Investigation of transport pollutant emissions and their associated health impacts for North Indian Region

Siddharth Jain
(PhD Research Scholar)

Under the supervision of
Dr. Shalini Rankavat

DEPARTMENT OF CIVIL ENGINEERING
SCHOOL OF ENGINEERING
Shiv Nadar Institution Of Eminence (SNIOE)

SHIV NADAR
INSTITUTION OF EMINENCE DEEMED TO BE
UNIVERSITY
DELHI NCR

Contents of presentation

- Introduction
- Motivation behind research
- Literature review
- Summary of gaps found in literature
- Objectives to fill gaps in past studies
- Methodology
- Results and Discussion
- Conclusion

Introduction

- According to a study by the **United Nations Framework Convention on Climate Change** (UNFCCC), the average global surface temperature has risen by 0.74°C since the late 1800s. If no action is taken, it will rise between **1.8°C to 4°C** by 2100

- Among all sectors, **transportation is the fastest growing** sector and the largest consumer of oil globally

- The transportation industry consumes 25% of the world's energy, while it is responsible for **23% of its total CO_2 emission**

- India is the world's third greatest emitter of CO_2, and **road transport is responsible for more than 10%** of the country's total CO_2 emissions

- Carbon dioxide (CO_2), carbon monoxide (CO), oxide of nitrogen (NO_x), Sulphur dioxide (SO_2), particulate matter (PM), and non-methane volatile organic compounds (NMVOC) are among the significant pollutants released by the transportation sector

Introduction

- **Particulate Matter**: PM stands for particulate matter. it is the mixture of solid particles and liquid droplets into the atmosphere such as - dust, soot, or smoke, etc.

Classification of particulate matter

- **Coarse particles-** When the aerodynamic diameter is (AED) ≤ 10 µm
- **Fine particle-** When the aerodynamic diameter (AED) ≤ 2.5 µm
- **Ultrafine particles-** these particles are smaller than 0.1 µm

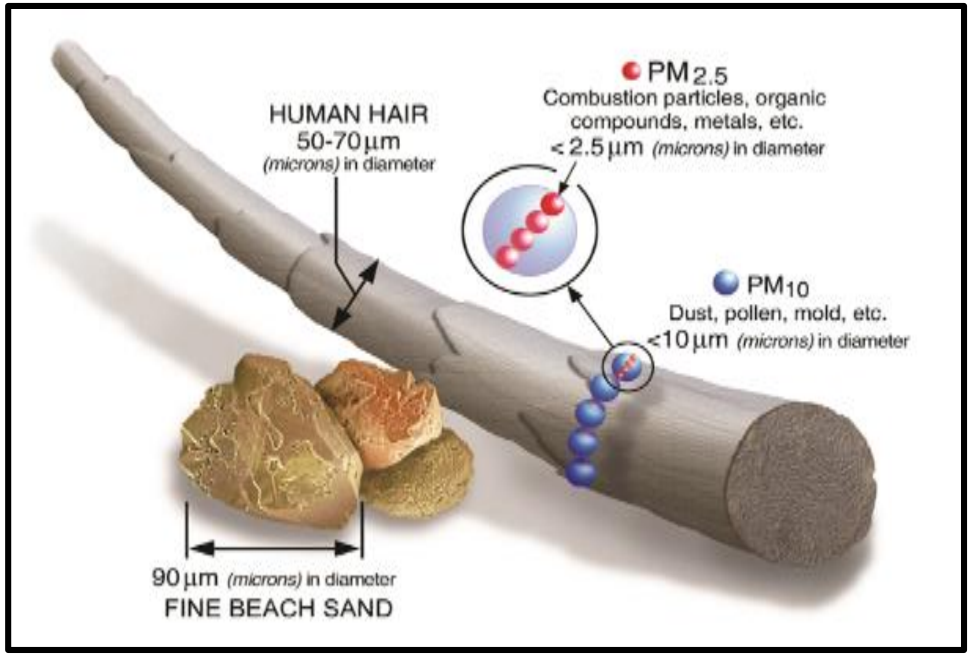
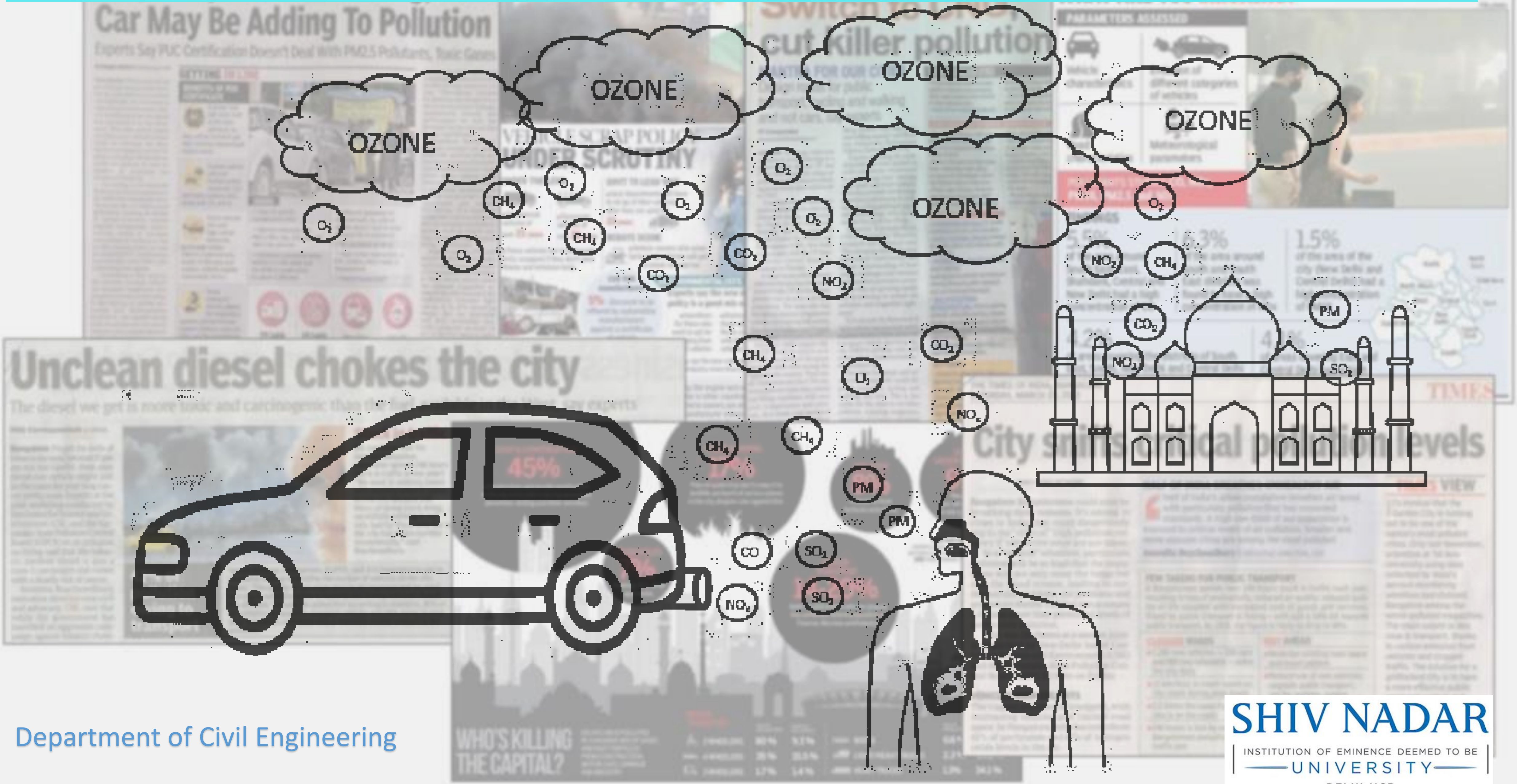


