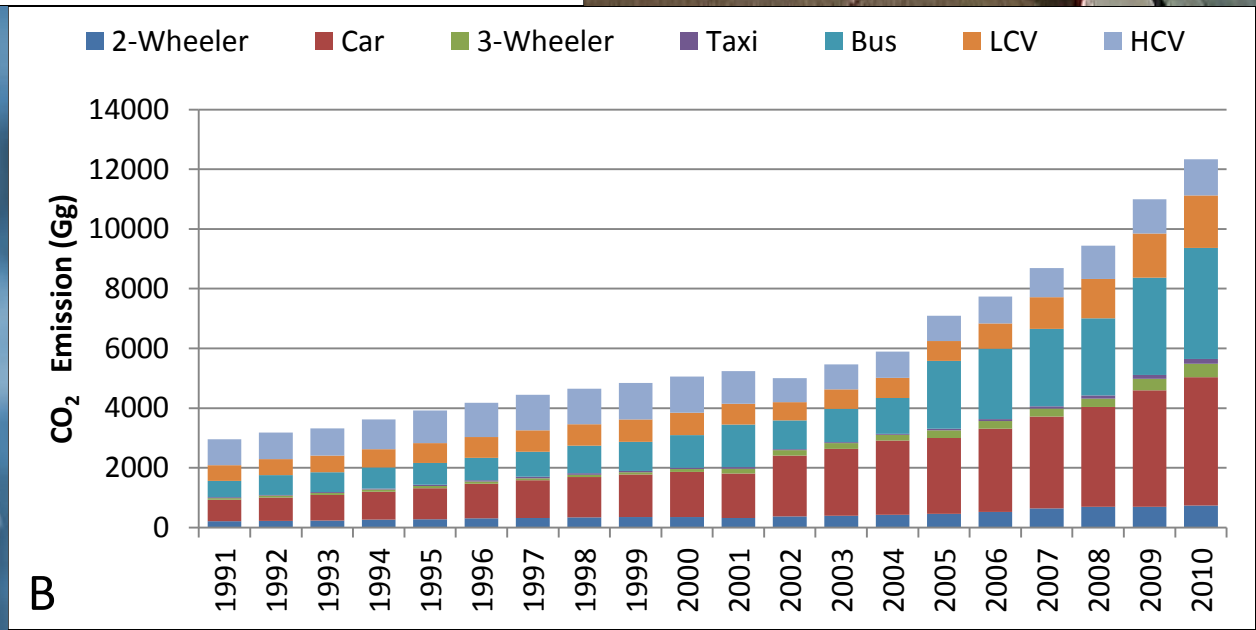
Policies Considered in Study

- *Bus Rapid Transit System (BRTS)*
- *CNG vehicles Population*
- *External Vehicles VKT*
- *Emission Norms*
- *Improvement in the quality of Fuel*
- *Phasing Out of vehicles*

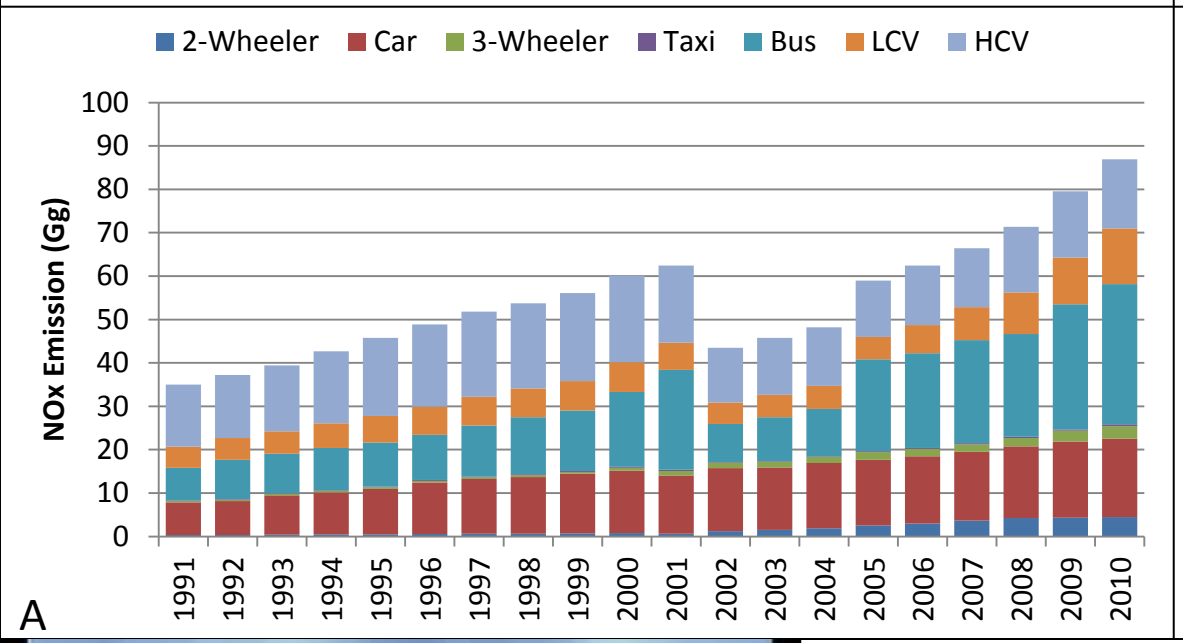
Results and Discussion

Emissions of (A) CO (B) CO_2 from various vehicle categories in megacity Delhi (1991-2010)

