

**Systems Analysis of Personal Transportation
Needs and Environmental Implications in the
People's Republic of China**

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Presentation Outline

- Spreadsheet Vehicular Air Pollution Information System
- Motivation for the Optimization Model
- The Optimization Model - Urban Transportation Planning for Air Quality Management

Purpose

- Automobile emissions are the most rapidly growing source of urban air pollution in most Chinese cities.
- Evaluate strategies and policies for guiding the development of Beijing's transportation sector.
- Determine the impact of economic policies and environmental regulations on future technology choices.
- Analyze the technological and traffic demand and supply options available to China (Beijing) to reduce vehicular pollution.
- Develop a mathematical model that will give the optimal transportation mix to meet the turnover, environmental goals, and other constraints through a variety of policy options at the minimum cost.

Transportation Sector in China

- Rapid rate of motorization (both number of passenger trips and distance of passenger trips increased)
- Outdated vehicle technologies and high emissions characteristics
- Inadequate road infrastructure
- Land use structure
- Mix of transportation modes
- Policies regarding transportation modes

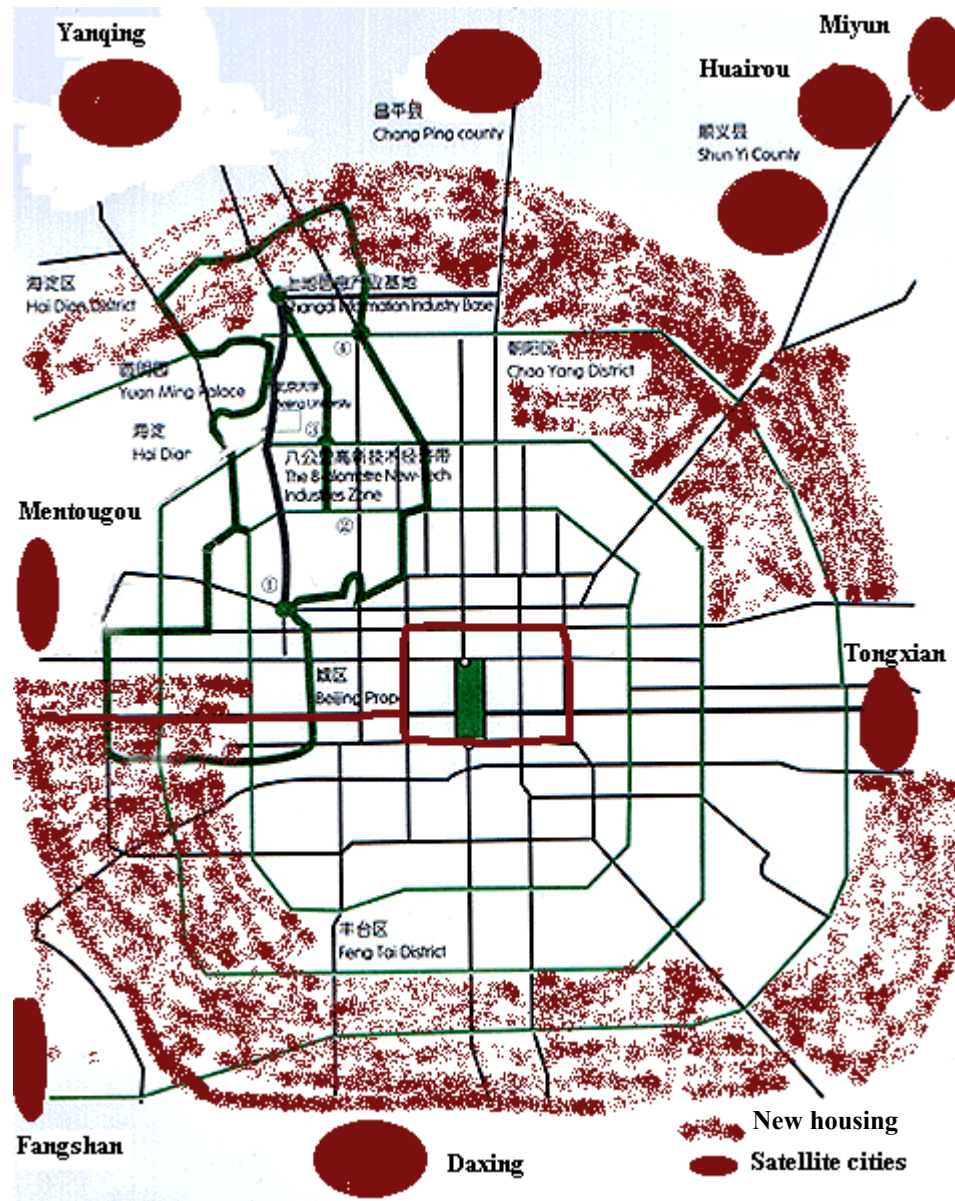
China

- 2500 NGV (1995), SEPA 1997: 4600 CNG and 1300 LPG
- Projects for 15,000 LPG and 3000-5000 electric vehicles by 2000
- US and China joint venture for electric bicycle, three wheel bicycle, scooters, and motorcycles
- Ban lead: July 1, 2000
- New cars will have electric fuel injection and catalytic converters
- Euro I: January 1, 2000

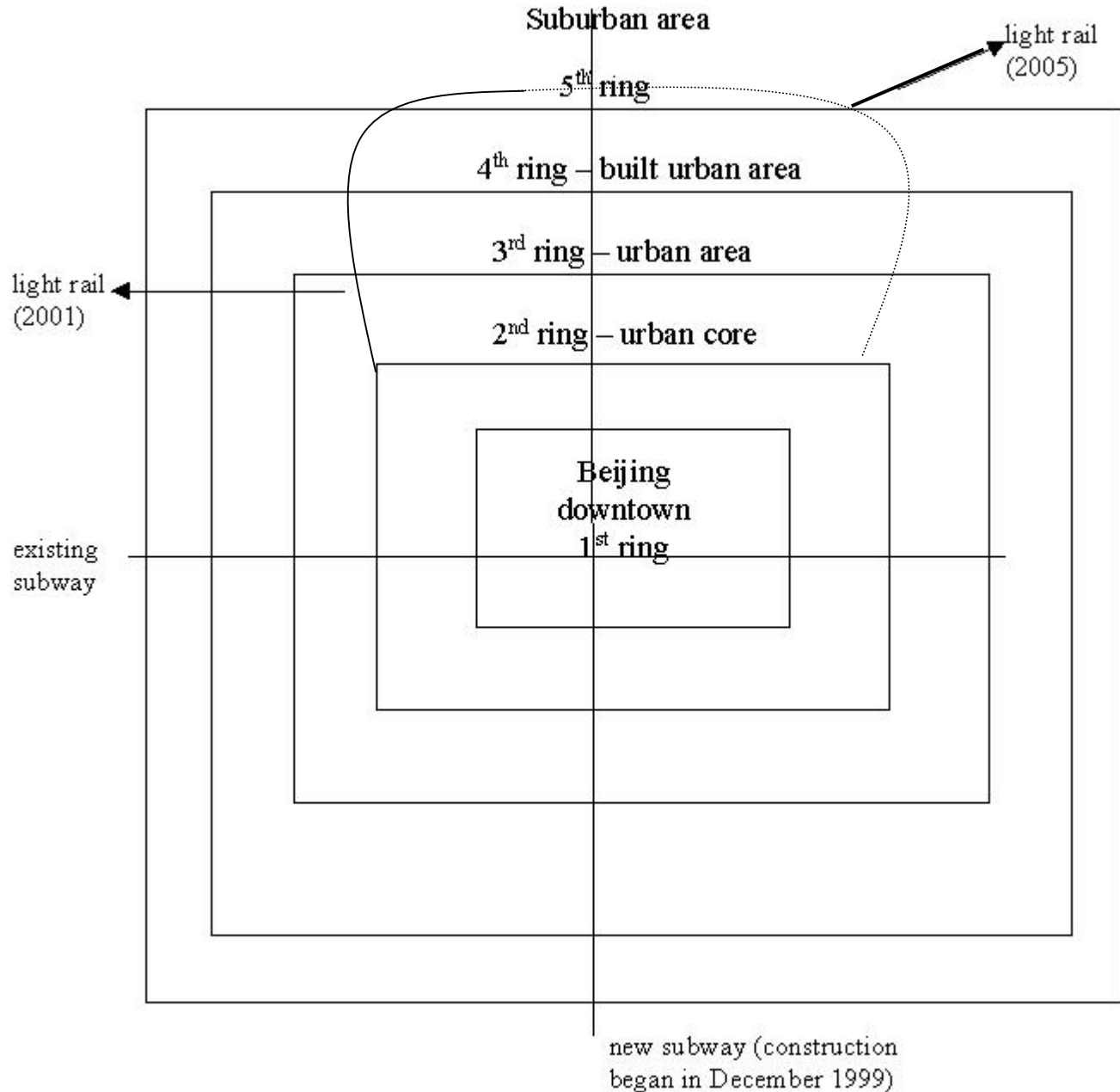
Beijing

- Ban lead: July 1, 1997
- Euro I since January 1, 1999
- Euro II: July 1, 2000
- Beijing government plans to meet Class 2 air quality standards by 2002
- Reduce sulfur level of gasoline and diesel
- Retirement age of vehicles
- Convert 6000 taxis and 60,000 cars to LPG and CNG