Fig. 1: Different PM size's

Source-https://www.epa.gov/sites/production/files/2016-09/pm2.5_scale_graphic-color_2.jpg

Motivation behind research



SHIV NADAR
INSTITUTION OF EMINENCE DEEMED TO BE
UNIVERSITY
DELHI NCR

Literature Review

No.	Authors	Particulars of Experiments	Main findings	Remarks
(1)	Singh et al., (2022)	Emission inventory for road transport in India in 2020: framework and post facto policy impact assessment	• High emission rates of CO_2, CO, PM, and NO_X • With increasing vehicle count fuel consumption was found to be increasing	• No detailed investigation on electric vehicles • Emissions future forecast is missing
(2)	Ramachandra TV (2009)	Emissions from India's transport sector: Statewise synthesis	• CO, CO_2, and CH_4 emissions have increased dramatically, with CO_2 from road transport contributing nearly 94.5% of total emissions	• For road transport emission, fleet modification with survival rate and modal share should be there • For railway emission, not much emphasis on electric locomotives
(3)	Singh et al., (2018)	Estimation of high resolution emissions from road transport sector in a megacity Delhi	• High resolution study show significant amount of PM, CO and No_x emissions • HCV contribute most followed by LCV and 2W	• Study didn't addressed electric vehicle • Deregistered vehicle should be neglected
(4)	Annadanam and Kota, (2019)	Emission of greenhouse gases and criteria pollutants from railways in India estimated using a modified top-down approach	▪ Average of 58% and 50% reduction in NO_x and CO_2 is expected by the proposed switch from road to rail. ▪ The emissions calculated by top-down approach were lower than bottom-up approach	• For calculation of electric locomotive emissions author consider only coal as main source of energy production and neglect diesel, gas and other energy sources

Literature Review

No.	Authors	Particulars of Experiments	Main findings	Remarks
(5)	Goel et al., (2015)	Assessment of motor vehicle use characteristics in three Indian cities	• Reported vehicles overestimates the actual number of in-use vehicles by up to 120%. • According to the survival functions for cars and MTW, 90% of the fleet will be replaced over a period of next 10 years	Study like these are more needed for remaining Indian cities for a comprehensive national study
(6)	Singh et al., (2017)	Emission inventory of trace gases from road transport in India	• Vehicle growth shows positive relation with GDP • 2 W, Cars, Buses and LMVs are the major contributors of CH_4, HC, CO in all major states	Revised vehicle fleet neglecting deregistered vehicle should be adopted
(7)	Singh et al., (2020)	Projection of Private Vehicle Stock in India up to 2050	• India follows the 'S' shaped curve and is currently in the initial stage of the Gompertz curve • Stock of private vehicles would be high in 2050	Good comparative study for future growth
(8)	Bastos et al., (2022)	Intake fraction estimates for on-road fine particulate matter ($PM_{2.5}$) emissions: Exploring spatial variation of emissions and population distribution in Lisbon, Portugal	• Overall iF value of 16.4 ppm for the Lisbon metropolitan area • Most exposure (12.0 ppm) occurs for the subset of the population	Calculation of dilution layer and breathing rate should be calculated precisely

Identification of gaps found in literature

Based on the literature review the following research gaps has been identified:

- For a number of pollutants, a comprehensive study in this domain that includes the most recent emission factors, specific fleet segregation, and accurate VKT is required
- Regarding railway emissions, the majority of studies only considered coal locomotives and diesel locomotives, omitting electric locomotives
- There is no estimation of pollutant emissions for electric vehicles
- The majority of the study assumed that electricity is generated solely from coal and its derivatives Where decadal changes and change in energy production sources must be considered
- For airways, estimations of various pollutants are lacking
- The effects of increasing pollutant concentrations on human health are absent