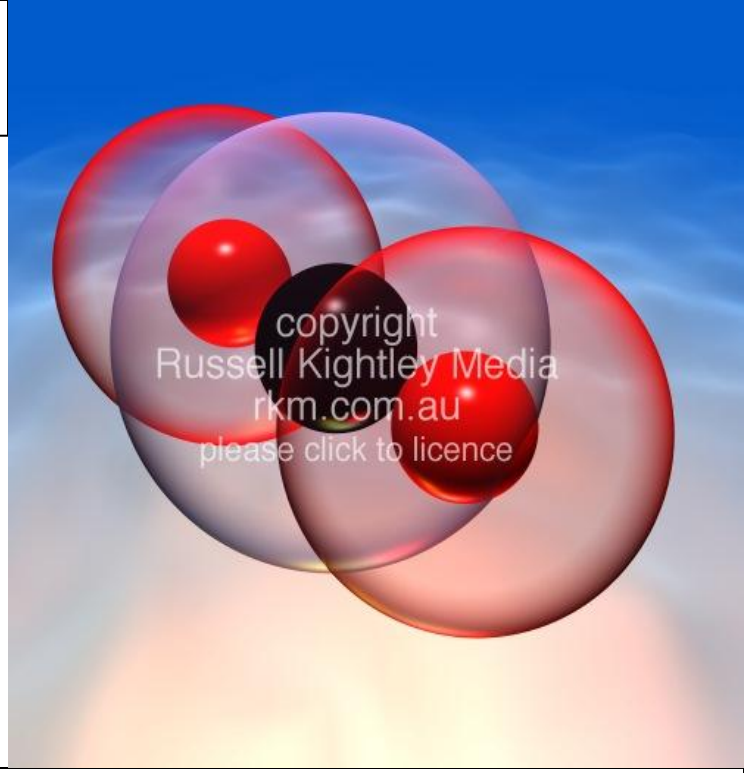


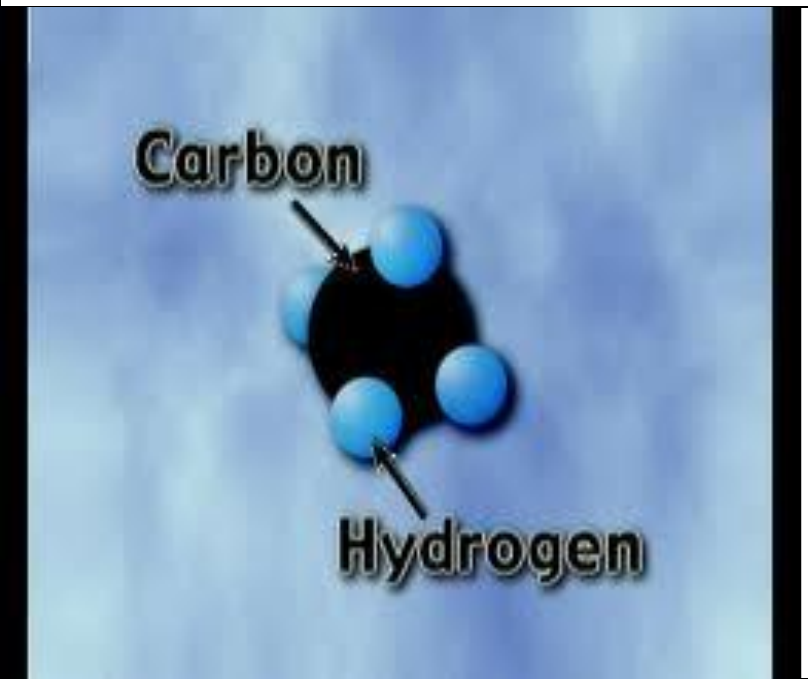


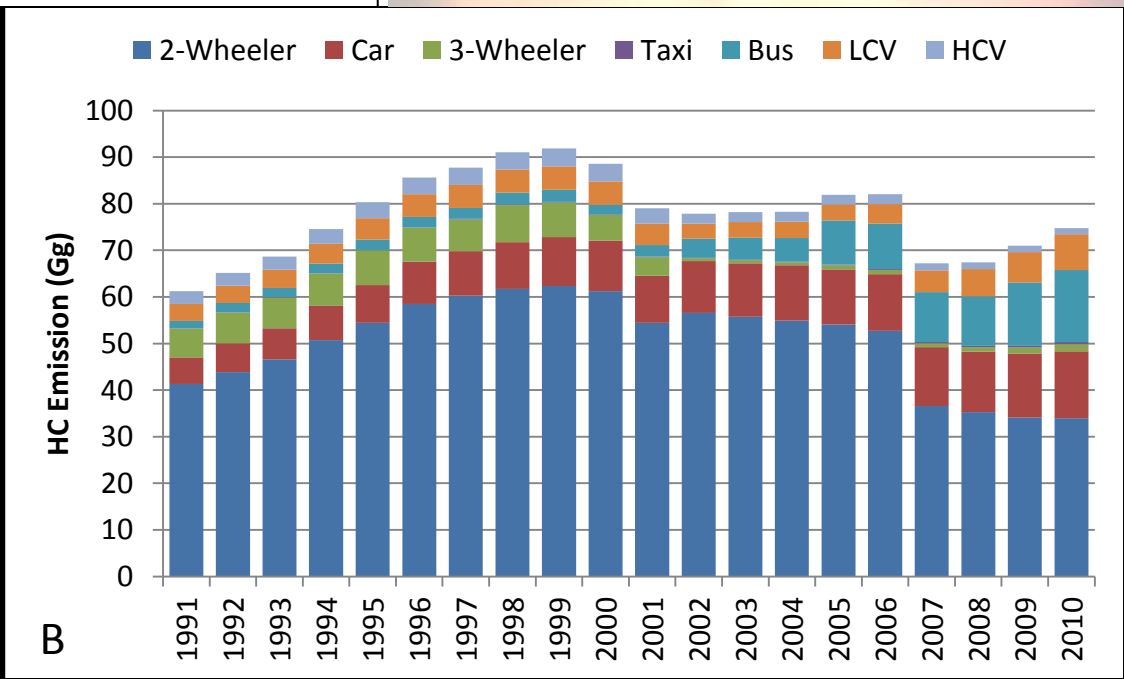
Emissions of (A) NOx (B) HC from various vehicle categories in megacity Delhi (1991-2010)



A







B

Future Vehicular Emission Scenarios for Megacity Delhi (2011-2020)

Business as Usual (BAU) Scenario

Best Estimate Scenario (BES)

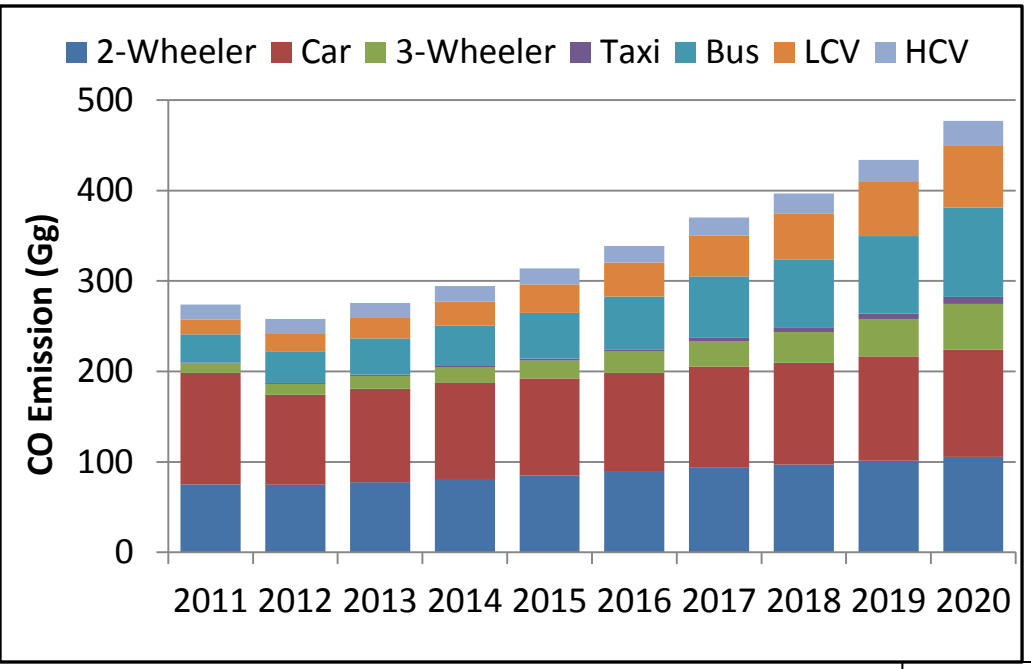
- Shift of two wheeler two stroke to four stroke
- Impact of Metro Rail on vehicles