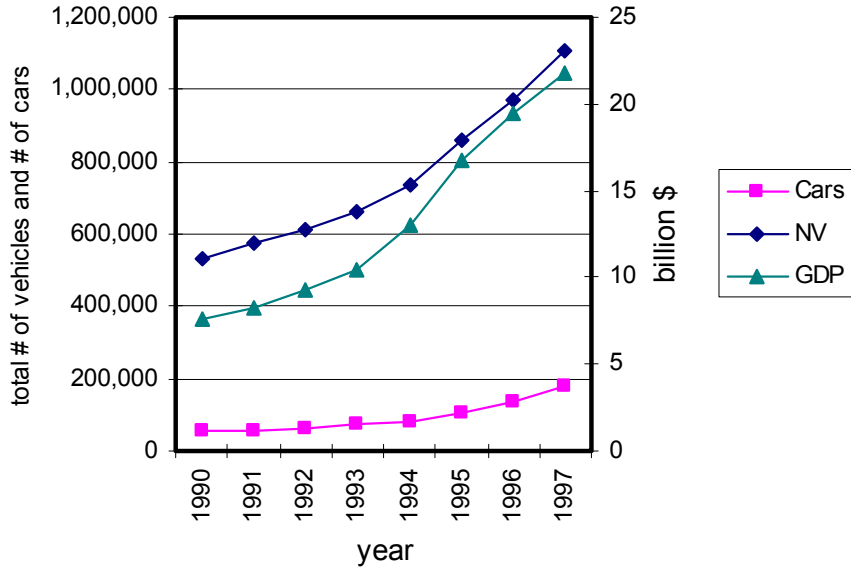
Beijing



Beijing Subway & Light Rail

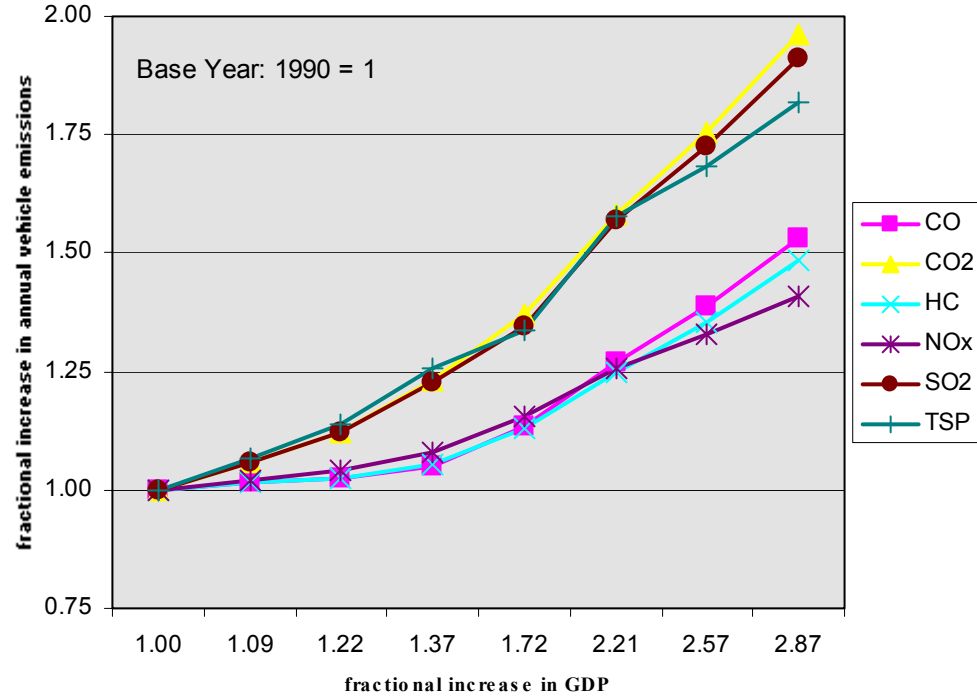


GDP vs Total # of Vehicles and # of Cars in Beijing

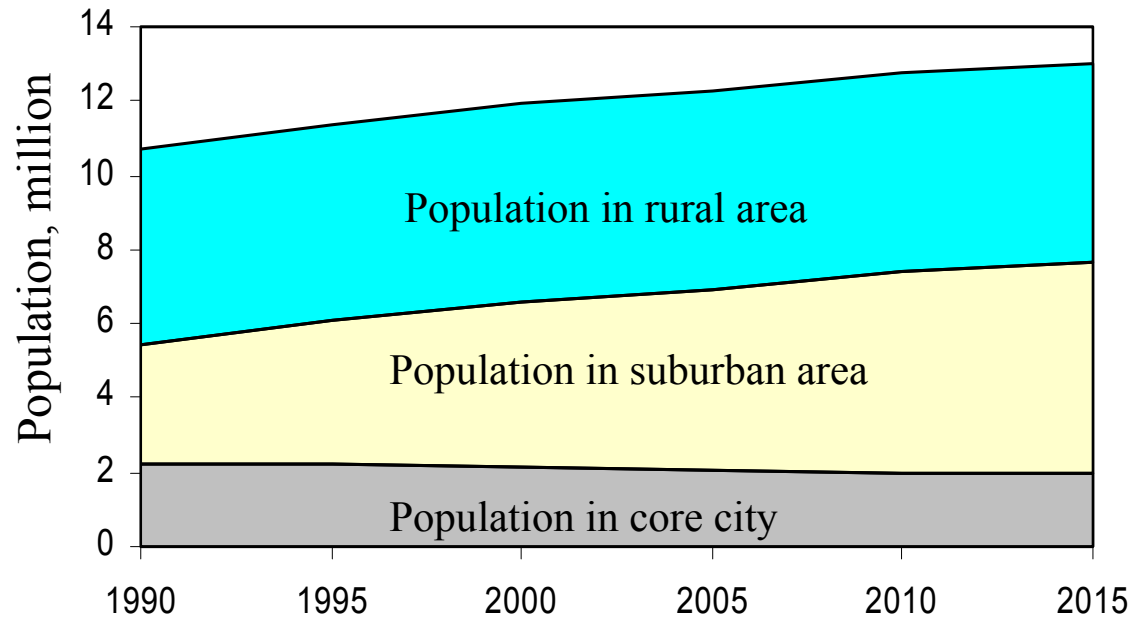


year	NV growth rates	Cars growth rates
1990	7.70%	10.02%
1991	8.34%	6.96%
1992	5.68%	9.42%
1993	8.10%	21.68%
1994	11.49%	7.30%
1995	16.73%	32.32%
1996	13.30%	29.50%
1997	13.74%	29.50%

Vehicle Emissions Growth vs GDP Growth from 1990 to 1997 in Beijing



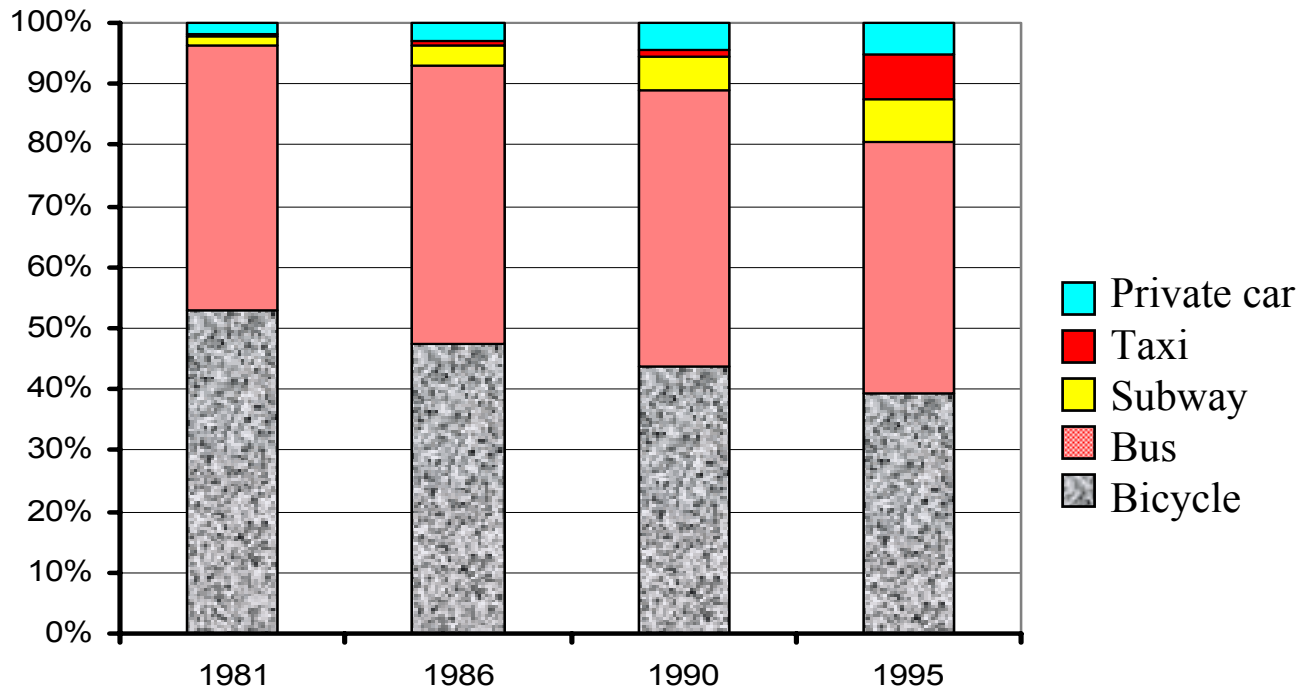
Beijing is developing its suburbanization and decentralization, which will increase the passenger kilometers traveled



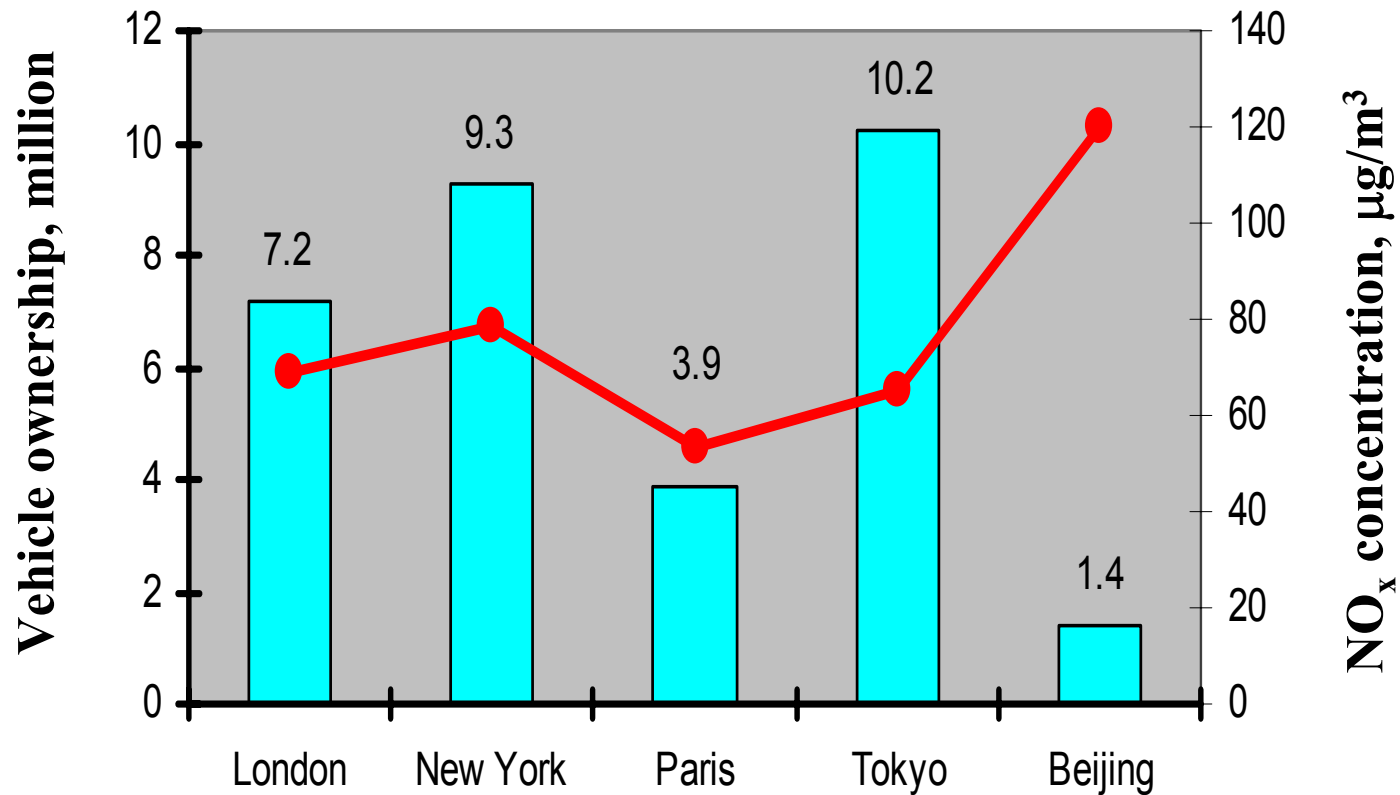
Source: Beijing's Master Plan, 1993.

Primarily due to past settlement patterns, the relatively short trips, and government policy to promote bicycle use, Beijing's transportation heavily relies on buses and bicycles. However, Beijing is beginning to experience a rapid rate of motorization, and most of the recently increased trips come from automobiles.

Percentage of Passenger Trips by Various Transportation Modes



Beijing is characterized by its low vehicle ownership and high pollution: Comparison of Beijing with four big cities



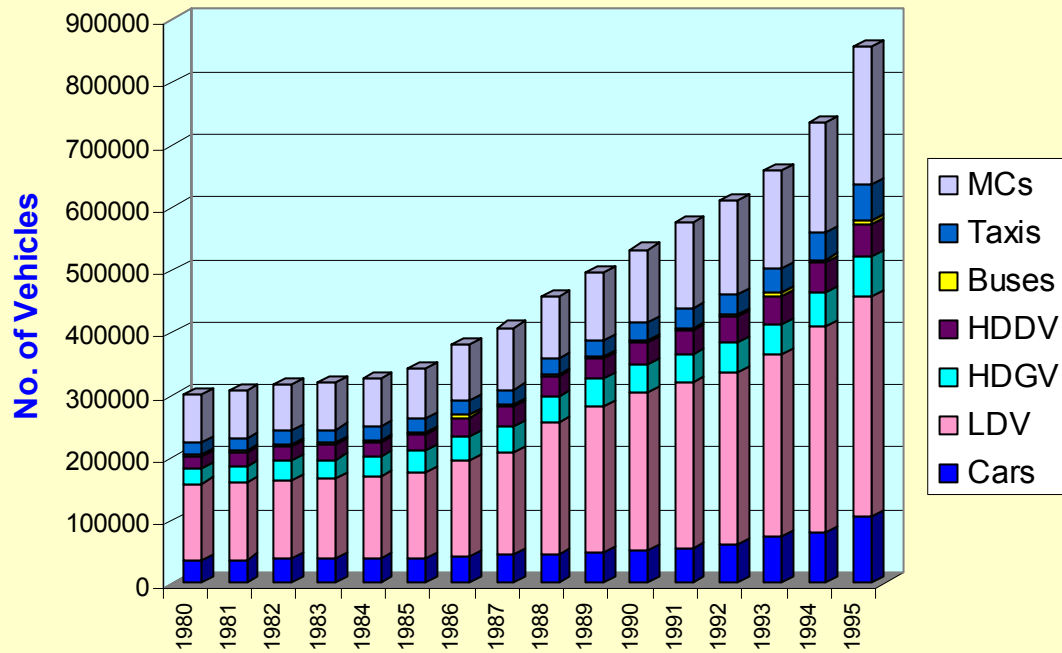
Data for Beijing is in 1998. Others are in 1990.