Objectives to fill gaps in past studies

- ✓ This research aims to evaluate North India's transportation emissions trends from 2010 to 2030 using comprehensive emission estimates at the zonal level
- ✓ Study includes railway estimates for both electric and coal locomotives
- ✓ For electric vehicles, a comprehensive emission inventory considered all dynamic vehicle characteristics for various pollutants is compiled
- ✓ We perform a back analysis for electricity production by considering all non - renewable energy production sources
- ✓ It includes Airways emission estimates considering appropriate emission factors and fuel consumption
- ✓ The age- and season-specific (summer, winter, and post-monsoon) human PM intake Fraction (iF) is commuted

Framework

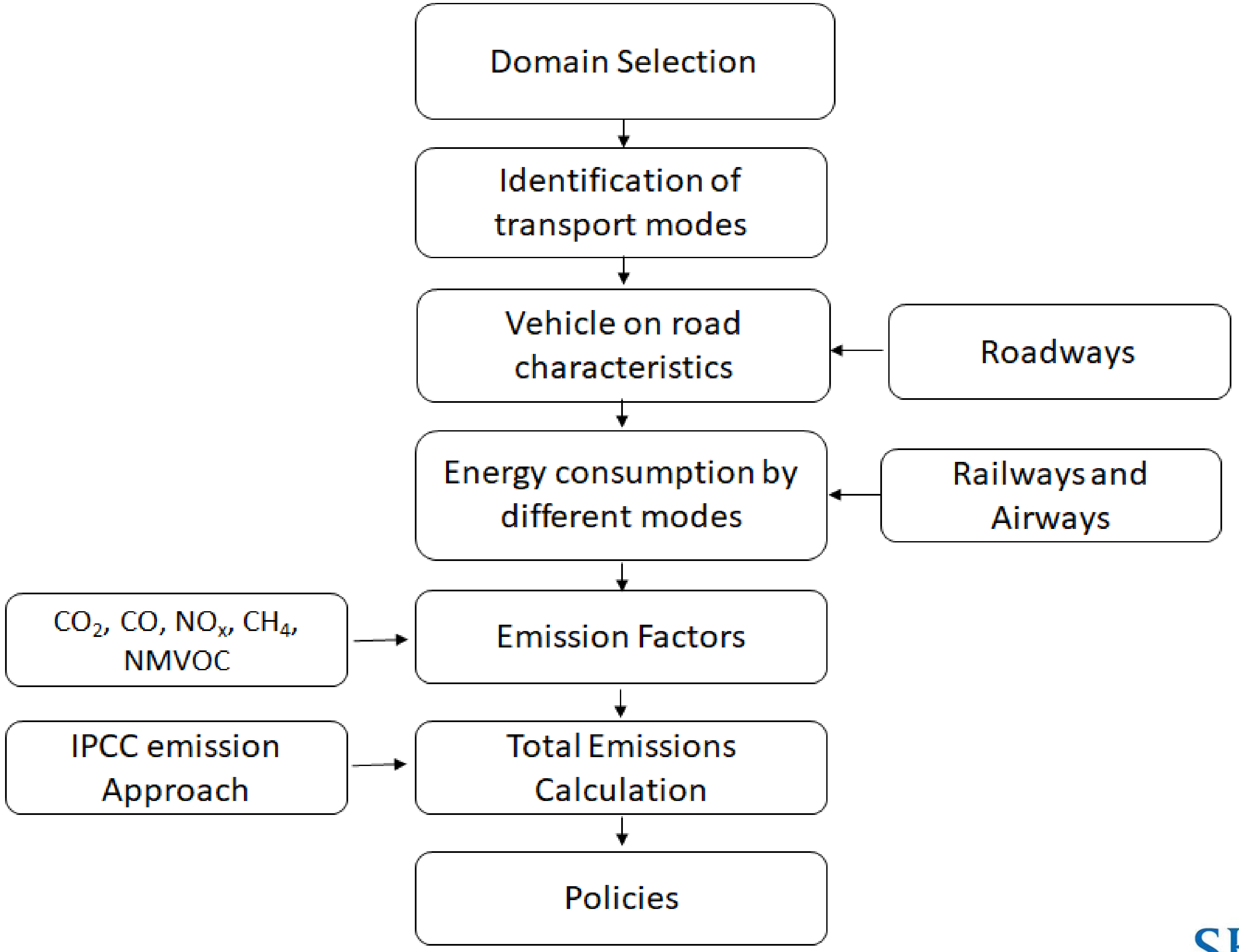


Fig 2: Framework for calculation of Transportation emissions

Study Area

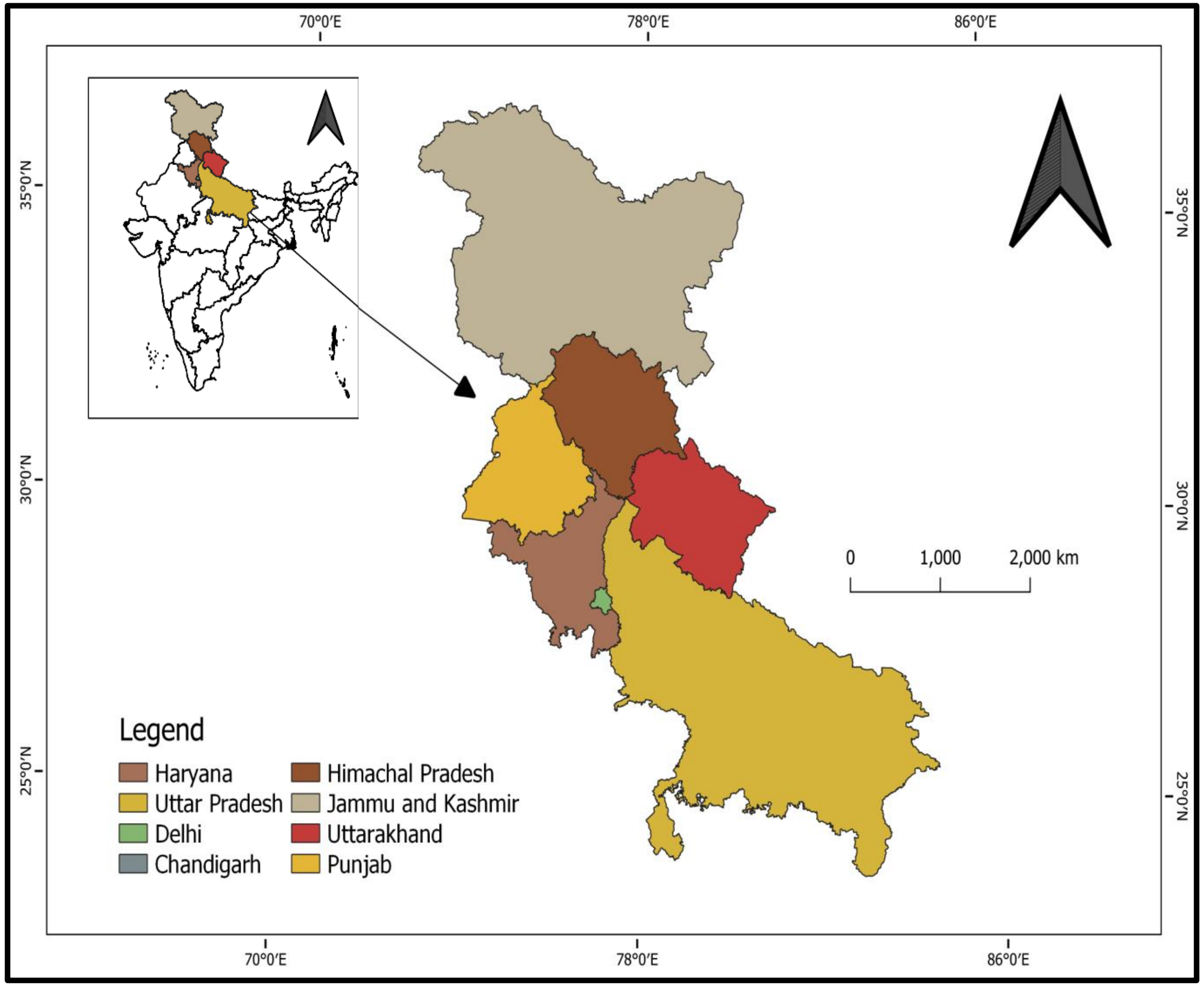


Fig. 2 : Northern India domain

Domain Area – 488497 km^2
Population - 340 million people

It comprises nearly 30% of the road vehicle population fleet, whereas 2W accounts for almost 75% of the entire fleet value. From 2011 to 2020, the CAGR of road transport is close to 8%.

- Rail track- 6,807 kilometers
- Airport - 26 types of airports (including commercial, civil enclave, and flying school), and
- Road network - 8.72 million kilometers

Data used from various sources like -

- National/state government database.
- Past literature
- Indian Meteorological Department (IMD)

Methodology

Characteristics and assumptions for Roadway transport -

- **Vehicle age** - The vehicle registered figures published by the Ministry of Transport, Government of India, include scrap/deregistered vehicles, therefore overestimating the number of registered vehicles We employ the vehicle fleet survival fraction presented by (Pandey and Venkataraman, 2014)

