6

TRANSPORT SECTOR

The equation (Eq. 16) to estimate the tailpipe emission of the transport sector is:

$$E_p = \sum_{c=1}^{n} \sum_{s=1}^{4} E_{c,s} \times EF_{c,s,p} \times \varepsilon_{c,s} \qquad (16)$$

where, Ep is the total emission of a pollutant (p); c is the category of vehicle; s is the emission control norm (BSI to BSIV); *E* is energy use; *EF* is the emission factor of pollutant p; and ε is the percentage of vehicle under an emission control norm.

The EF of PM_{10}, $PM_{2.5}$, NO_x, SO_x, hydrocarbon and carbon monoxide for this exercise was adopted primarily from Automotive Research Association of India (ARAI, 2010). ARAI has carried out a series of measurements to ascertain indigenous emission factors for different categories of vehicles in Indian conditions (Table 18). The EF of NH_3 was taken from the GAINS-ASIA simulation system. The estimated national level energy consumption (E) under different categories of vehicles during 2016 was adopted from the MARKAL energy system model (Annexure V).

Table 18 Tailpipe emission factors of different categories of vehicles

Fuel	Category	Vintage	g/km				
			PM	NOx	HC	CO	NH_3
Gasoline	2W–2s	1991–1996	0.07	0.03	3.29	5.82	0.87
		1996–2000	0.07	0.1	3.0	4.2	0.87
		Post 2000	0.05	0.05	2.10	2.51	0.87
		Post 2005	0.06	0.04	0.97	0.30	0.87
	2W–4s	1991–1996	0.01	0.23	0.78	3.12	1
		1996–2000	0.02	0.30	0.74	1.58	1
		Post 2000	0.04	0.50	0.52	1.50	35
		Post 2005	0.01	0.15	0.52	0.72	15
		Post 2010	0.003	0.25	0.42	1.17	15
	3W–2s	1996–2000	0.110	0.30	6.04	3.15	0.87
		Post 2000	0.045	0.20	2.53	1.37	0.87
		Post 2005	0.043	0.16	1.63	1.15	0.87
	3W–4s	Post 2000	0.011	0.61	1.57	4.47	35
		Post 2005	0.015	0.53	0.77	2.29	15
	LDV–4s	1991–1996	0.01	0.95	0.84	4.75	0.73
		1996–2000	0.01	0.75	0.66	4.53	0.73
		Post 2000	0.01	0.18	0.21	2.35	30
		Post 2005	0.00	0.09	0.12	0.84	12
		Post 2010	0.00	0.04	0.09	0.98	12

Fuel	Category	Vintage	g/km				
			PM	NOx	HC	CO	NH_3
Diesel	3W–4s	Post 2000	0.347	0.69	0.16	2.09	0.45
		Post 2005	0.091	0.51	0.14	0.41	0.4
		Post 2010	0.090	0.72	0.06	0.29	0.4
	LDT–4s	1991–96	0.57	1.70	1.39	2.49	0.45
		1996–2000	0.45	0.67	0.73	3.07	0.45
		Post 2000	0.24	0.97	0.29	1.13	0.45
		Post 2005	0.06	0.47	0.13	0.21	0.4
		post 2010	0.06	0.52	0.08	0.49	0.4
	LDT–4s	1991–96	1.00	3.03	2.28	3.07	0.45
		1996–2000	0.66	2.48	1.28	3.00	0.45
		Post 2000	0.48	2.12	1.35	3.66	0.45
		Post 2010	0.12	1.69	0.30	1.44	0.4
	HDT	1991–96	1.57	9.41	1.83	8.73	0.29
		1996–2000	0.88	12.85	1.05	6.43	0.29
		Post 2000	1.2	11.1	1.4	7.6	0.29
		Post 2005	0.42	8.64	0.29	4.14	0.25
		Post 2010	0.39	8.35	6.13	4.85	0.25
	HDT	1991–96	2.01	11.24	2.40	13.06	0.29
		1996–2000	1.21	15.25	1.46	4.48	0.29
		Post 2000	0.56	6.49	2.01	3.97	0.29
		Post 2005	0.30	6.53	0.16	3.92	0.25
		Post 2010	0.48	5.17	0.21	4.73	0.25
CNG	2W–4s	Post 2000	0.07	0.35	1.16	0.85	4.9
		Post 2005	0.18	0.20	5.56	1.29	4.9
		Post 2010	0.02	1.07	1.79	1.03	0
	LDV–4s	1996–2000	0.00	0.53	0.79	0.85	0.5
		Post 2000	0.00	0.38	0.41	0.33	4.9
		Post 2010	0.00	0.07	0.26	1.95	3
	HDB	Post 2000	0.04	6.21	3.75	3.72	10
		Post 2010	0.02	15.15	7.80	9.22	5
LPG	2W–4s	1996–2000	0.17	0.05	5.08	7.20	0
		Post 2000	0.13	0.04	1.03	1.70	0
	LDV–4s	Post 2000	0.00	0.20	0.23	2.72	0