Share of Air Pollutant Emissions from the Mobile Sector

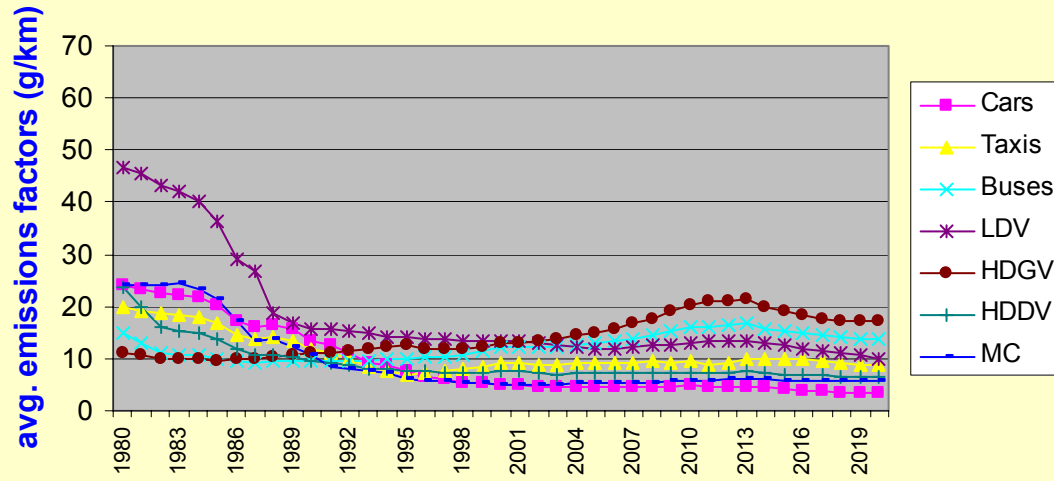
	CO	HC	NO _x	SO ₂	PM
Mexico, 1994	100%	53.3%	70%	26.5%	4.3%
Santiago, 1992	94.2%	82.7%	84.6%	24%	11.5%
São Paulo, 1995	96.4%	90.9%	97.3%	85.5%	42.7%
Rio de Janeiro, 1978	96.4%	73.2%	69.6%	9.5%	3.5%
Beijing, 1992	63.4%	73.5%	21.7%		
Beijing, 1995	86.2%		49.1%	10%	

Source: World Bank Report. Vehicular Air Pollution: Experience from Seven Latin American Urban Cities, 1997. Data in Beijing comes from the report titled China's Strategies for Controlling Motor Vehicle Emissions, 1997.

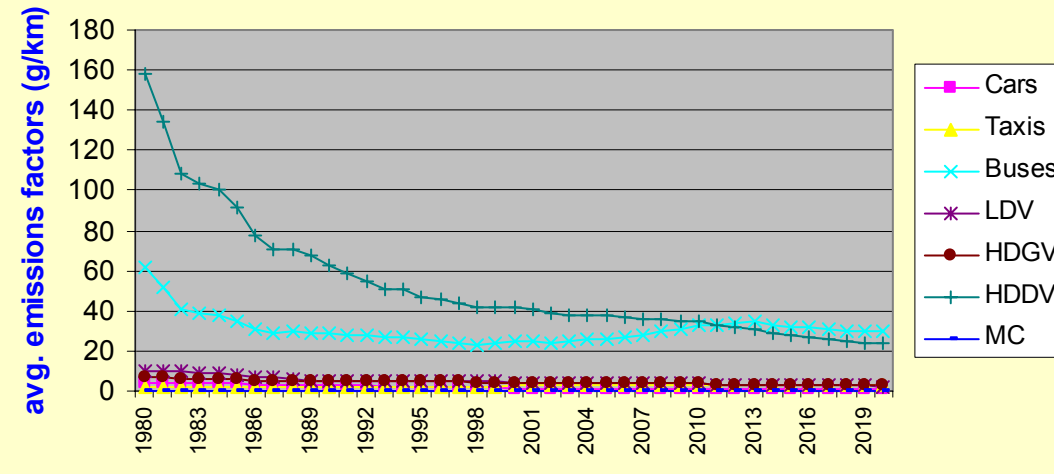
Historical Vehicle Growth in Beijing



Vehicle Fleet Average HC Emission Factors Trend

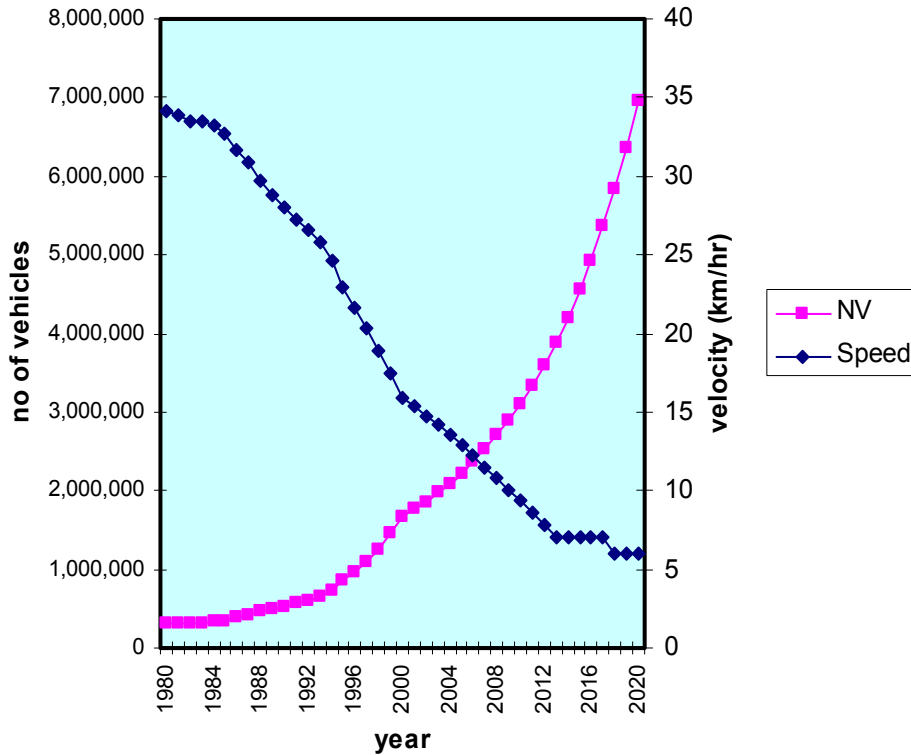


Vehicle Fleet Average NOx Emission Factors Trend

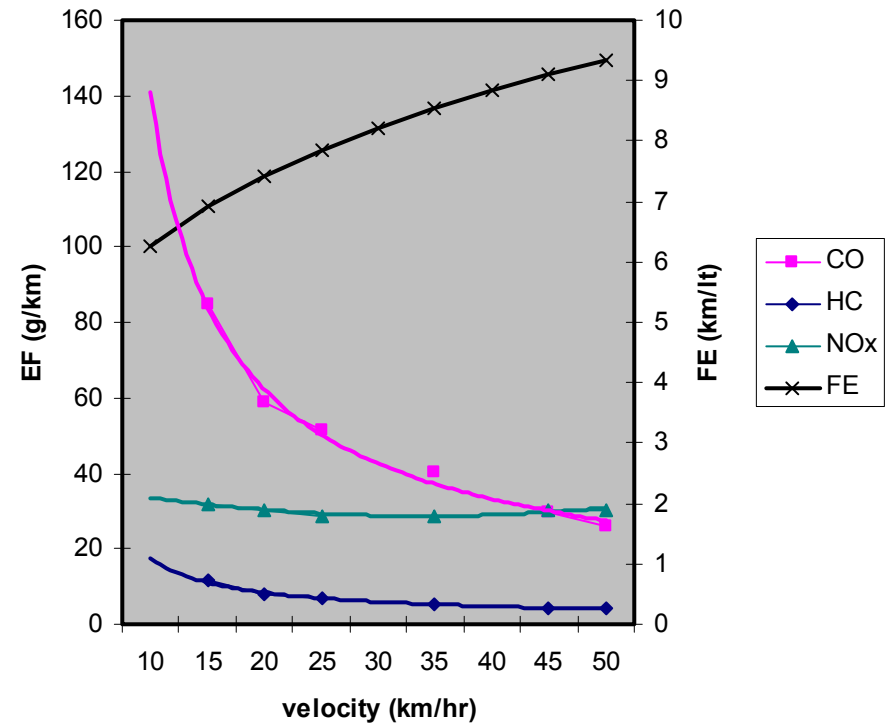


Vehicle Growth, Speed, Fuel Efficiency and Emission Factors for Cars

Vehicle Growth and Reduced Speeds



Fuel Efficiency and Emission Factors vs Speed



Speed Effect on Fuel Efficiencies and Emission Factors

$$RA(t) = RA95 + \text{SUM}(t, AM(\text{"ro"}, t) \times \text{width})$$

$$\text{Speed}(t) = [-10.635 \times \ln(NV(t)) + 168.3] \times [RA(t)/RA95] \times (1 + \Sigma \text{fri}^1) \times (1 \pm \text{fhb}^2)$$

$$FE_{\text{old}}(v, f, t) = FE95(v, f) \times [(1 + \text{imp}^3(v, f)/100)^{\text{ORD}(t)-1}]$$

$$FE_{\text{new}}(v, t) = A(v) \times \text{Speed}(t)^{0.2501}$$

$$FE(v, f, t) = FE_{\text{old}}(v, f, t) \times FE_{\text{new}}(t) / FE_{\text{new}}(\text{"1995"})$$

$$EFs(p, v, f, t) = A(v, p, f) \times \text{Speed}(t)^{B(v, p, f)}$$

$$EF(p, v, f, \text{"avg"}, t) = E = [(\text{SUM}(f, EF(p, v, f, \text{"0"}, t)) \times NV(v, \text{"0"}, f, t)) + \text{SUM}((a, f), EF(p, v, f, \text{"avg"}, t-1) \times NV(v, a, f, t))] / (\text{SUM}((f, a), NV(v, a, f, t))) \times EFs(p, v, f, t) / EFs(p, v, f, \text{"1995"});$$

$$EF(\text{"SO}_2\text{"}, v, f, \text{"avg"}, t) = E = 2 \times \text{scontent}^4 \times \text{density}(f) \times 1000 / FE(v, f, t)$$

$$EF(\text{"TSP"}, v, f, \text{"avg"}, t) = E = \text{pcontent}^4 \times \text{density}(f) / FE(v, f, t)$$