$$Sf\,(i\,,a) = \frac{1}{1 + e^{\left[A\left(1-\frac{A}{L_{50}}\right)\right]}}$$

Sf = survival rate, a = age, i = vehicle type,
A = is the form factor indicating the beginning of substantial retirement, L_{50}= age at which 50% of vehicles have retired.

- **Fuel share**

Table 1: Fuel share % by different modes of roadways in India. (Singh et al., 2021)

% Share	2010 onwards (%)	2015 to 2020(%)
Truck (D)	100	100
Bus (D)	92	90
Bus (CNG)	8	10
LCV (D)	100	100
Taxi (G)	65	60
Taxi (D)	20	20
Taxi (CNG)	15	20
3W (G)	65	60
3W (CNG)	15	20
3W (D)	20	20
2W (2s)	5	4
2W (4s)	95	96
Car (G)	65	60
Car (D)	35	40

- **VKT**

Table 2: VKT for various types of vehicles. Ramachandra and Shwetmala (2009)

Type of Vehicles	VKT (km/year)
Motor Cycles, Scooters & Mopeds	6300
Cars and Jeeps	12600
Taxis	12600
Buses	100000
Light Motor Vehicles (Passengers)	33500
Light Motor Vehicles (Goods)	63000
Trucks and Lorries	25000
Tractors and Trailers	21000
others	21000

Methodology

Formula's used in this study -

- The Energy Consumption (EC) of diesel and electric locomotives for both passenger and freight loads

$$\text{EC (in Litres)}_{\text{electric,diesel}} = \text{Net load of trains}_{\text{electric,diesel}} \times \frac{\text{fuel consumption}}{\text{GTKM}}$$

- Fuel Consumption (FC) by roadways transportation system considering various characteristics and assumptions -

$$\mathrm{FC}_{i,g,f} = \sum_i \sum_g \sum_f \frac{(\mathrm{NV}_{i,g,f} \times \mathrm{D}_{i,f} \times \mathrm{S}_{i,g,f})}{\mathrm{FE}_i}$$

NV = Number of Vehicle (population)
D = Distance travelled (yearly)
S = Modal share
FE = Fuel efficiency

- Compound emission by different transportation system -

$$\mathrm{EC}_{i,g,f} = \sum_i \sum_g \sum_f (\mathrm{FC}_{i,g,f} \times \mathrm{E}_{i,f} \times \mathrm{NCV}_{i,f})$$