BAU

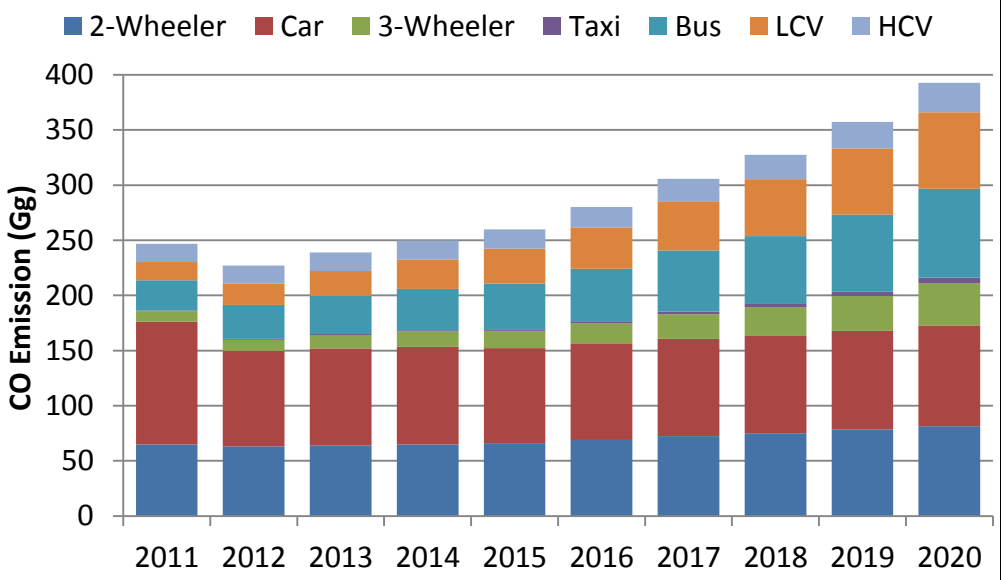
BES

CO Emission

BAU

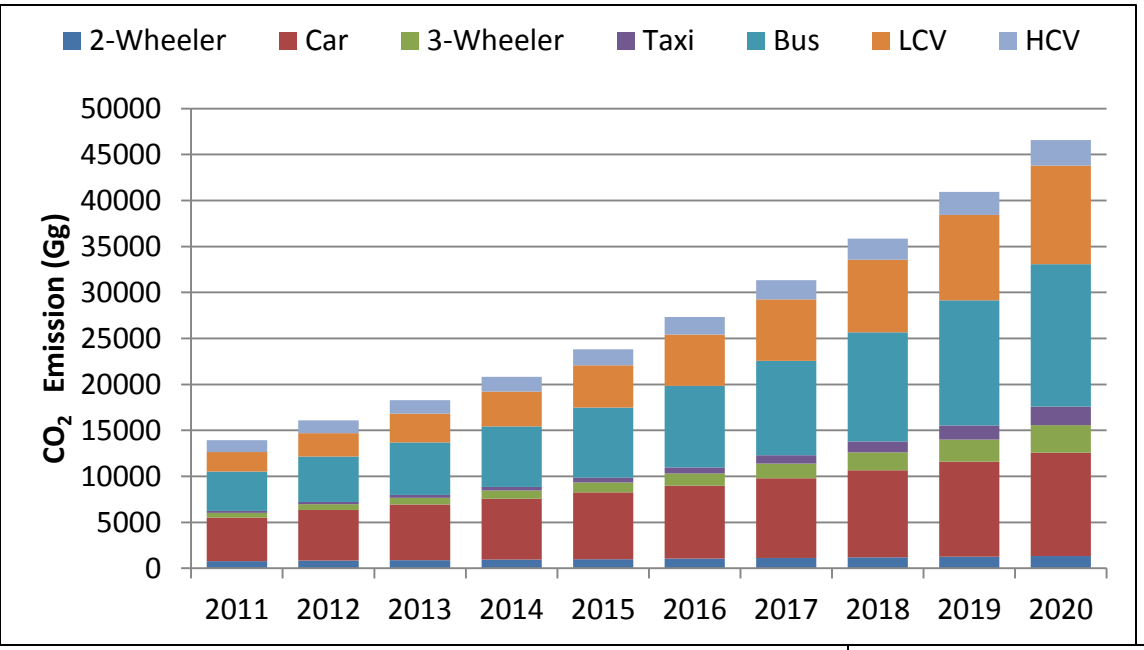


BES



CO_2 Emission

BAU



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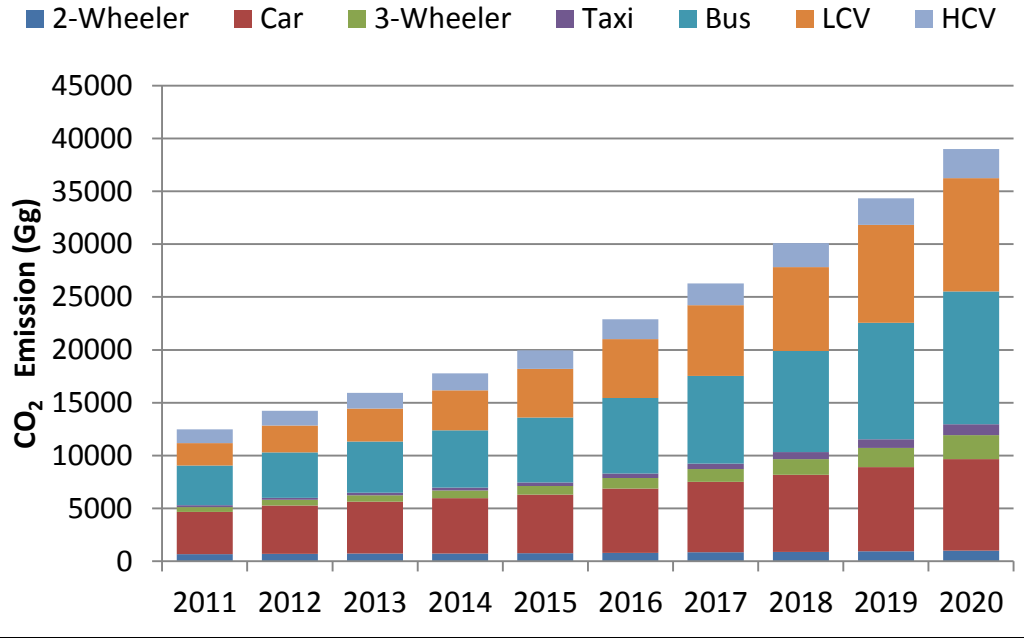
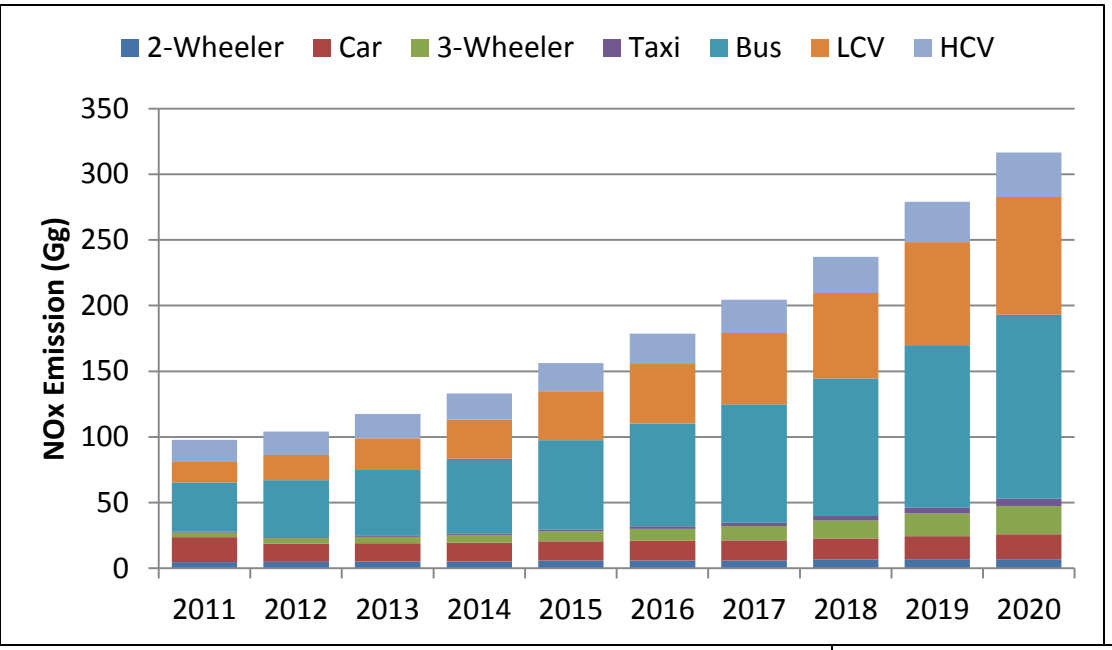
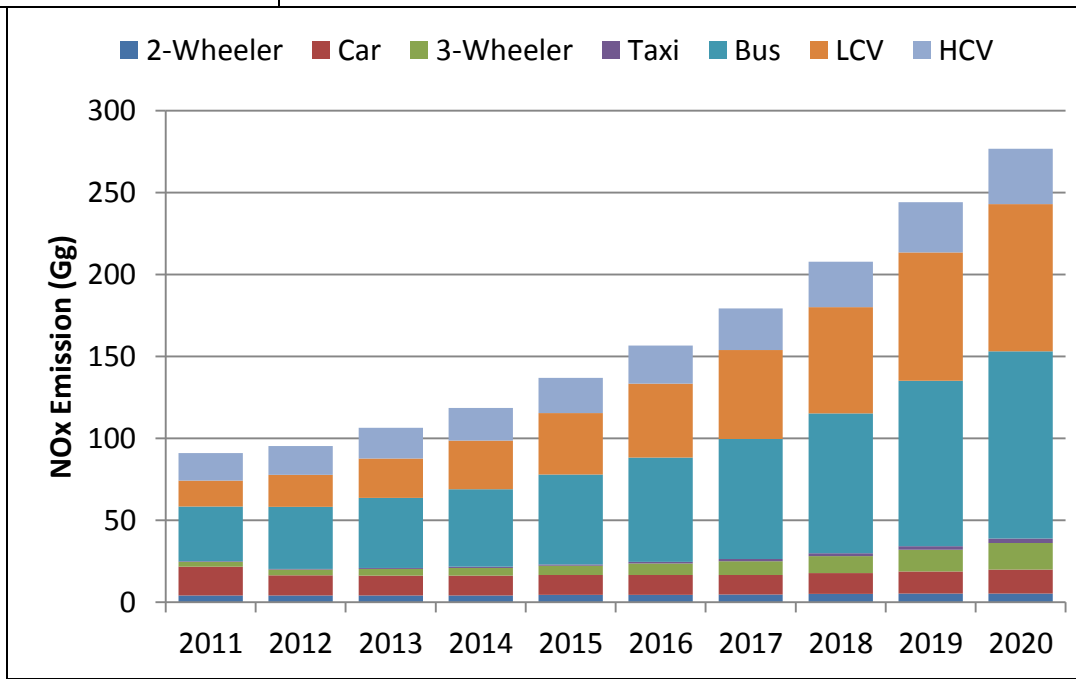