2W: 2-wheeler; 3W: 3-wheeler; LDV: Light duty vehicle; HDB: Heavy duty bus; HDT: Heavy duty truck; 2s: 2-stroke engine; 4s: 4-stroke engine

National level energy consumptions in different categories of on-road vehicles were brought down to the district level on the basis of district-wise on-road number of vehicles. The data of district-wise on-road numbers of vehicles were obtained from the registered number of vehicles. District-level information on category-wise number of vehicles was obtained from Directorate of Economic and Statistics of different states. The National Green Tribunal (NGT), India has imposed a ban on diesel and gasoline vehicles older than 10 and 15 years, respectively in the Delhi-National Capital Region (NCR) in 2015. However, in the absence of an effective vehicle scrapping policy, these vehicles are still in use in the Delhi-NCR and in other parts of the country. Following this, we assumed 20 years as the average life time of a vehicle in India during 2016.

Fugitive emissions of PM from re-suspension of road dust due to movement of vehicles on paved roads was calculated using the following equation as provided in AP-42,

$$[E_p]_t = \sum_{r=1}^{3} VKT_r \times k \times w^{1.02} \times Mo^{0.91} \quad (17)$$

where, $[E_p]_t$ is the fugitive emission of pollutant (p) from the transport sector; r is the type of road (1 arterial, 2 sub-arterial and 3 local); VKT is Vehicle Kilometre Travelled, k is function of particle size (0.62 for PM_{10} and 0.15 for $PM_{2.5}$); w is the average weight of vehicle travelling on the road; and Mo is road surface silt (≤ 75 µm in physical diameter) loading in unit area. The $[E_p]_t$ is directly proportional to the silt loading on the road surface and average weight of the vehicles plying on the road. The spatial variation of Mo was established during this study (Annexure III).

After estimating $[E_p]_t$ using the above equation, the effect of rainy days was considered to finalize the fugitive emission ($f[E_p]_t$) from road dust re-suspension using Eq. 18:

$$f[E_p]_t = [E_p]_t \times (1 - D_p) / (4 \times 365) \quad (18)$$

where, D_p is the number of rainy days in a year.

6.1 Energy consumption in the transport sector

According to the MARKAL model, total energy consumption in on-road transport sector in the year 2016 was 4081 PJ. Buses and trucks are major consumers of energy in the transport sector followed by light commercial vehicles (LCVs), cars, 3-w and 2-w (Figure 8).

6.2 Tailpipe emissions of different pollutants

The tailpipe emissions of different pollutants from various categories of on-road vehicles were calculated using *eq. 16*. Higher PM emissions were calculated from the tailpipe emissions of heavy duty vehicles (Table 19) followed by light duty vehicles and passenger cars.

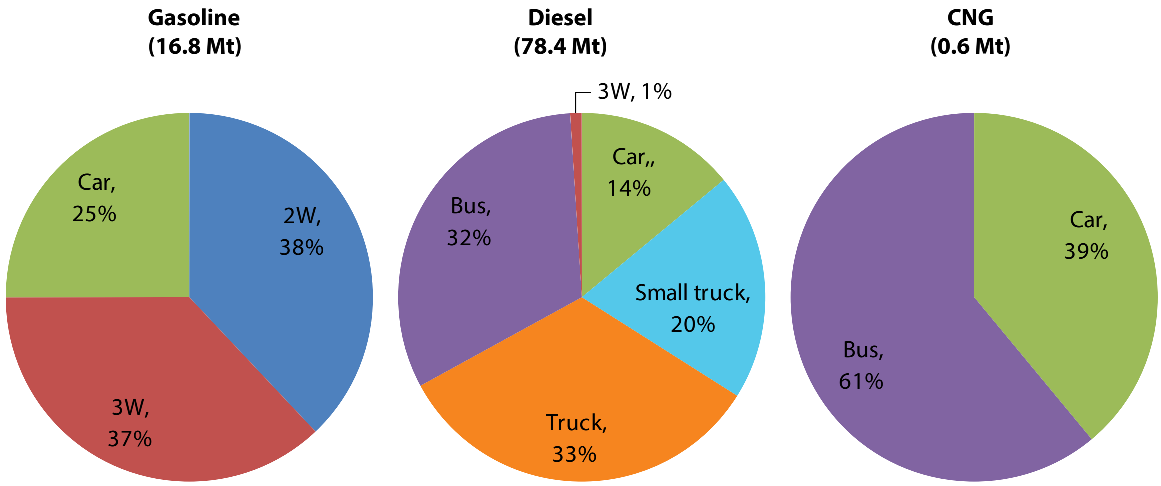

Figure 8 Energy consumption in different categories of vehicles during 2016 according to the MARKAL model