¹ fri: fractional increase in speed from the use of control options

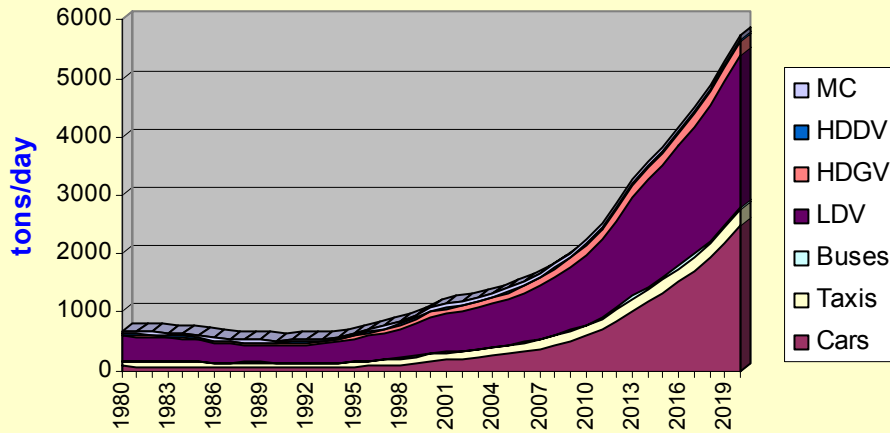
² fhb: fractional increase/decrease in speed from the use of HOV and bus lanes

³ imp(v, f) annual fuel efficiency improvement rate

⁴ scontent is the % sulfur content of fuel f and pcontent is the g/kg particulates content of fuel f

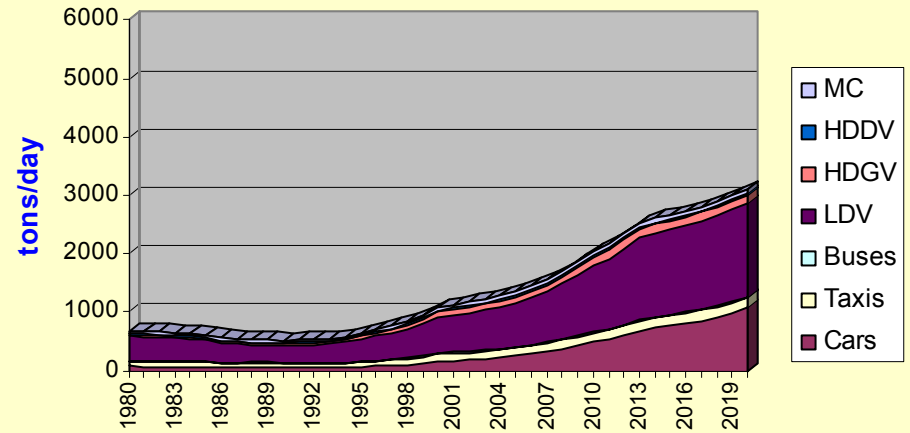
UNREGULATED

HC Emissions from Vehicles in Beijing

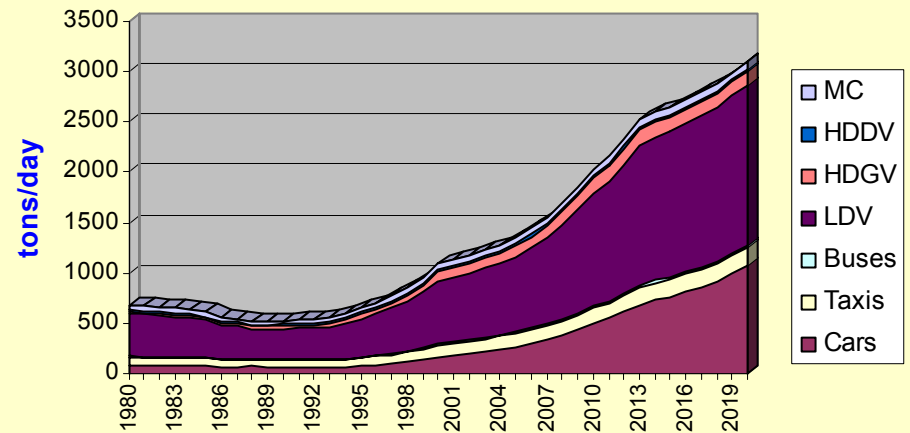


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HC Emissions from Vehicles in Beijing



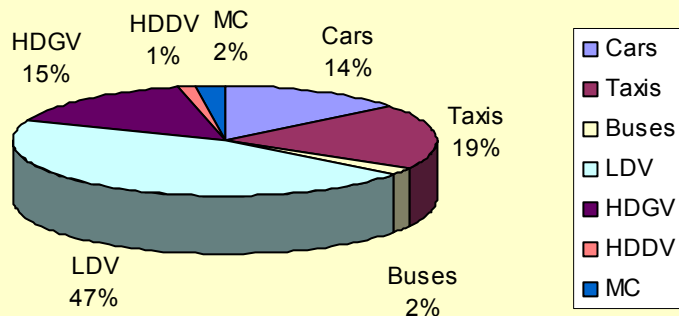
HC Emissions from Vehicles in Beijing



Percentage of Emissions by Vehicles in 1995

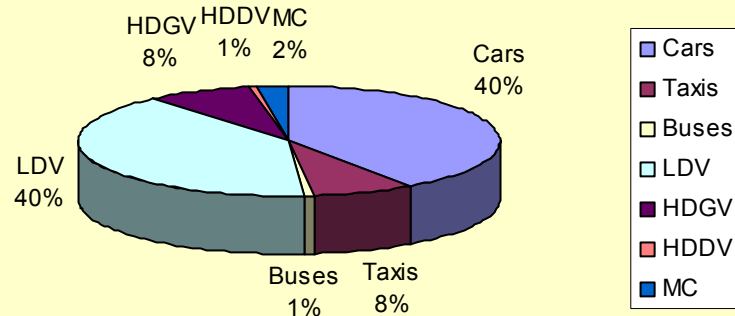
Percentage of Emissions by Vehicles in 2020

CO Emissions by Vehicle Type (tons/day)



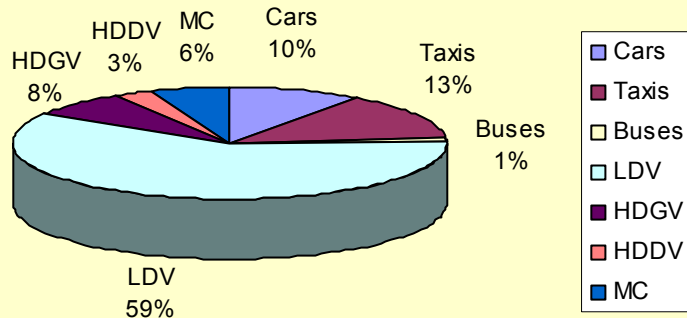
Total = 1,627,111 tons/yr

CO Emissions by Vehicle Type (tons/day)



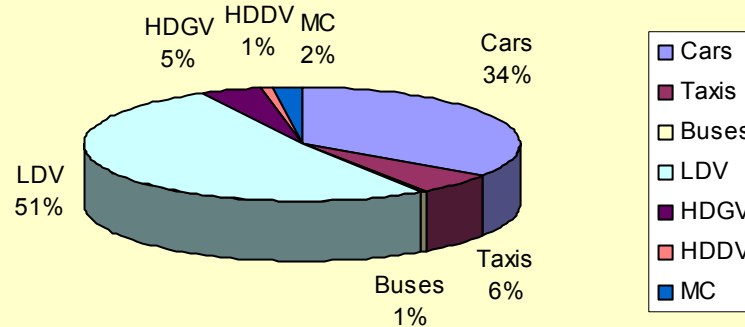
Total = 7,149,756 tons/yr

HC Emissions by Vehicle Type (tons/day)



Total = 235,024 tons/yr

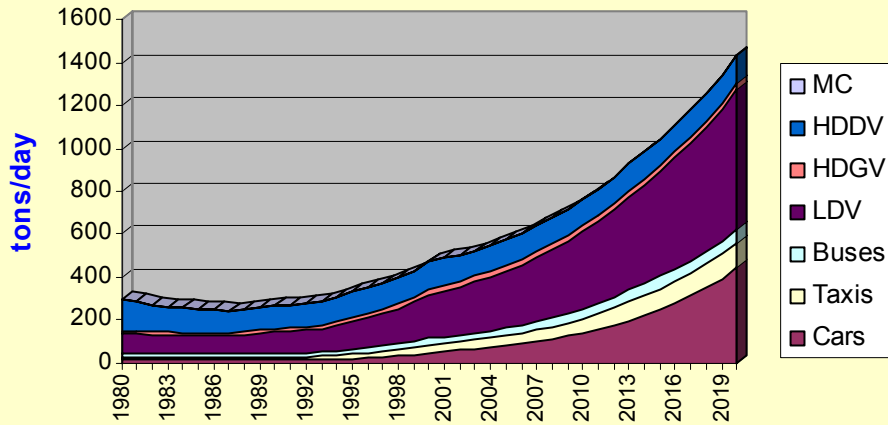
HC Emissions by Vehicle Type (tons/day)



Total = 1,132,125 tons/yr

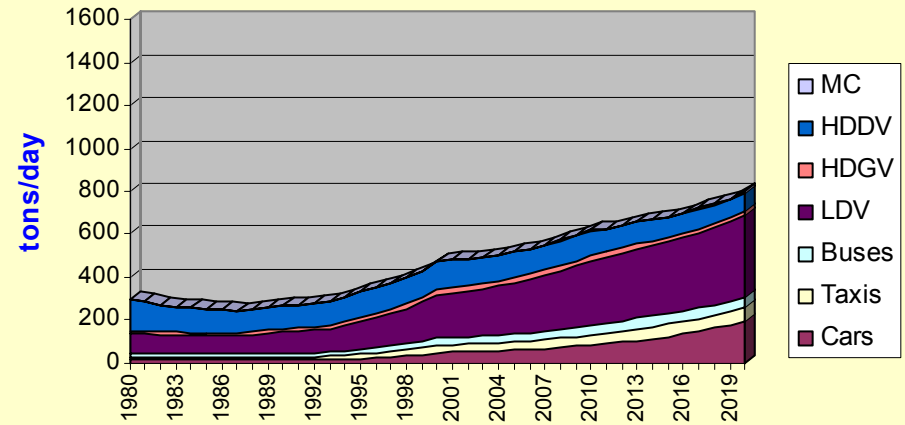
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NOx Emissions from Vehicles in Beijing

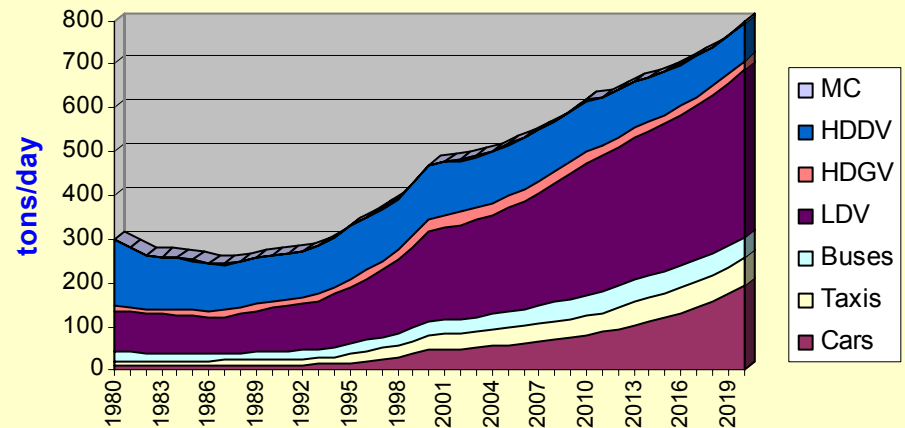


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NOx Emissions from Vehicles in Beijing