NOx Emissions_

BAU

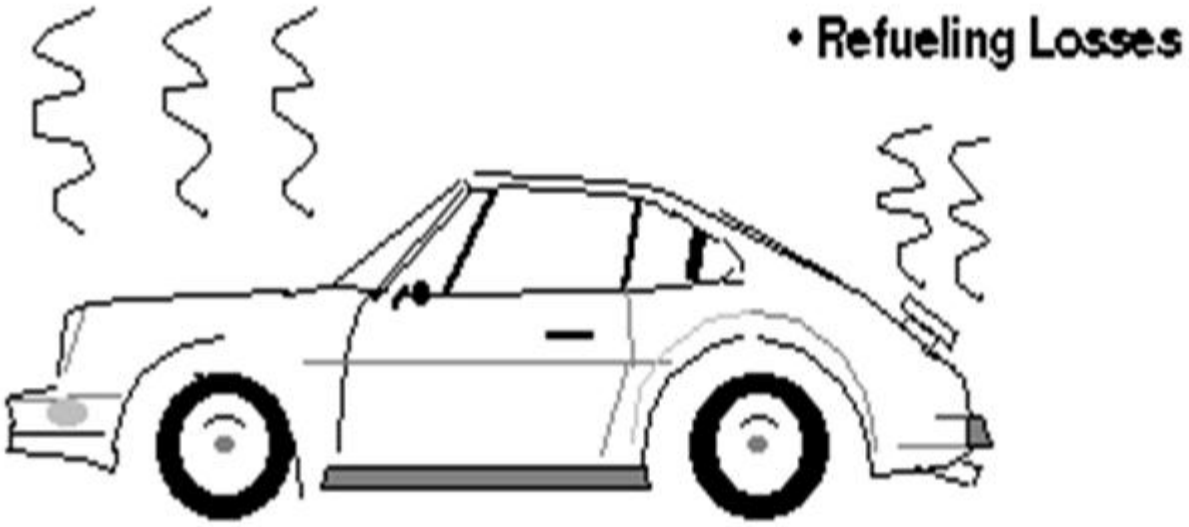


BES

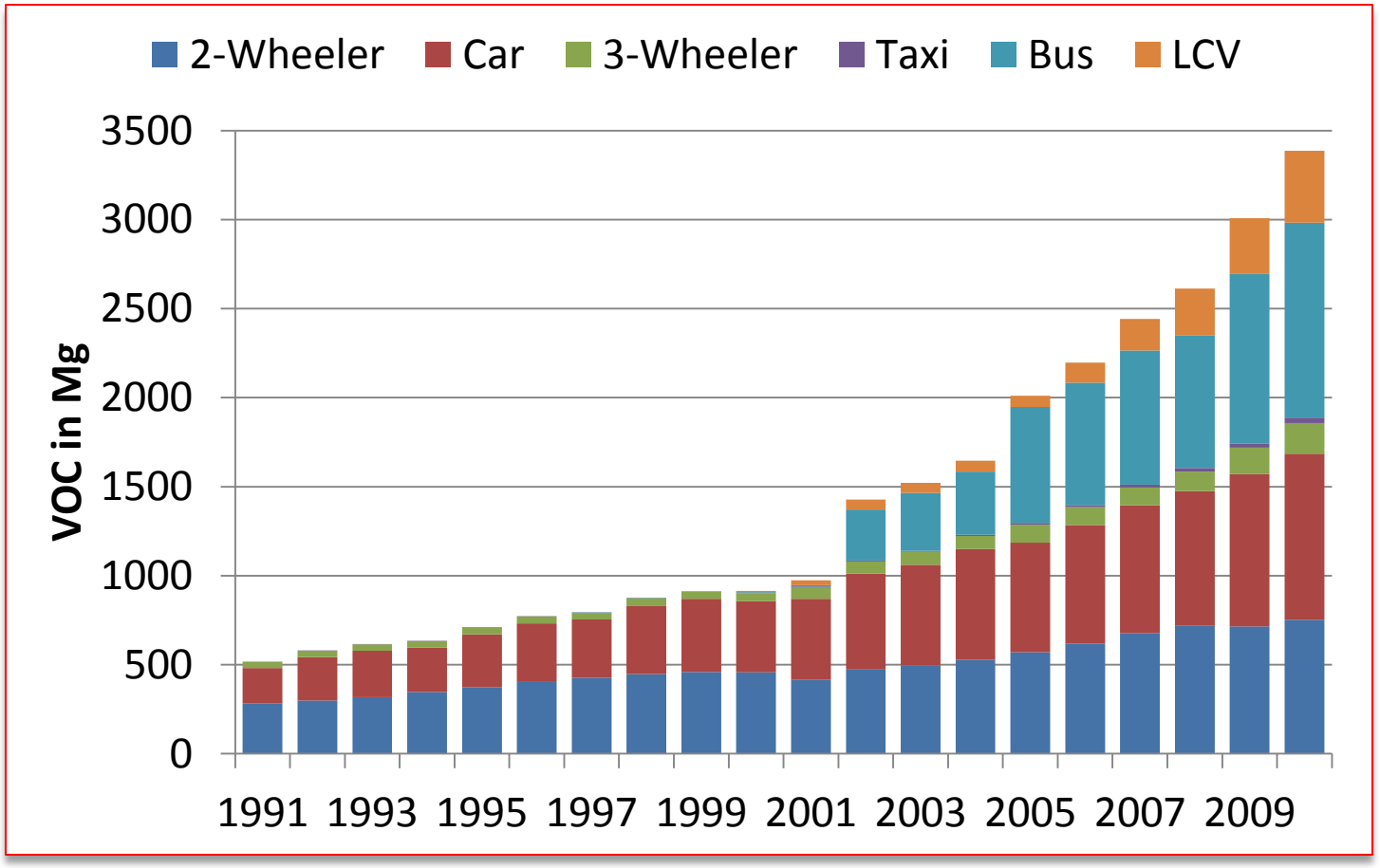


Non Exhaust Emissions from Vehicles in Megacity Delhi (1991-2010)

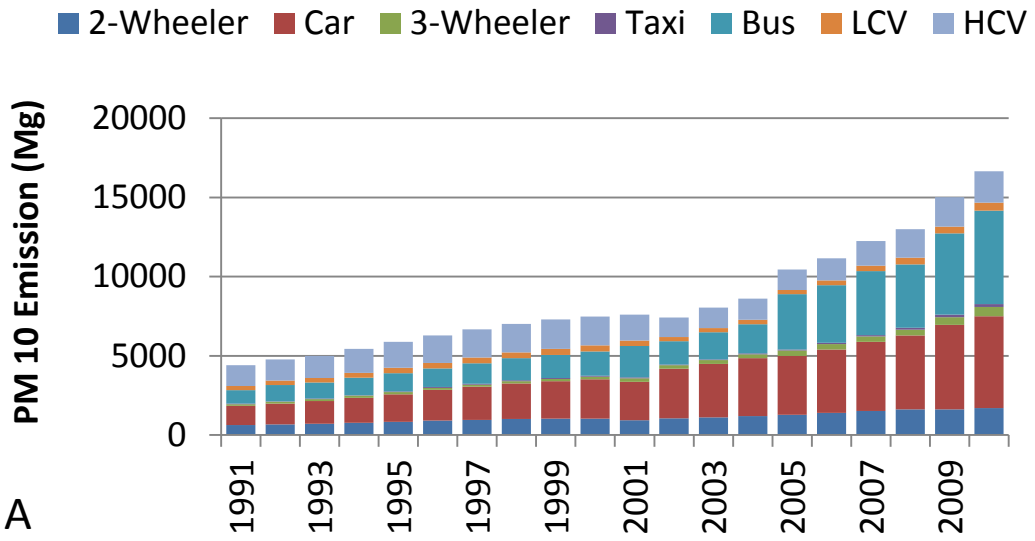
- Evaporative Emissions



Evaporative emission from various vehicles in megacity Delhi



Emission of (A) PM_{10} and (B) $PM_{2.5}$ from road dust suspension by various vehicles in megacity Delhi