Table 19 Tailpipe emissions (Kt) of different pollutants during 2016

PM_{10}	6.86	9.07	24.28	36.47	53.80	61.97	**192.44**
PM_{25}	6.66	8.80	23.55	35.37	52.18	60.11	**186.67**
SO_X	4.69	5.35	2.74	0.28	0.43	0.29	**13.78**
NO_X	137.35	185.31	124.34	232.31	703.27	845.74	**2228.32**
CO	564.96	775.77	270.53	290.45	534.47	501.84	**2938.03**
NH_3	4.69	5.35	2.74	0.28	0.43	0.29	**13.78**

2W: 2-wheeler; 3W: 3-wheeler; LDV: Light duty vehicle; HDB: Heavy duty bus; HDT: Heavy duty truck

Earlier, Venkataraman et al. (2018) have estimated the emission inventory of the transport sector of India using the same emissions factors (ARAI, 2010) used in the present study. That study reported 286, 6078 and 105 Gg of $PM_{2.5}$, NO_x and SO_2 emissions respectively from the transport sector during 2015 with reported uncertainties of -54% to +91%, -63% to +122%, and -71% to +157%, respectively.

6.3 Inventory of road dust resuspension

The silt and clay content of the road dust samples were higher in the states of Odisha (Annexure III). Re-suspension of road dusts due to movement of the vehicle contributes to PM_{10} and $PM_{2.5}$ concentrations in the atmosphere. The contribution of road dust suspension to PM_{10} and $PM_{2.5}$ was calculated using Eq. 18. Among other states, higher road dust resuspension in the state of Maharashtra (Table 20) is mainly attributed to comparatively higher road length in the state (MoSPI, 2017) apart from average vehicle weight and silt concentration on the road.

Table 20 State-wise contribution of road dust suspension to atmospheric PM_{10} and $PM_{2.5}$ during 2016

State	$PM_{2.5}$ (Kt)	PM_{10} (Kt)
Andhra Pradesh	5.91	24.44
Arunachal Pradesh	0.01	0.06
Assam	0.70	2.88
Bihar	1.73	7.15
Chhattisgarh	1.98	8.18
Goa	0.08	0.32
Gujarat	31.76	131.26
Haryana	1.14	4.71
Himachal Pradesh	0.18	0.74
Jammu & Kashmir	0.29	1.22
Jharkhand	1.21	5.01
Karnataka	13.62	56.30
Kerala	9.68	40.02
Madhya Pradesh	4.89	20.21
Maharashtra	77.13	318.80
Manipur	0.01	0.06
Meghalaya	0.11	0.44
Mizoram	0.00	0.02
Nagaland	0.06	0.25
Odisha	3.17	13.09
Punjab	4.82	19.92
Rajasthan	12.58	52.01
Sikkim	0.00	0.00
Tamil Nadu	30.45	125.88
Telangana	2.82	11.67
Tripura	0.01	0.04
Uttarakhand	0.19	0.79
Uttar Pradesh	32.90	135.97
West Bengal	2.97	12.26
Andaman & Nicobar Islands	0.0008	0.0031
Chandigarh	0.0518	0.2141
Dadra & Nagar Haveli	0.0006	0.0026
Daman & Diu	0.0004	0.0018
NCT of Delhi	1.6544	6.8380

State	$PM_{2.5}$ (Kt)	PM_{10} (Kt)
Lakshadweep	0.0000	0.0000
Puducherry	0.0207	0.0858
Total	242.14	1000.83

District-level total tailpipe emissions of each pollutants and emissions from the road dust resuspension were distributed to grid based on i) the ratio of polygon area to the district area using Eq. 19 and ii) the ratio of the length of national highways in a polygon to the length of national highway in a district using Eq. 20.

$$G_{Pol} = \sum_{p=1}^{n} \sum_{d=1}^{n} \frac{A_p}{A_d} \times (E_{pol,d} \times 0.6) \qquad (19)$$

$$G_{Pol} = \sum_{p=1}^{n} \sum_{d=1}^{n} \frac{LN_p}{LN_d} \times (E_{pol,d} \times 0.4) \qquad (20)$$

where, G_{Pol} is the emission of a particular pollutant (Pol) in the Grid (G); A and LN are the area and length of national highway respectively in a polygon (p) and d (district); and $E_{Pol,\ d}$ is the estimated emission of the pollutant (Pol) in the district (d). Spatial variations of different pollutants emissions from the transport sector were distributed over a 36 km × 36 km gridded map after adding the gridded values derived from Eq. 19 and Eq. 20 (Figure 9).