FC = Fuel consumption
E = Emission Factor
NCV = Net caloric value

- $PM_{2.5}$ calculation for roadways transportation system -

$$PM_{2.5} = \sum (V_i \times VKT_i) \times EF_{j,km}$$

NV = Number of Vehicle (population)
VKT = Vehicle km travelled (yearly)
E = Emission Factor

Methodology

Logistic growth curve

- A study conducted by (Singh et al., 2020) discovered that India follows the 'S' shaped curve and is currently at the first stage of the Gompertz curve.
- Following that, we use the logistic curve method using 'R' software to forecast CO_2 future emissions for the years 2025 and 2030.
- Factors like as fuel advancement and shifting driving patterns were taken into account while predicting CO_2 emissions.$PM_{2.5}$ emissions and their associated heath impacts

Emission factor

Table 3 – Emission factors and NCV used for different fuels (Source: IPCC, 1996; IPCC,2006)

Fuel	NCV TJ/kt	CO_2 tC/TJ	CH_4 t/TJ	CO t/TJ	NO_x t/TJ	NMVOC t/TJ
Diesel	43.33	20.2	0.005	1	0.8	0.2
Petrol	44.3	18.9	0.02	0.8	0.6	1.5
CNG	48.6	15.3	0.092	0.4	0.6	0.005
Coal	19.63	25.8	0.001	0.15	0.3	0.02
ATF	44.1	2.94 (ton/ton)	2.64 (g/kg)	1034 (g/kg)	3.52 (g/kg)	19 (g/kg)

Table 4 - $PM_{2.5}$ Emission factors for different vehicle types

Vehicle Type	$PM_{2.5}$ Emission factor (g/km)
Truck D	1.24
Bus D	0.3
Bus CNG	0.044
LCV D	0.475
Car G	0.004
Car D	0.06
Car CNG	0.002
3W G	0.015
3W cng	0.015
3W D	0.091
2W G	0.035
Trailers and tractors D	1.24

Intake Fraction (iF) Box Model -

- We use a dynamic one-compartment model to estimate iF of emissions in urban areas
- The one-compartment model estimates concentrations based on a mass-balance, assuming that the air is well mixed within the urban area and is vertically mixed up to the atmospheric mixing height

$$iF = \frac{Total\ intake}{Total\ emissions} \qquad iF_i = \frac{Pop_i \times Br_i}{u_j \times VH_j \times A}$$

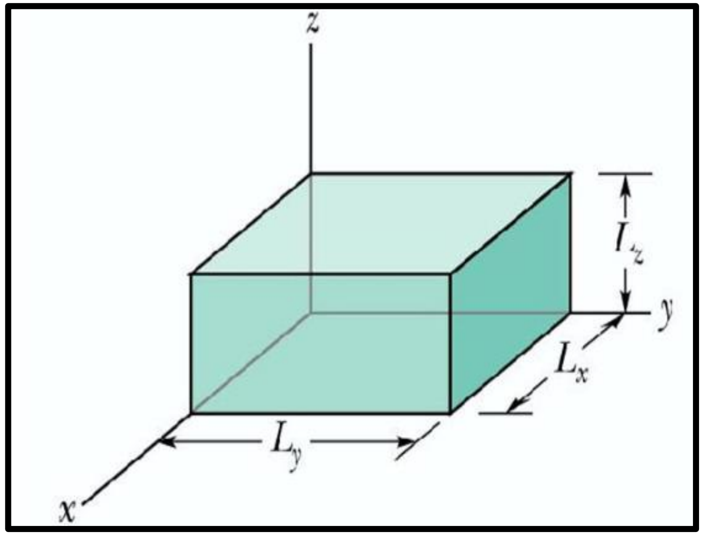


Fig. 3 : 3D box model

Where,
Pop = population of specific age group (i),
Br = breathing rate per person (m3 /s) of specific age group (i), (i) = infant, child, adult
μ = mean wind speed (m/s) during specific season (j)
H = average mixing layer height during specific season (j), j = summer, winter and post monsoon
A = area of domain (m^2)

Table 5 – Inputs used for calculation of age specific iF.

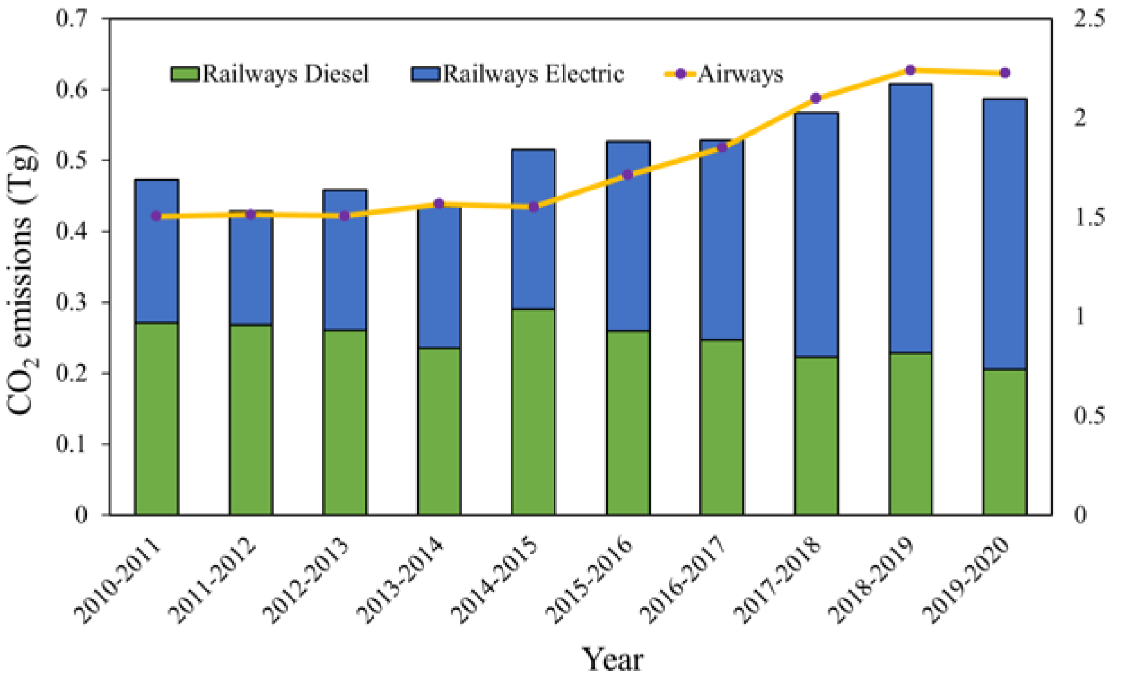
	Population	Breathing rate (m^3 person-s^{-1})		Mixing layer height (m)	Wind speed ($m\ s^{-1}$)	Area (km^2)
Infant (0-5 years)	33917687	39	Summer	2457.14	3.2	488497
Children (5-18)	104199978	17	Winter	910	2.3	
Adult (18 onwards)	210289653	14	Post Monsoon	1692.85	2.45	