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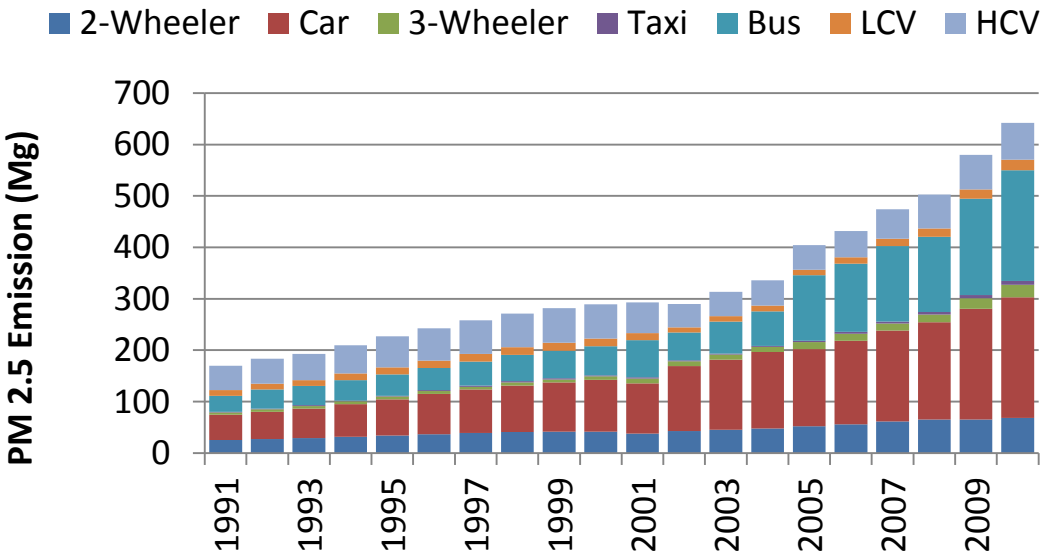
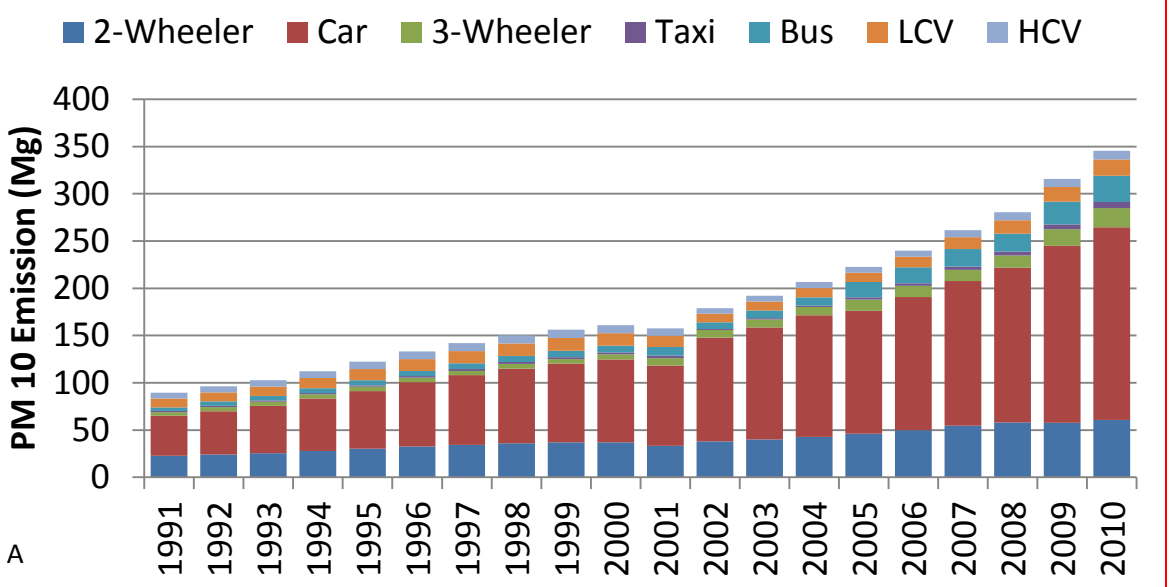


B

Emission of (A) PM_{10} and (B) $PM_{2.5}$ from various vehicles tyre wears in megacity Delhi



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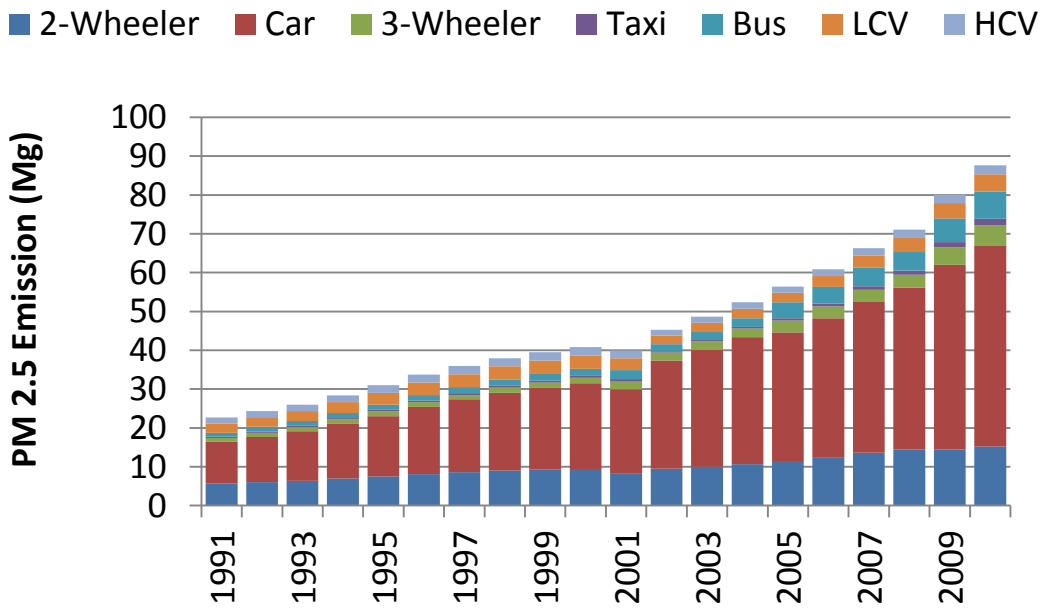
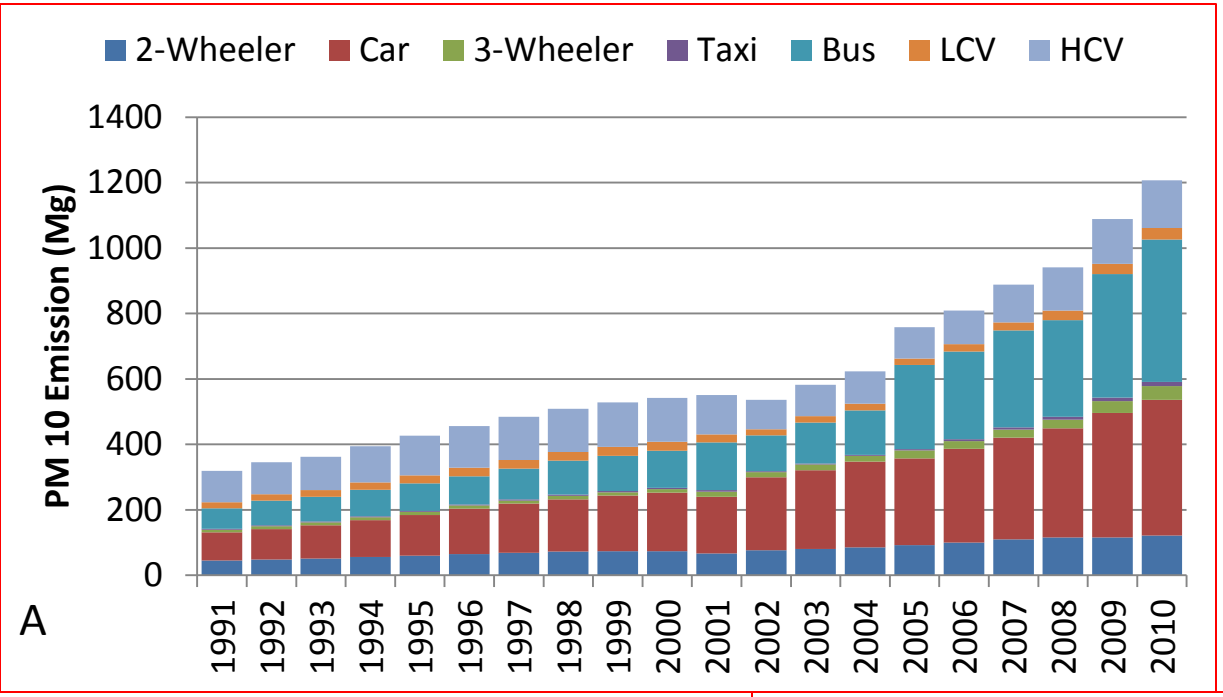
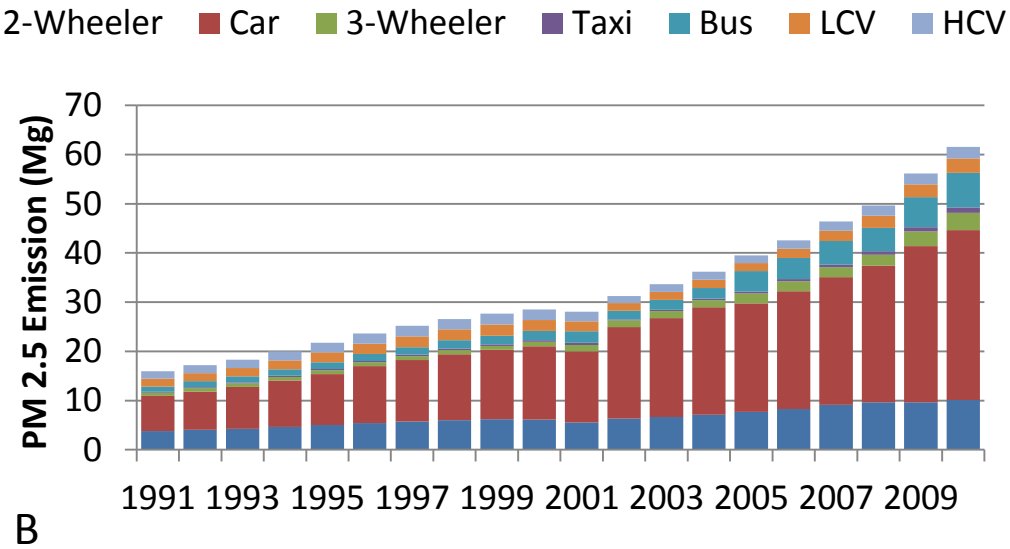