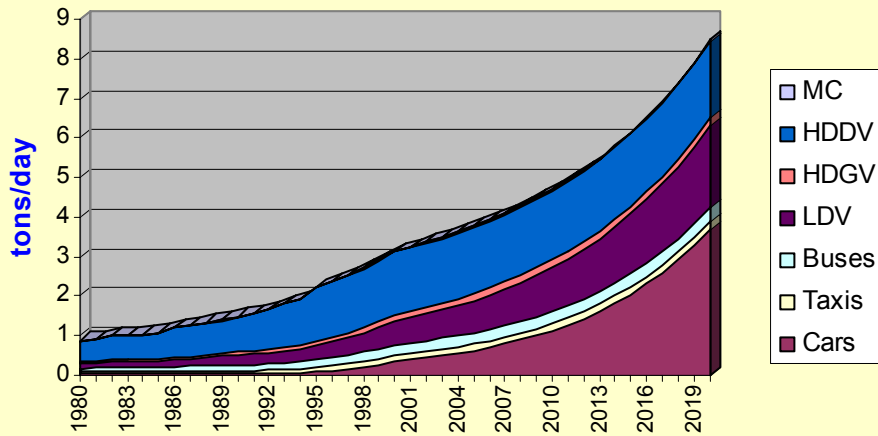


NOx Emissions from Vehicles in Beijing



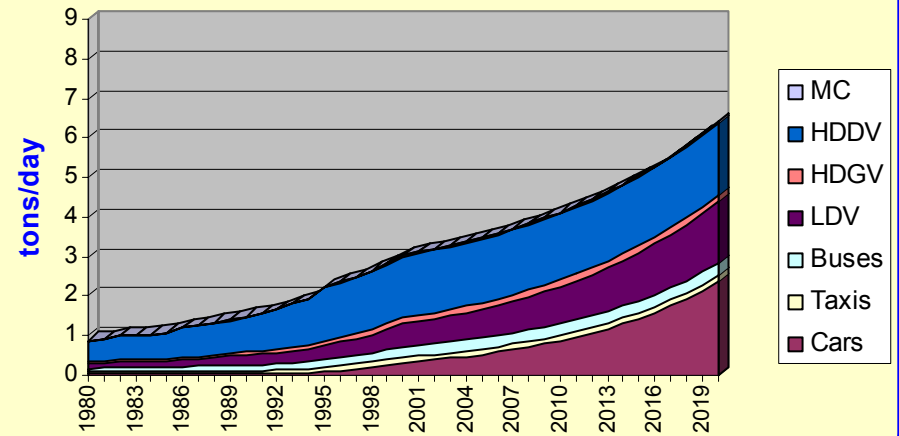
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TSP Emissions from Vehicles in Beijing

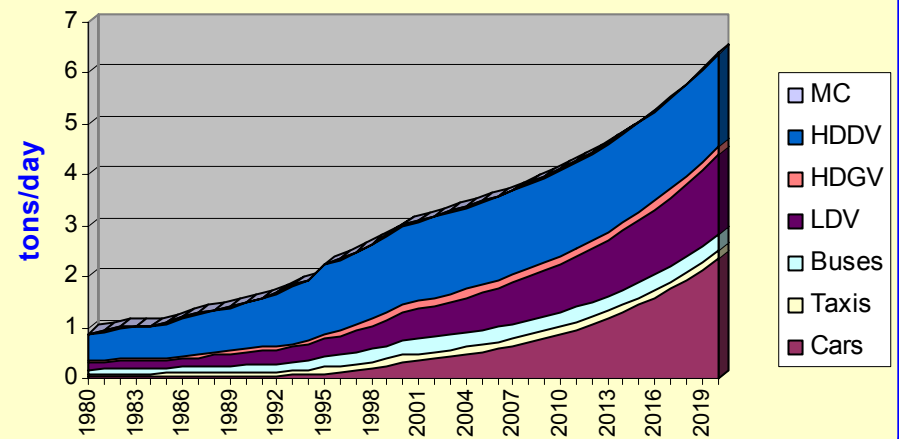


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TSP Emissions from Vehicles in Beijing

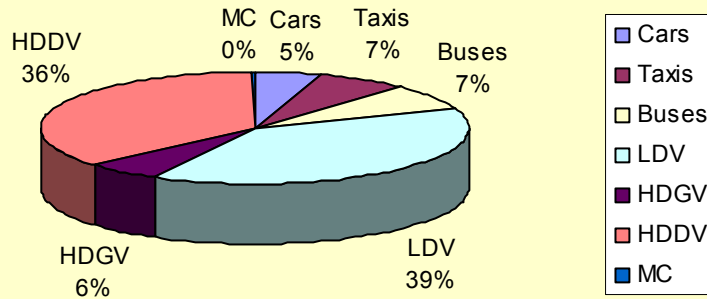


TSP Emissions from Vehicles in Beijing



Percentage of Emissions by Vehicles in 1995

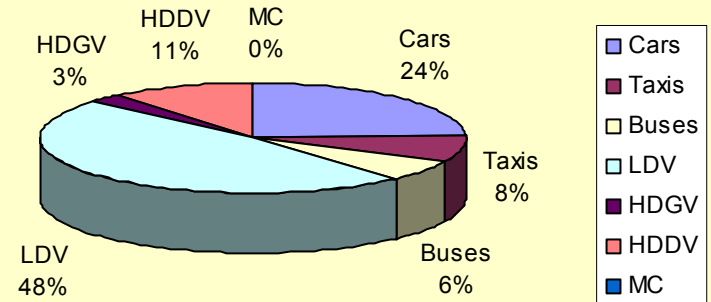
NOx Emissions by Vehicle Type (tons/day)



Total = 120,846 tons/yr

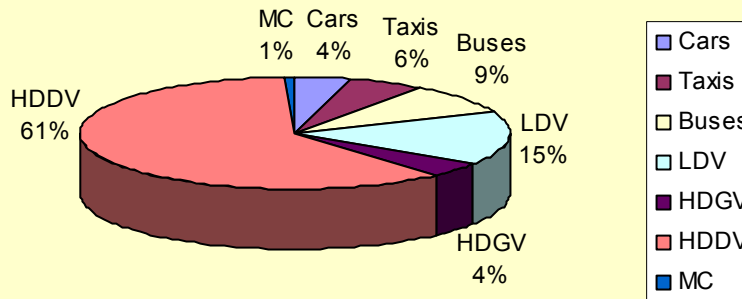
Percentage of Emissions by Vehicles in 2020

NOx Emissions by Vehicle Type (tons/day)



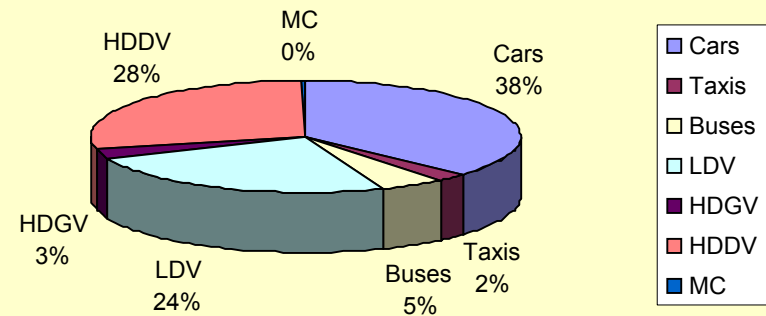
Total = 290,540 tons/yr

TSP Emissions by Vehicle Type (tons/day)



Total = 818 tons/yr

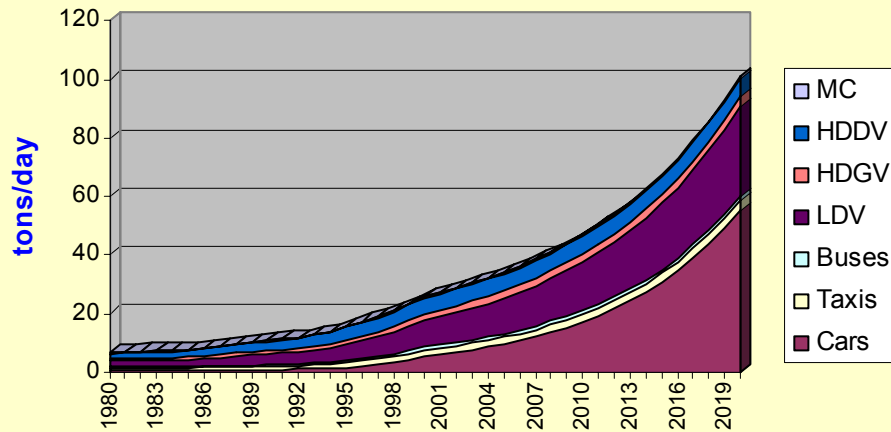
TSP Emissions by Vehicle Type (tons/day)



Total = 2,342 tons/yr

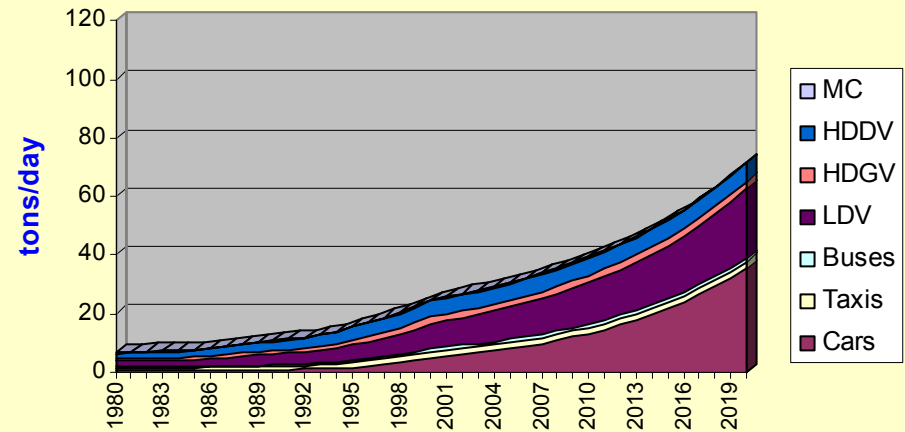
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SO2 Emissions from Vehicles in Beijing

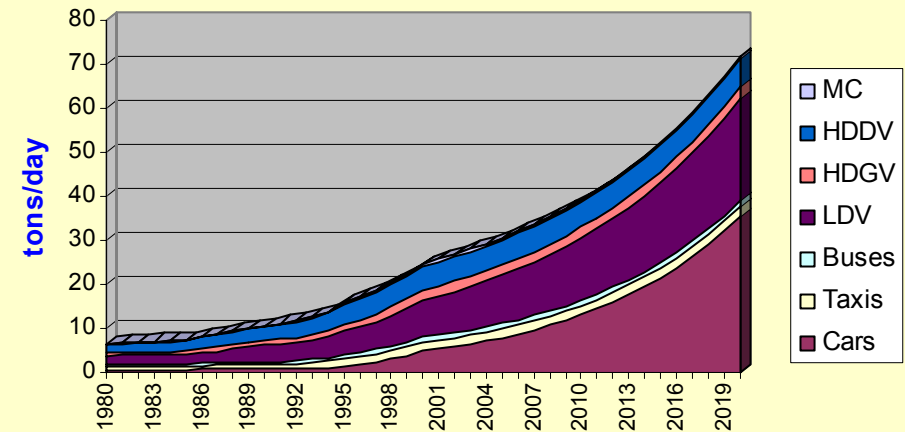


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SO2 Emissions from Vehicles in Beijing