Results

Table 6: Total CO_2 emissions from the North Indian Transportation system

Year	Roadways	Railways	Airways	Total (Tg)
2010-2011	37.07	0.43	1.51	39.01
2011-2012	39.10	0.47	1.51	41.08
2012-2013	39.19	0.46	1.51	41.15
2013-2014	41.77	0.46	1.57	43.79
2014-2015	44.58	0.56	1.55	46.69
2015-2016	55.85	0.54	1.71	58.10
2016-2017	66.26	0.59	1.85	68.70
2017-2018	66.65	0.60	2.10	69.35
2018-2019	62.11	0.61	2.24	64.96
2019-2020	64.78	0.60	2.22	67.61

Fig 4: CO_2 emission from different railway system and airways transportation



- Roadways – 95.2%
- Railways – 1.1%
- Airways – 3.6%
- CAGR = 6%

- **Diesel locomotive** – 0.27 Tg in 2010 to 49.64 Tg in 0.20 with CAGR of -3%
- **Electric locomotive** – 0.20 Tg in 2010 to 0.38 Tg in 2020 with CAGR of 7%
- **Airways** – 1.50 Tg in 2010 to 2.22 Tg in 2020 with CAGR of 4%

Results

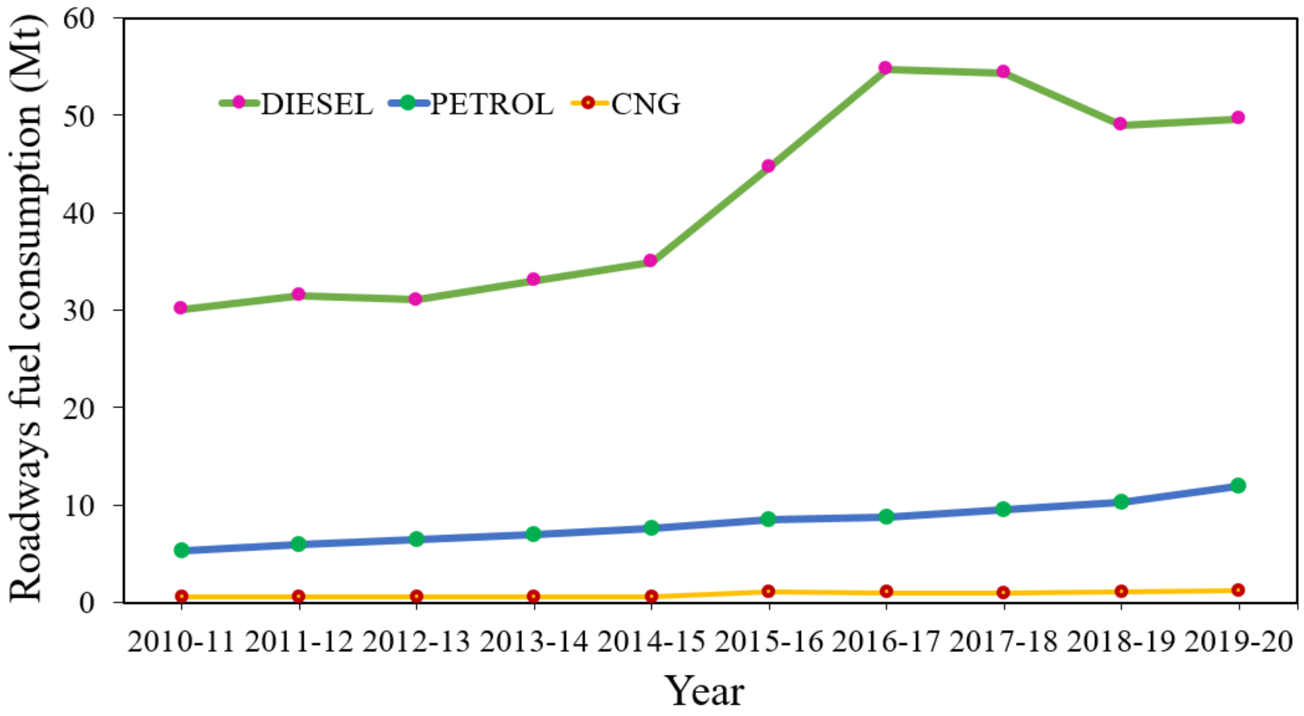
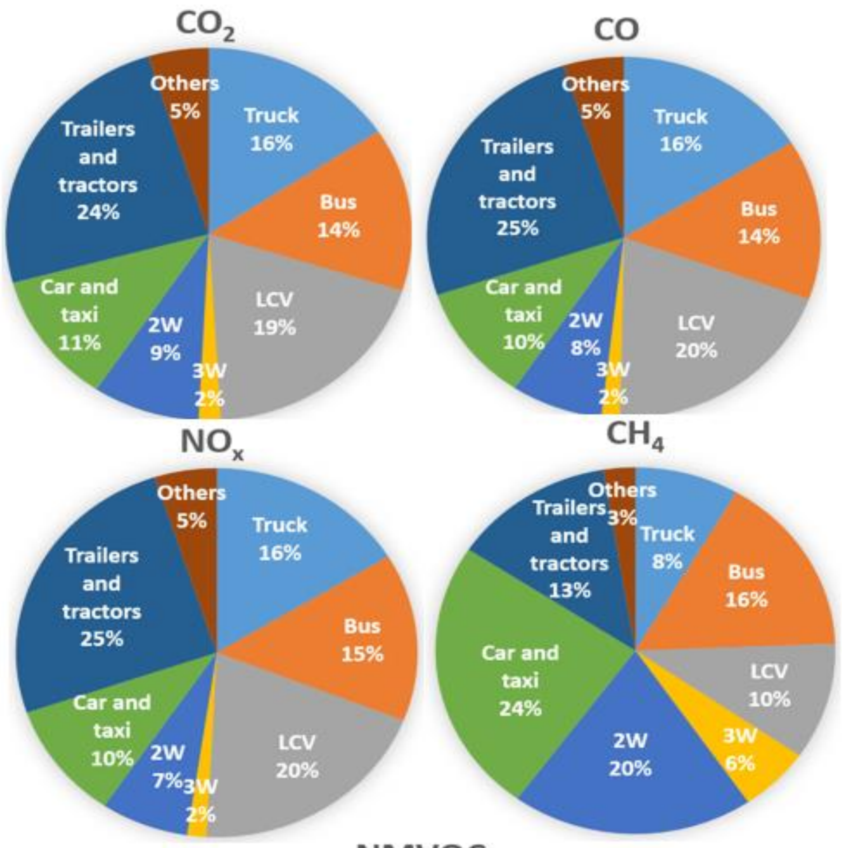
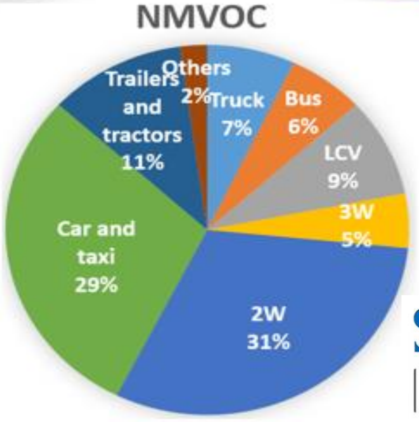