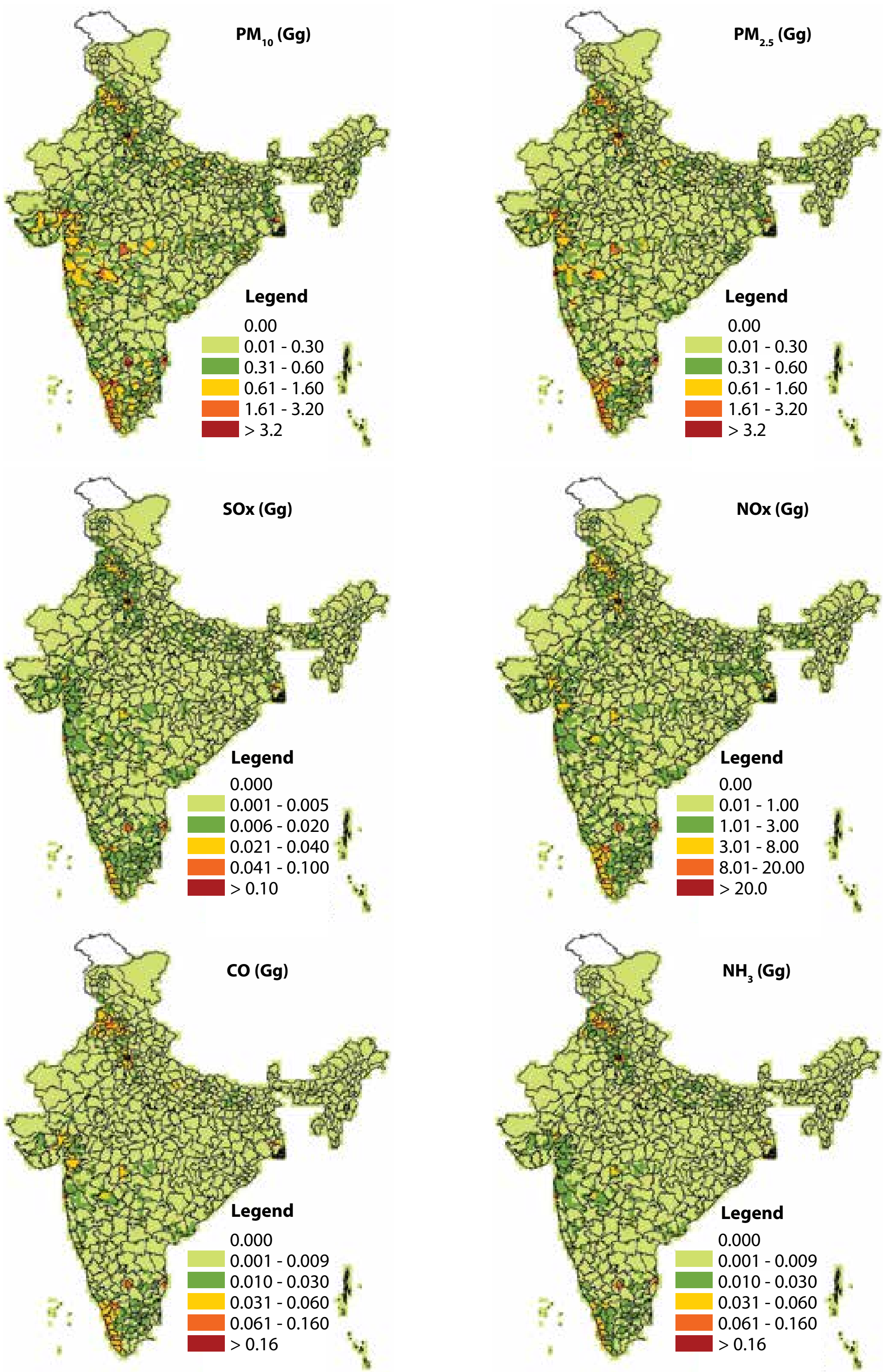

Figure 9 Spatial variations of emissions of different pollutants from the transport sector during 2016