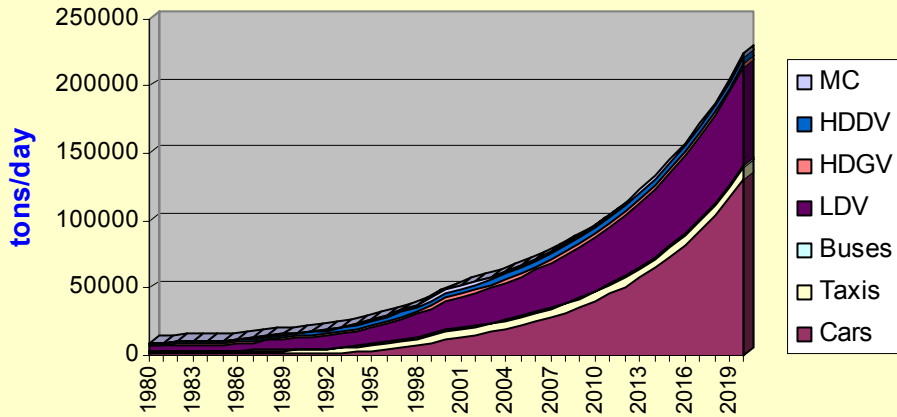


SO2 Emissions from Vehicles in Beijing



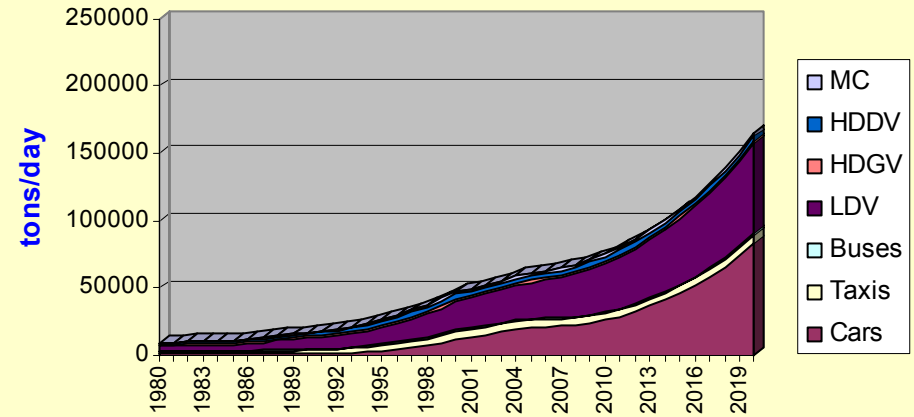
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CO2 Emissions from Vehicles in Beijing

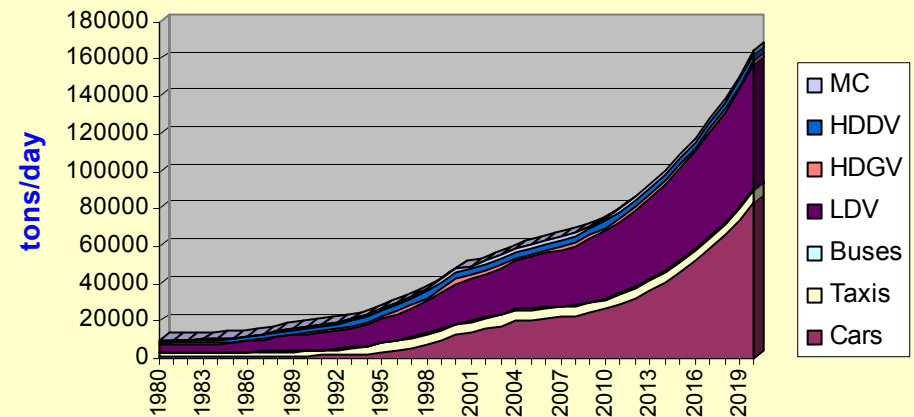


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CO2 Emissions from Vehicles in Beijing



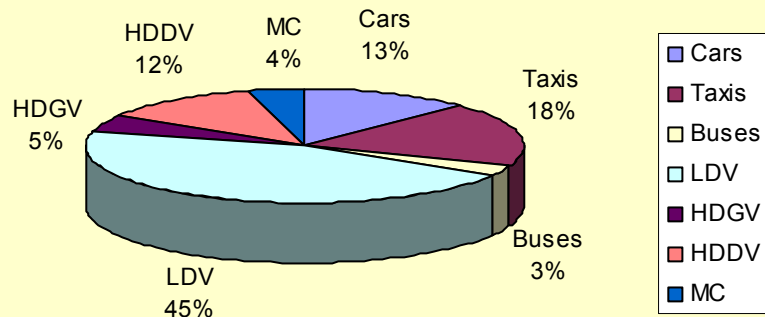
CO2 Emissions from Vehicles in Beijing



Percentage of Emissions by Vehicles in 1995

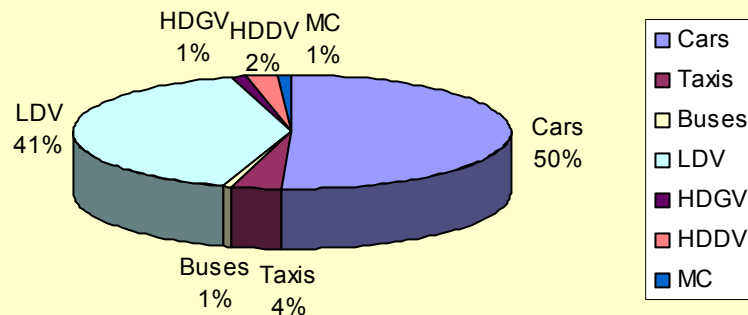
Percentage of Emissions by Vehicles in 2020

CO2 Emissions by Vehicle Type (tons/day)



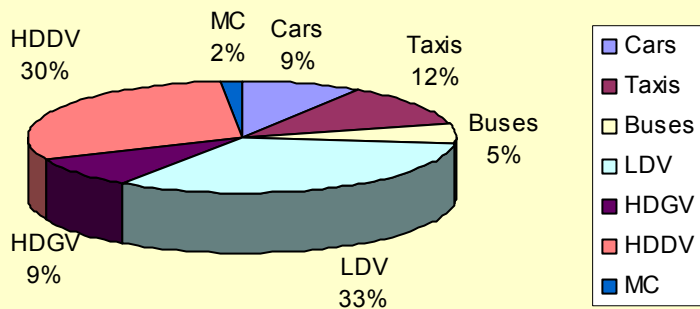
Total = 9,922,926 tons/yr

CO2 Emissions by Vehicle Type (tons/day)



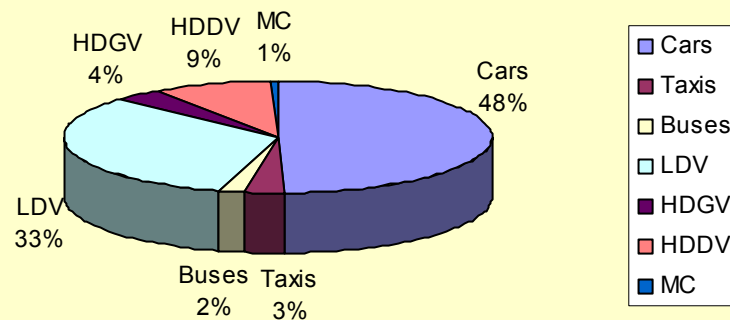
Total = 60,153,968 tons/yr

SO2 Emissions by Vehicle Type (tons/day)



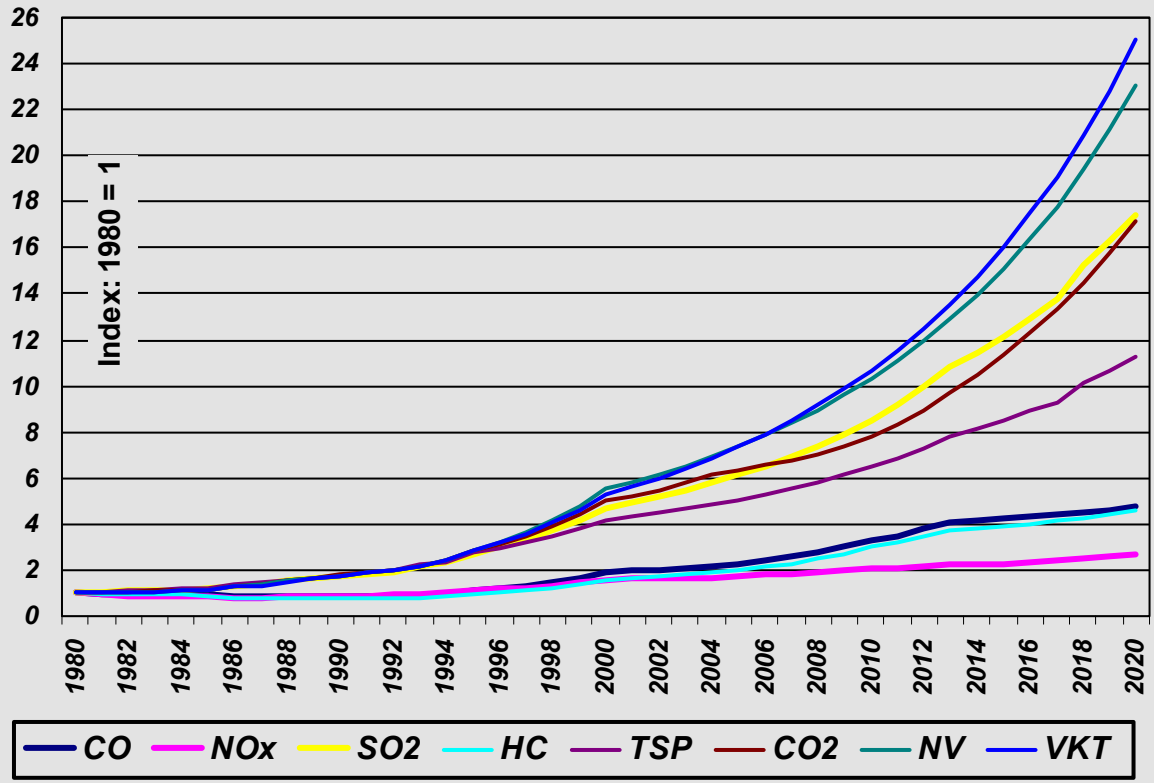
Total = 5,759 tons/yr

SO2 Emissions by Vehicle Type (tons/day)



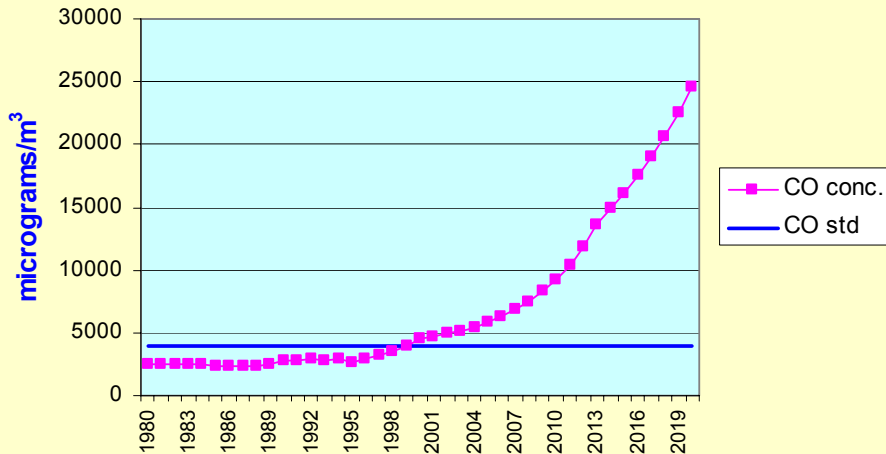
Total = 26,232 tons/yr

VKT, No. of Vehicles, and Emissions Trend



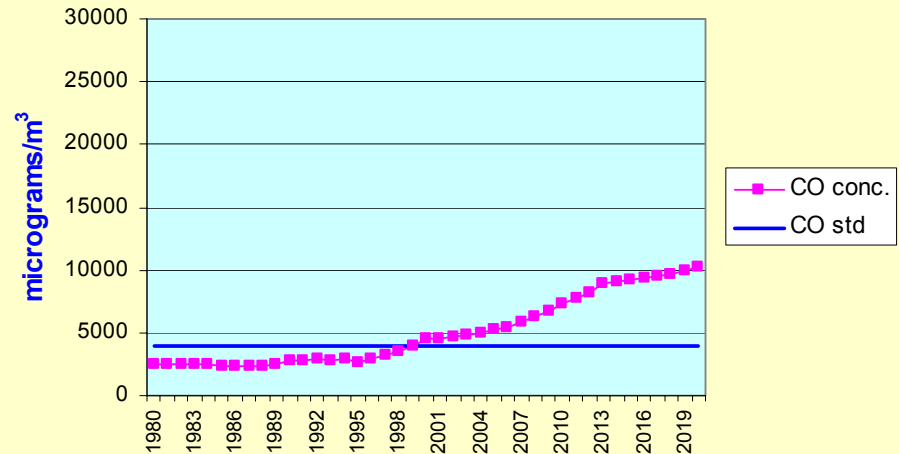
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CO Concentration in Beijing City