Fig 5: Fuel consumption by North Indian roadways





- **Diesel** – 30.07 Mt in 2010 to 49.64 Mt in 2020 with CAGR of 6%
- **Petrol** – 5.36 Mt in 2010 to 11.92 Mt in 2020 with CAGR of 9%
- **CNG** – 0.63 Mt in 2010 to 1.26 Mt in 2020 with CAGR of 8%

Results

Table 7: Emissions of CH_4, CO, NO_X, and NMVOC (Gg) from the North Indian transport system

Year	CH_4			CO			NO_X			NMVOC		
	Road	Rail	Air	Road	Rail	Air	Road	Rail	Air	Road	Rail	Air
2010-11	16.8	0.1	4.9	1781.1	10.8	1907	1420.9	9.8	6.5	780.5	2.1	35
2011-12	17.7	0.1	4.9	1877.4	11	1916.8	1496.6	10.1	6.5	830.1	2.1	35.2
2012-13	17.8	0.1	4.9	1879.2	10.7	1908.1	1495.7	9.9	6.5	875.1	2.1	35.1
2013-14	19.1	0.1	5.1	2002	9.9	1984.3	1593.3	9.5	6.8	942.5	1.9	36.5
2014-15	20.7	0.1	5	2134.6	12.2	1965.8	1698.4	11.6	6.7	1027.7	2.3	36.1
2015-16	26.3	0.1	5.5	2677.3	11.1	2168.4	2136.5	10.9	7.4	1136	2.1	39.8
2016-17	28.8	0.1	6	3192.1	11	2341.6	2546.9	11.2	8	1260.9	2.1	43
2017-18	29.5	0.1	6.8	3205.7	10.4	2656.3	2556.2	10.9	9	1292.4	1.9	48.8
2018-19	29.3	0.1	7.2	2973.9	10.6	2838.2	2369.7	11.1	9.7	1316.1	2	52.2
2019-20	32.3	0.1	7.2	3089.6	9.8	2817.5	2460.7	10.6	9.6	1558.4	1.8	51.8
CAGR	**8%**	**0%**	**4%**	**6%**	**-1%**	**4%**	**6%**	**1%**	**4%**	**8%**	**-2%**	**4%**

Table 8: Emissions of CH_4, CO, NO_X, and NMVOC (Gg) from Electric vehicles

Year	CO_2	CH_4	NO_x	CO	NMVOC
2018	196.89	0.09	2.67	1.43	0.15
2019	219.93	0.10	2.96	1.58	0.16
2020	148.14	0.06	2.00	1.06	0.11
CAGR	**-13%**	**-15%**	**-14%**	**-14%**	**-13%**