B

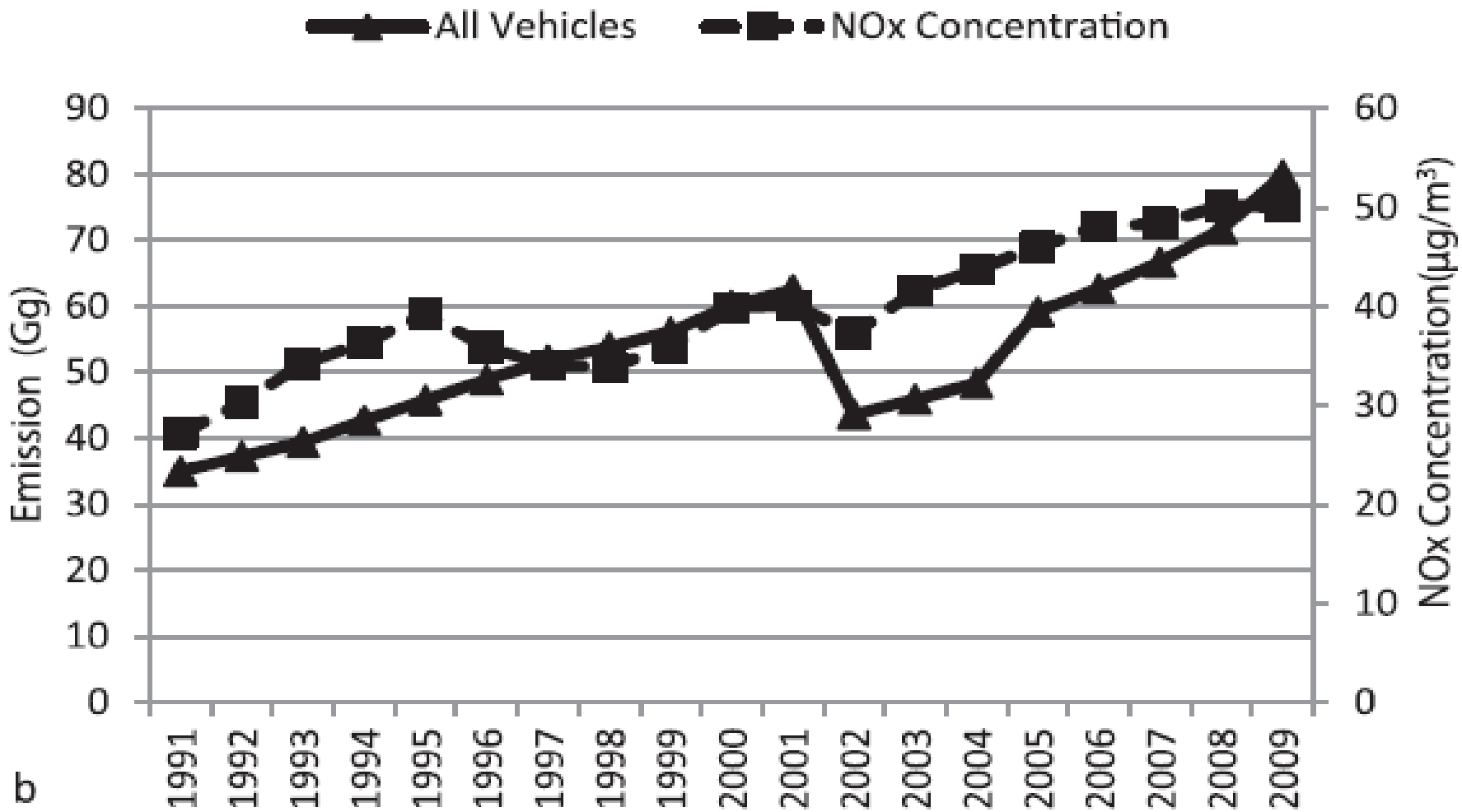
Emission of (A) PM $_{10}$ and (B) PM $_{2.5}$ from various vehicles brake wears in megacity Delhi