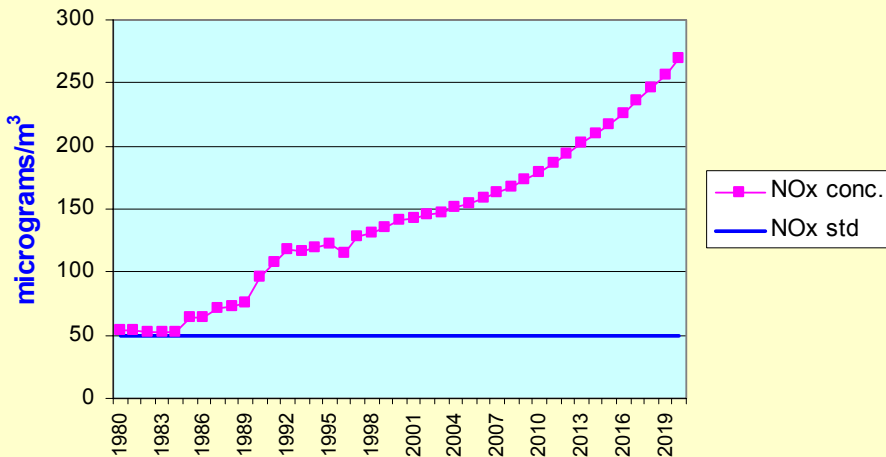


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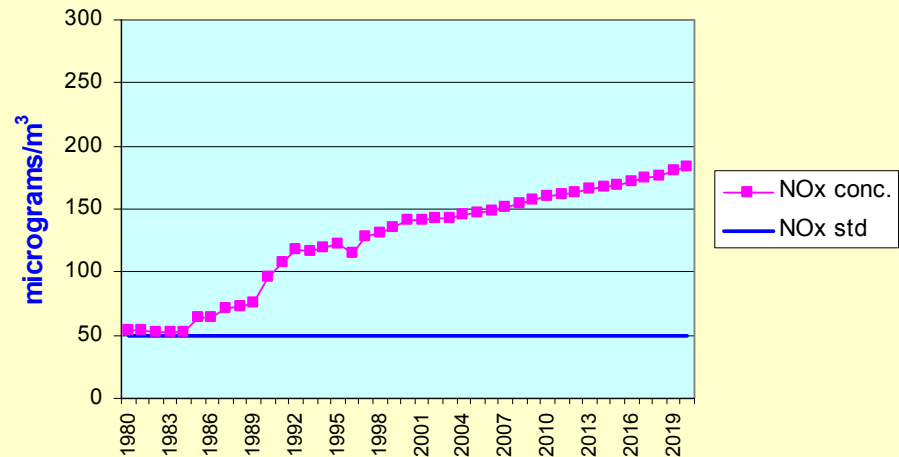
CO Concentration in Beijing City



NOx Concentration in Beijing City

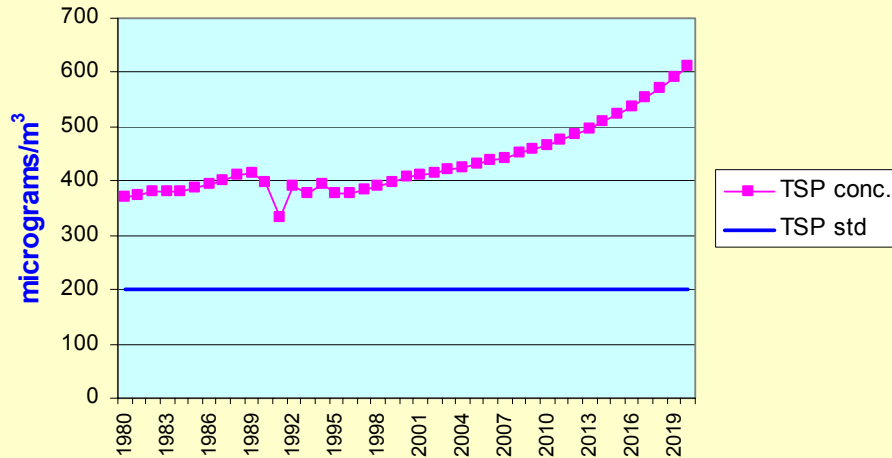


NOx Concentration in Beijing City



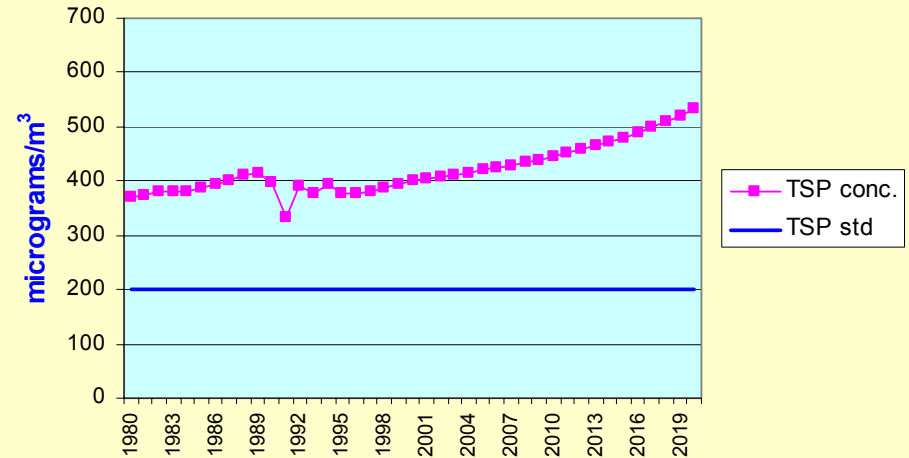
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TSP Concentration in Beijing City

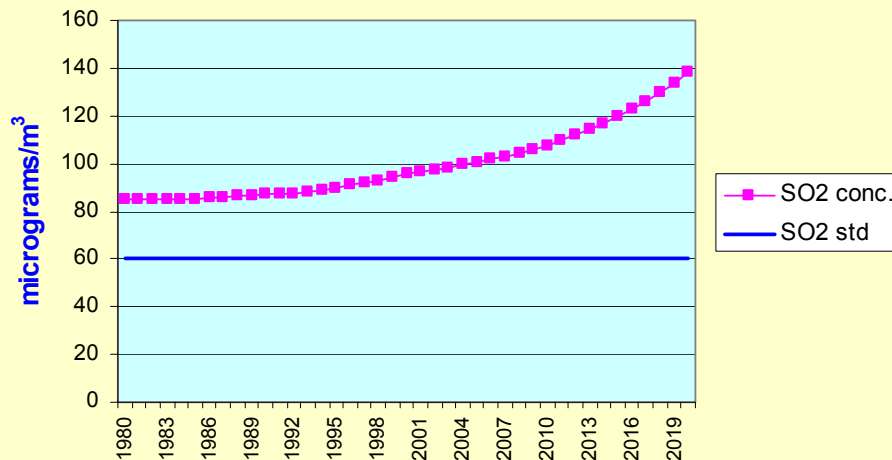


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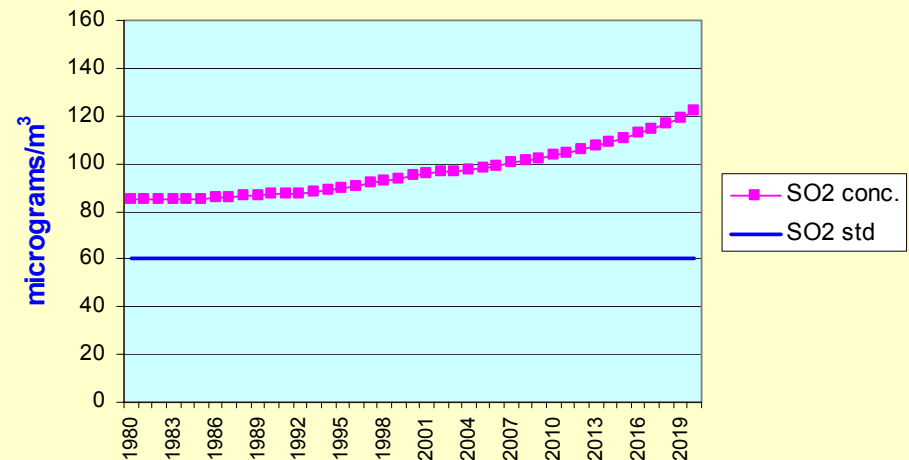
TSP Concentration in Beijing City



SO₂ Concentration in Beijing City



SO₂ Concentration in Beijing City



Health Impacts of Mobile Sources Emissions in Beijing

	DRC	Cases	Cost/Case	Total Cost	Cases	Cost/Case	Total Cost	Cases	Cost/Case	Total Cost
			US \$	US \$ million		US \$	US \$ million		US \$	US \$ million
				1995			2000			2020
PM10										
Premature mortality(/1million)	16.6	10152	36804.03	373.65	14714	49183.57	723.67	43940	130487.03	5733.55
RHA (/100,000)	1.2	7339	855.91	6.28	10636	1143.80	12.17	31764	3034.58	96.39
ERV (/100,000)	23.5	143723	21.40	3.08	208295	28.60	5.96	622037	75.86	47.19
RAD in adults (/adult)	0.0575	29363785	5.14	150.80	42556497	6.86	292.06	127087369	18.21	2313.94
LRI in children(/child)	0.00169	170541	85.59	14.60	247162	114.38	28.27	738106	303.46	223.98
Asthma attacks(/asthmatic)	0.0326	2392525	6.85	16.38	3467451	9.15	31.73	10354924	24.28	251.38
RS in adults(/adult)	0.183	93453437	0.86	79.99	135440676	1.14	154.92	404469365	3.03	1227.40
Chronic bronchitis(/100,000)	6.12	37429	8559.08	320.36	54245	11438.04	620.46	161994	30345.82	4915.85
Subtotal				965.12			1869.23			14809.68
SO₂										
Premature mortality(/1million)	2.4	253	36804.03	9.31	553	49183.57	27.22	2183	130487.03	284.89
RS in children(/1000children)	0.018	313	0.86	0.00	685	1.14	0.00	2702	3.03	0.01
Chest discomfort in adults(/adult)	0.01	879631	0.86	0.75	1925356	1.14	2.20	7595949	3.03	23.05
Subtotal				10.06			29.42			307.95
TOTAL				975.18			1898.65			15117.63

RHA: respiratory hospital visits, ERV: emergency room visits, RAD: restricted activity days, LRI: lower respiratory illnesses, RS: respiratory symptoms.

Value of Time and Fuel Costs of Commuting & Health Costs of Mobile Sources Emissions in Beijing

million \$	1995	2000	2020
Value of Time	182.33	743.63	19,514.94
Fuel Costs	641.00	1,569.22	19,509.85
Health Costs	975.18	1,898.65	15,117.62

Also should include accidents costs, and agricultural and materials damages from air pollution.