Results

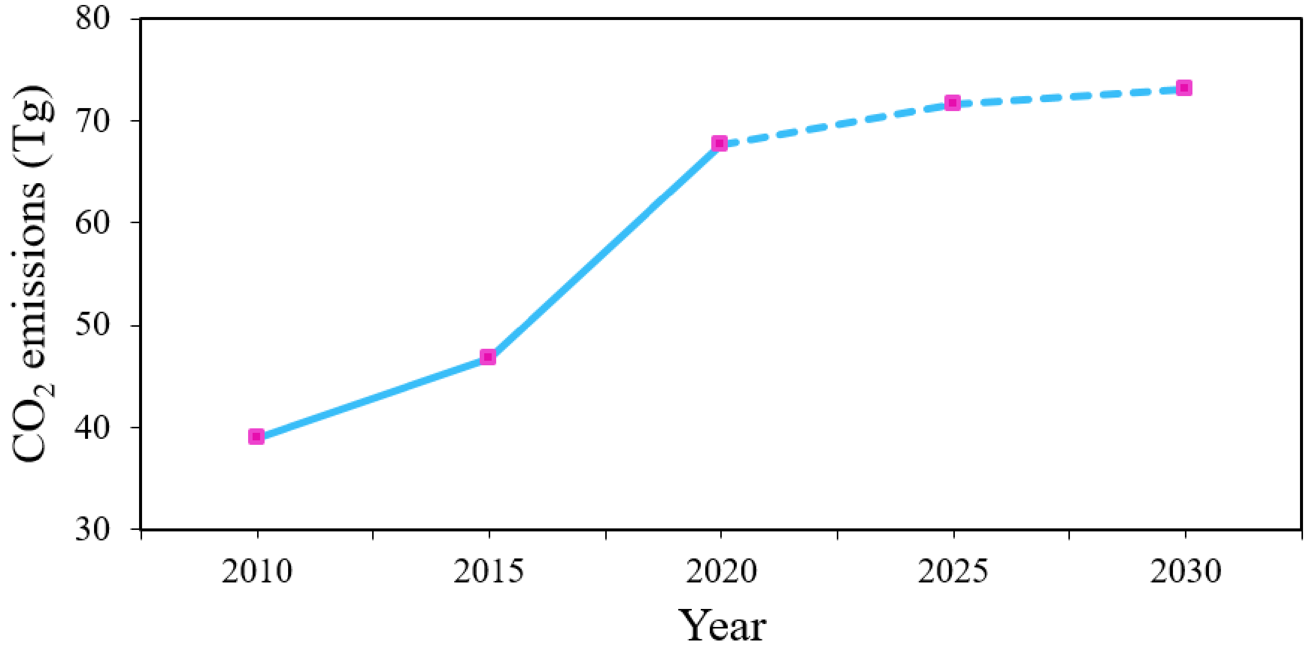


Fig 6: Transportation CO_2 emissions Prediction for year 2025 and 2030

CO_2 emissions future forecast

- 2020 – 67.61 Tg
- 2025 – 71.58 Tg
- 2030 - 73.05 Tg

$PM_{2.5}$ emissions were 109.15 Gg in 2010 to 190.40 Gg in 2020 with increase by CAGR of 6%.

- Infants (0-5 years) = 2.02 ppb (summer), 1.07 ppb (post monsoon), and 0.54 ppb (winter)
- Children (5-18 years) = 0.49 ppb (summer), 0.26 ppb (post monsoon), and 0.13 ppb (winter)
- Adults = 0.15 ppb (summer), 0.08 ppb (post monsoon), and 0.08 ppb (winter)

Conclusion

- ✓ The transportation sector, railways and airways has been estimated to emit 39 Tg, 0.43 Tg and 1.29 Tg of CO_2 in 2010 to that 67.6 Tg, 0.59 Tg and 2.2 Tg in 2020, with a CAGR of 6%, 4% and 4%
- ✓ Road transport sector has contributed 95.2% of CO_2 emission whereas railways and airways contributed 1.1% and 3.6% of total CO_2 emission
- ✓ Trailer and tractors (24%) > LCV (19%) > truck (16%) share of CO_2 emission. Car/taxi and 2W share less but significant with 11% and 9%
- ✓ EV's CO_2 emissions levels were 196.8 Gg, 219.9 Gg, and 148.1 Gg for the years 2018, 2019, and 2020
- ✓ Infants had the highest levels of iF, followed by children and adults. Summer iF was found to be high due to an increase in dilution rates caused by stronger winds and a higher mixing altitude
- ✓ Switching the whole roadway fleet to CNG can reduce emissions by 14%
- ✓ Replacing electric locomotives with diesel locomotives can reduce CO_2 by 55%

References

1. Annadanam, S.K. and Kota, S.H., 2019. Emission of greenhouse gases and criteria pollutants from railways in India estimated using a modified top-down approach. *Journal of Cleaner Production*, *213*, pp.610-617.
2. Bastos, J., Milando, C., Freire, F. and Batterman, S., 2018. Intake fraction estimates for on-road fine particulate matter (PM2. 5) emissions: Exploring spatial variation of emissions and population distribution in Lisbon, Portugal. *Atmospheric Environment*, *190*, pp.284-293.
3. Goel, R., Mohan, D., Guttikunda, S.K. and Tiwari, G., 2016. Assessment of motor vehicle use characteristics in three Indian cities. *Transportation research part D: transport and environment*, *44*, pp.254-265.
4. Ramachandra, T.V., 2009. Emissions from India's transport sector: statewise synthesis. *Atmospheric Environment*, *43*(34), pp.5510-5517.
5. Singh, N., Mishra, T. and Banerjee, R., 2020. Projection of private vehicle stock in India up to 2050. *Transportation Research Procedia*, *48*, pp.3380-3389.
6. Singh, N., Mishra, T. and Banerjee, R., 2022. Emission inventory for road transport in India in 2020: Framework and post facto policy impact assessment. *Environmental Science and Pollution Research*, *29*(14), pp.20844-20863.
7. Singh, R., Sharma, C. and Agrawal, M., 2017. Emission inventory of trace gases from road transport in India. *Transportation Research Part D: Transport and Environment*, *52*, pp.64-72.
8. Singh, V., Sahu, S.K., Kesarkar, A.P. and Biswal, A., 2018. Estimation of high resolution emissions from road transport sector in a megacity Delhi. *Urban Climate*, *26*, pp.109-120.

Thank you

SHIV NADAR
INSTITUTION OF EMINENCE DEEMED TO BE
UNIVERSITY
DELHI NCR