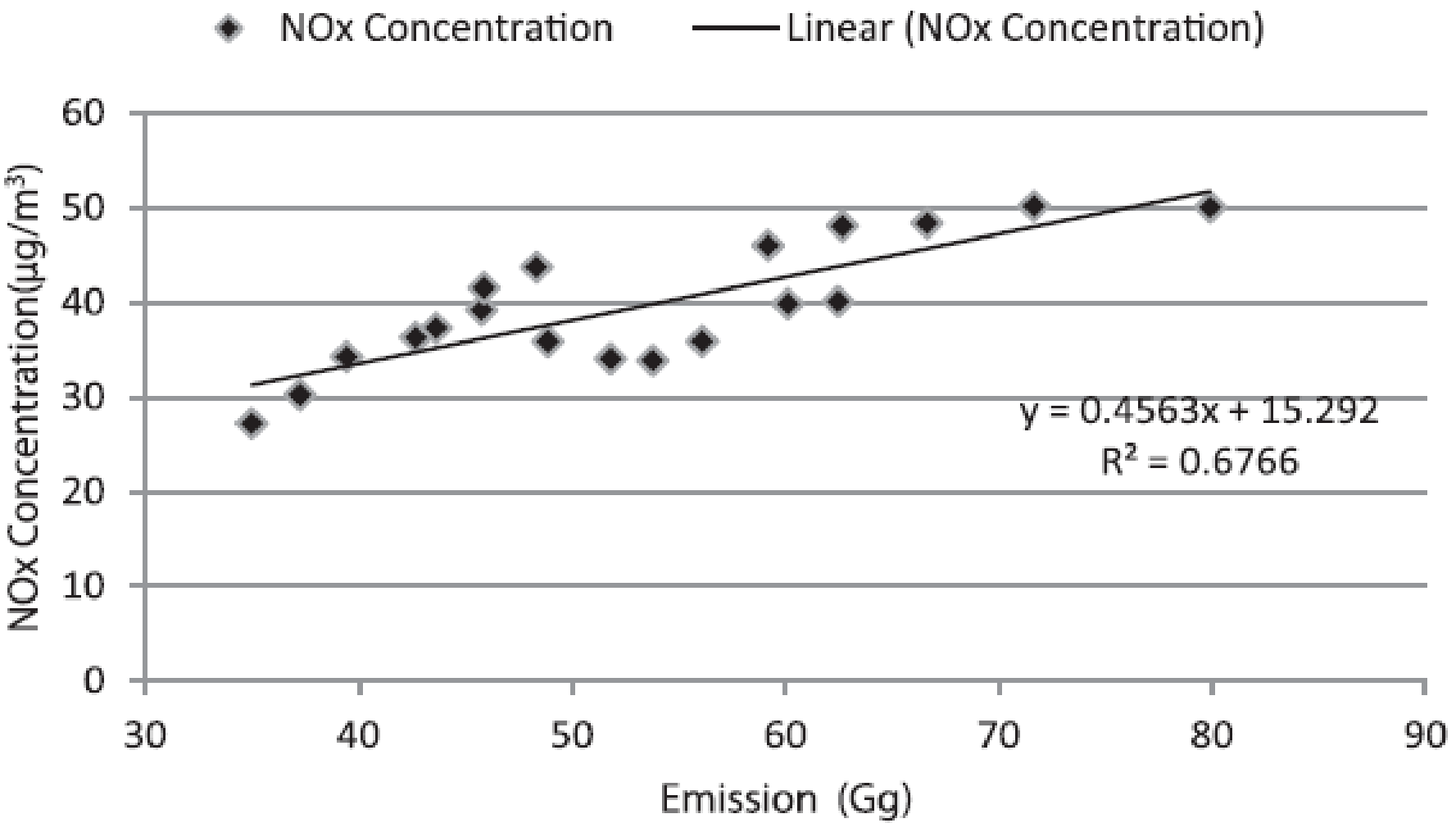


VALIDATION OF RESULTS

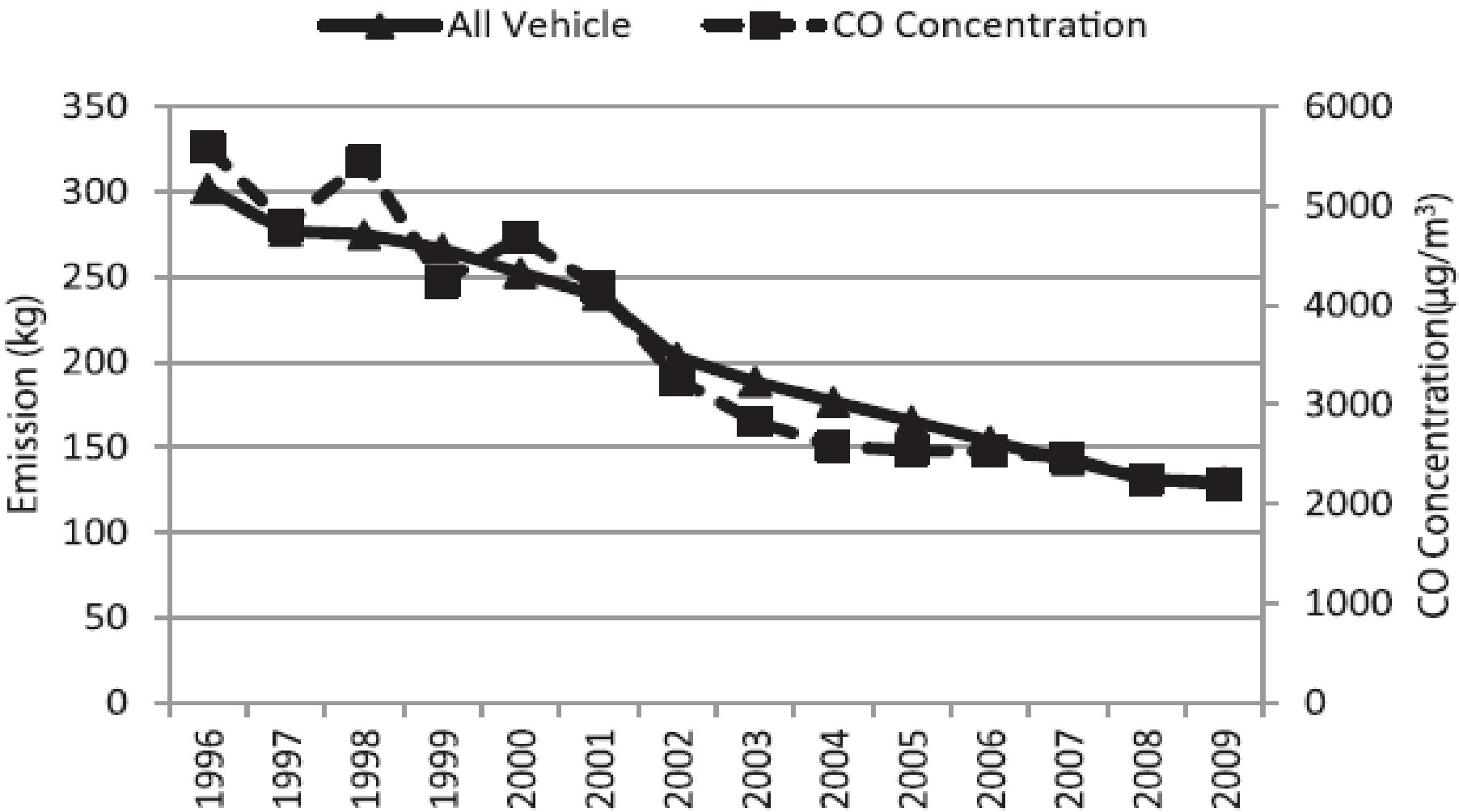
NOx concentration versus emission of NOx from all vehicle categories in megacity Delhi.



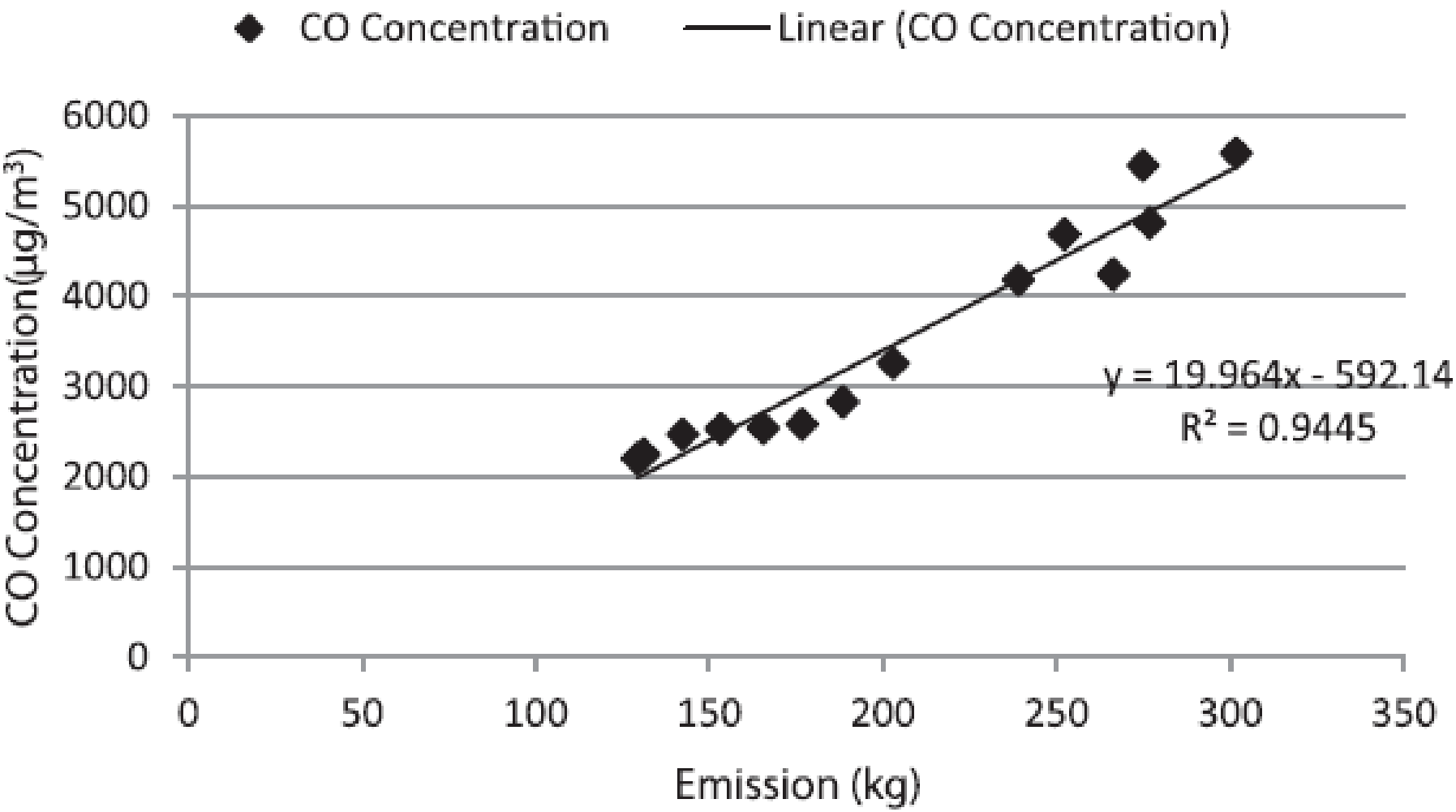
Coefficient correlation between NOx emission and concentration in megacity Delhi from 1991 to 2009.



CO concentration at ITO station versus emission share of CO from "goods vehicles" at ITO station in megacity Delhi.



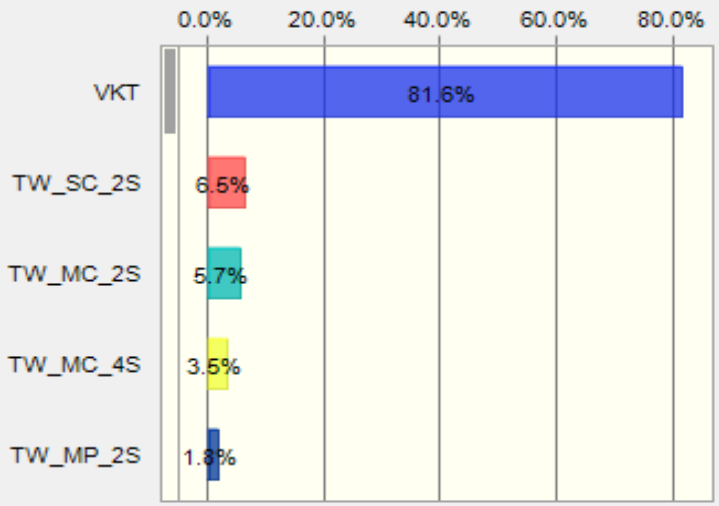
Coefficient correlation between CO emissions from goods vehicles and concentration at ITO monitoring station in megacity Delhi from 1996 to 2009.



Uncertainty and Sensitivity Analysis of Exhaust and Non Exhaust Emissions from Vehicles

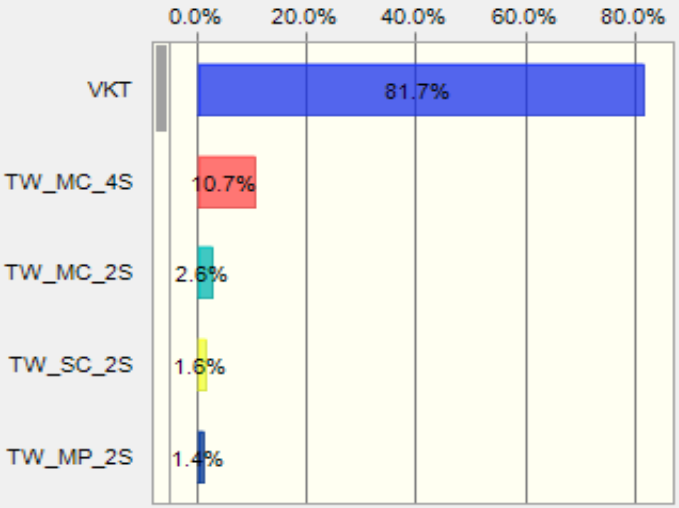
20,000 Trials Contribution to Variance View

Sensitivity: Emission of CO from Two Wheelers (2007)



20,000 Trials Contribution to Variance View

Sensitivity: Emission of CO2 from Two Wheelers (2007)



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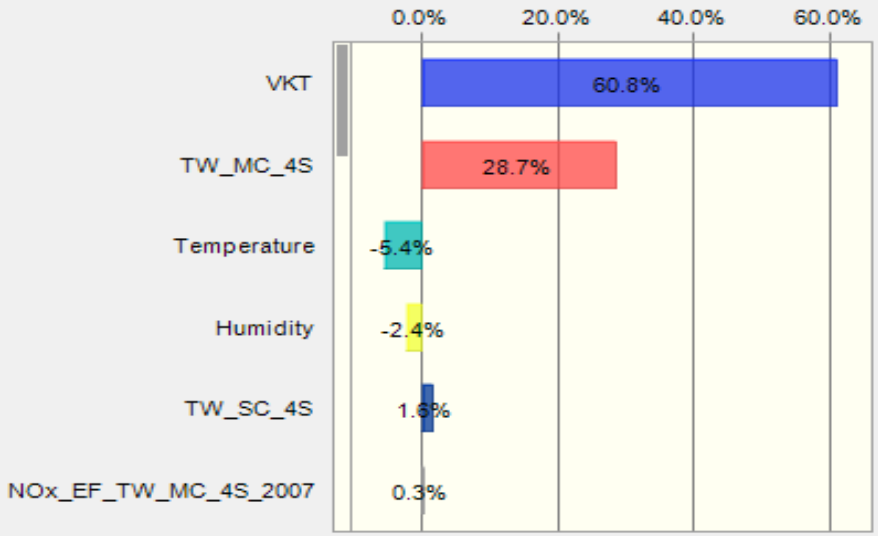
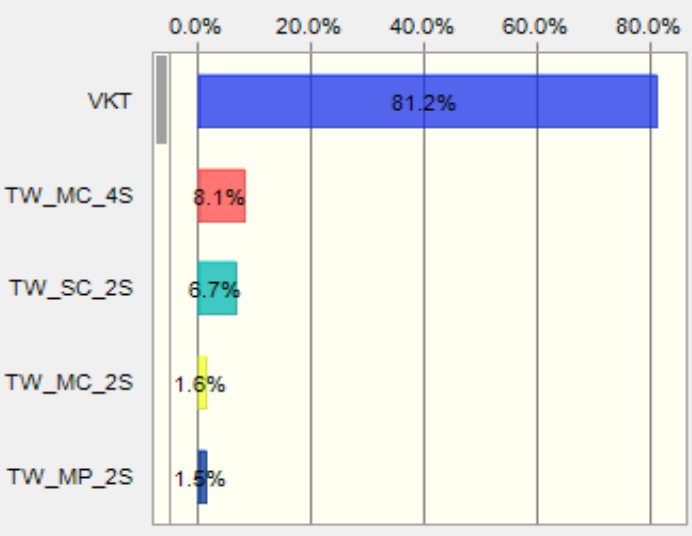


20,000 Trials Contribution to Variance View

Sensitivity: Emission of PM from Two Wheelers (2007)



Conclusion

- **For the first time, a simple and straightforward spread-sheet method -- the VAPI Model has been proposed for Indian urban road transport sector, applied and evaluated for CO and NOx emissions in megacity Delhi.**

- **The proposed model is aimed to calculate emissions of various pollutants from road transport in the urban areas of India.**

- **It require less input variable according to data available in Indian conditions.**

- **Three correction factors, two climatic (humidity, temperature) and one geographic (altitude) have been used in VAPI model to make emission estimations more realistic.**

- **The emission results with respect to CO and NOx obtained from the VAPI model shows fair agreement with existing ambient air concentrations.**

- **The proposed model can be used for estimating emissions from urban on-road vehicles in developing countries like India where paucity of extensive and exhaustive dataset limits the use of sophisticated models frequently used in advanced countries.**

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