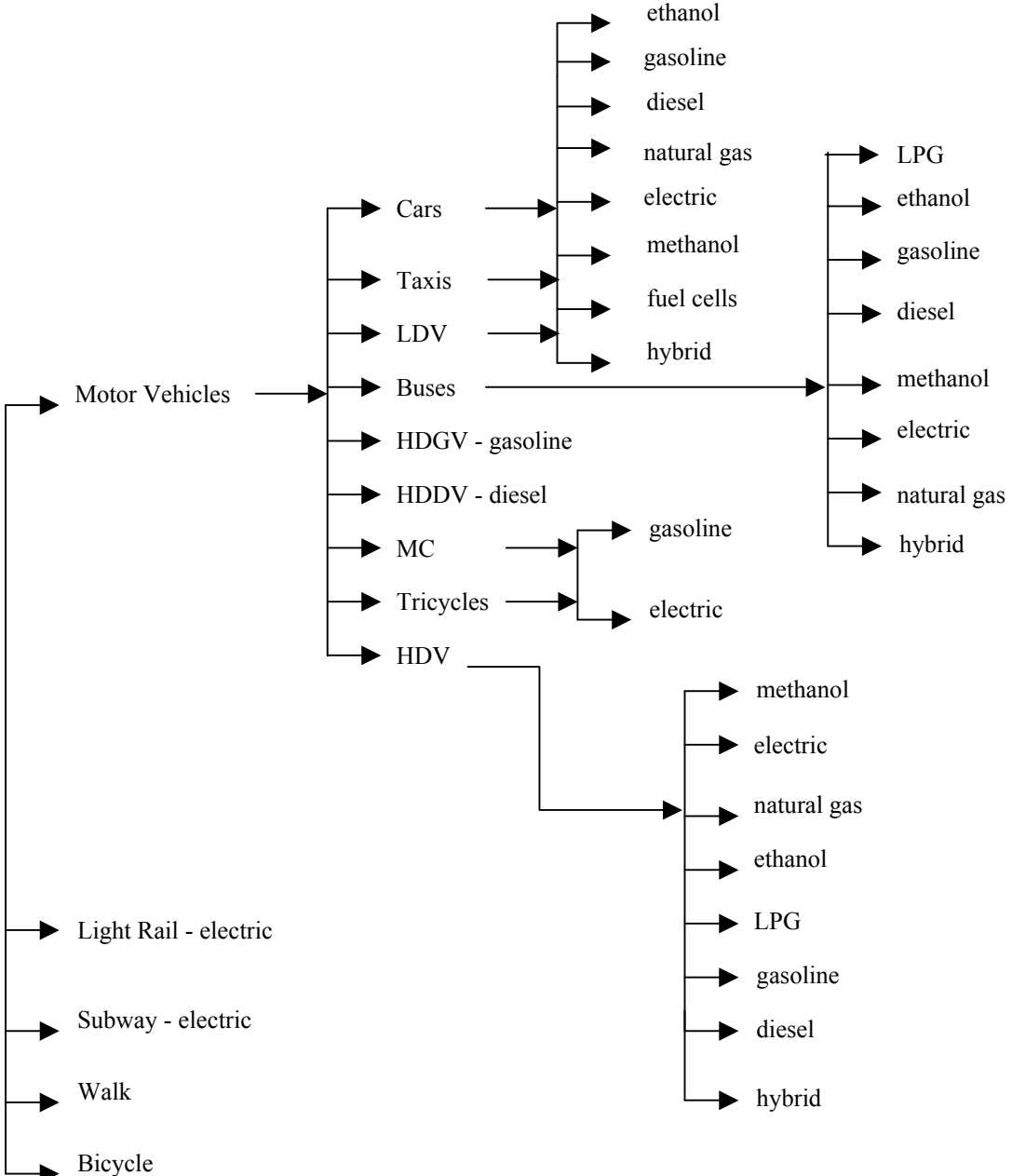
Costs under Different 2020 Scenarios for Beijing

	At 6 km/hr	At 16km/hr	With Tokyo's pass-trip mix
million \$	2020	2020	2020
Value of Time	19,514.94	9,348.51	8,631.77
Fuel Cost	19,509.85	15,281.42	17,879.25
Health Costs	15,117.62	11,794.00	8,635.45
Total	54,142.41	36,423.93	35,146.47

MATHEMATICAL MODEL

- Include all modes of transportation
- Include different types of fuels and technologies for each mode
- Include investment opportunities in infrastructure for all transportation modes
- Include different control options

TRANSPORTATION MODES FOR BEIJING

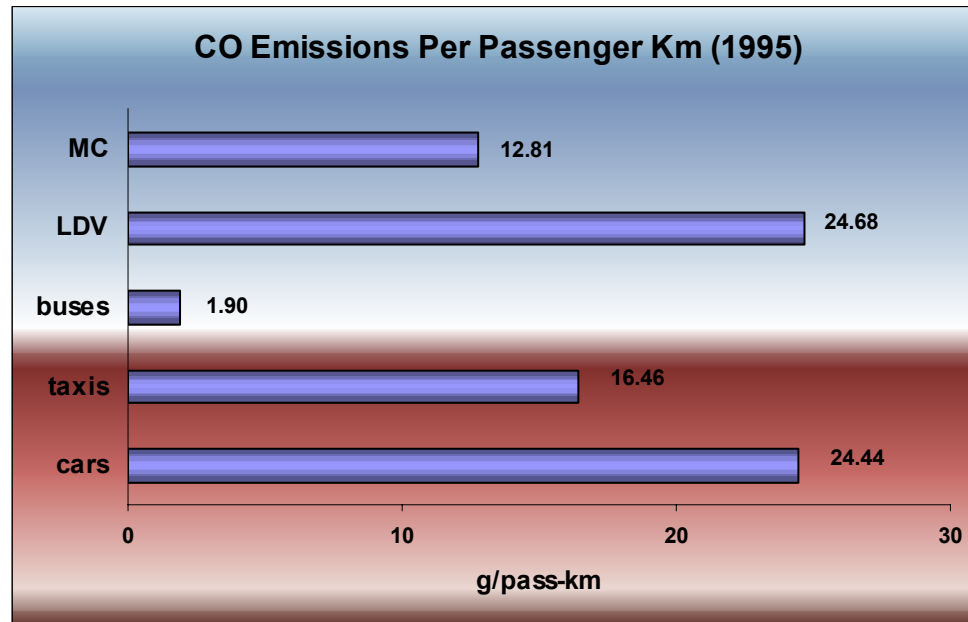


Energy Use per Km and per Passenger-Km for Different Transportation Modes in Beijing (1995)



Emissions/Passenger-km for Different Modes of Transportation in Beijing

		emissions/pass-km (g/pass-km)					
	year	CO	NOx	SO ₂	HC	TSP	CO ₂
cars	1995	24.44	0.7134	0.0509	2.528	0.0034	120.6
taxis	1995	16.46	0.5029	0.0349	1.664	0.0023	88.4
buses	1995	1.90	0.4692	0.0154	0.193	0.0037	13.9
LDV	1995	24.68	1.5786	0.0607	4.560	0.0041	145.4
MC	1995	12.81	0.0745	0.0299	4.434	0.0020	122.3
All	1995	15.04	1.3582	0.0629	2.405	0.0104	99.0

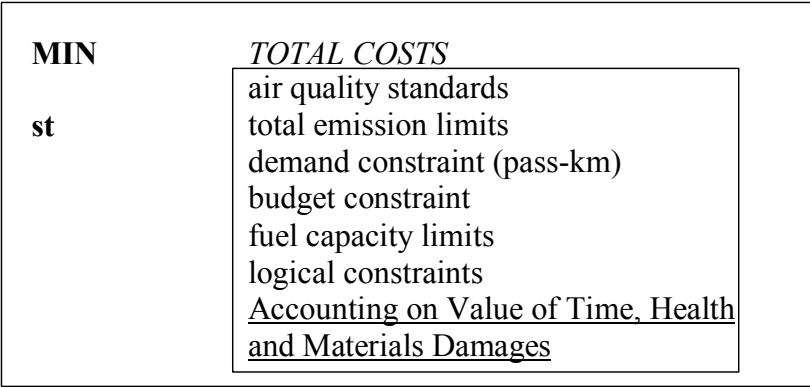
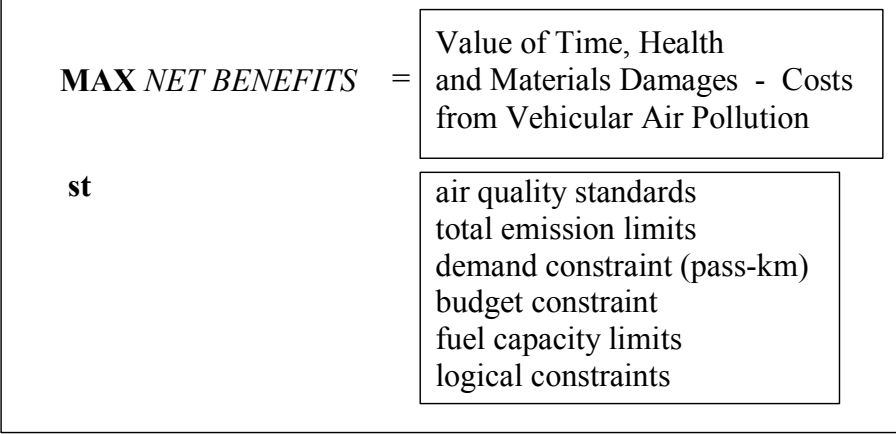


Pollution Control Options for The Transportation Sector

- Technology options (such as new vehicle emission standards, fuel reformulation, alternative fuels) alone are not enough - standards will still be exceeded
- Infrastructure investments (build roads and develop infrastructure to sustain the growth in transportation) - road area in Beijing is 6.1% whereas in other developed cities goes up to 30%
- Traffic management options to reduce congestion and increase speeds (a set of transportation system improvements such as arranging the traffic flow direction, and installation and better coordination of traffic signals)
- Employer based controls such as giving transit passes, arranging telecommuting programs, providing ride-matching information and services, and modified work schedules
- Enhanced I/M and accelerated vehicle retirement programs
- Improve public transit as a good alternative for the commuters and also by options such as parking management and road fees discourage extensive use of cars
- Environmental education and awareness programs
- Land use management

Control Options To Be Considered in The Model

- Incentive related and educational policy options:
 - education and driver behavior
 - ride sharing
 - telecommuting
- TDM measures
 - I/M programs
 - traffic management
 - parking management
 - provide HOV and bus lanes
- Technical policy options
 - engine designs
 - improve fuel quality
 - catalytic converters
 - fuel switching
 - decrease scrappage rate
 - infrastructure investments
 - increase transit services
- Pricing Measures:
 - tax measures
 - subsidize transit services
 - subsidize clean fuels



Look at results of \$, Health, Time, and Other Damages.

Change Constraints

Agree on Policy

Total Costs = Costs of Implementing a Package of Policy Options

= Fuel Costs + Cost of Vehicle + Infrastructure Investments

+ Other Operations and Maintenance Costs + cost from switching fuel & cost of control options utilized – cost of fuel savings

= Σ present value of all annualized costs

- repairs, maintenance, tires, oil,...
- parking costs
- ownership costs (insurance, license, registration, taxes, depreciation, finance charge)

- Technology options
- Fuel options
- Management options
- Legislative options
- Incentive related and educational options
- Pricing measures

- Construction costs
- Land costs

For example: lifetime for highways may be assumed to be 35 years and for railroads 50 years.

For example for rail:

- Capital expenditure for electrification
- Signals and train control facilities
- Per mile road bed trackage costs
- Terminal costs
- Operations and maintenance costs

CONSTRAINTS

- Sum of demand (pass-km) by each mode (t) \leq Turnover projections (t)
- Annualized Infrastructure Investment Costs + Public Transport Vehicle Costs and their O&M costs + Costs of Control Options + Subsidies – Taxes \leq Budget for each year allocated to the transportation sector
- Total Emissions (taking into consideration the reductions resulting from the use of different policy options) \leq Air Quality Limits
- Concentration of Each Pollutant (as a function of emissions) \leq Air Quality Standards
- Logical Constraints (example: sum of fraction of vehicle v using option oo equals 1)
- Age distribution, emission factors calculation, fuel efficiencies, calculation of electricity use by electric vehicle v, speeds, fuel consumption, # of vehicles in each year, infrastructure construction, and utilization of control options
- Bounds on vehicle numbers for different types & fuel switching option for vehicles
- Calculation of fractional reduction of commute time from investments into infrastructure (keeping in mind the increase in the total # of vehicles)
- Fuel Capacity Limits (example: Total use of NG in transportation sector in year i \leq Total available NG supply for the transportation sector for that year)
- Social Cost Equation (\$) = Value of Time + Health Impacts of Air Pollution + Materials Damages from Air Pollution

Pollution

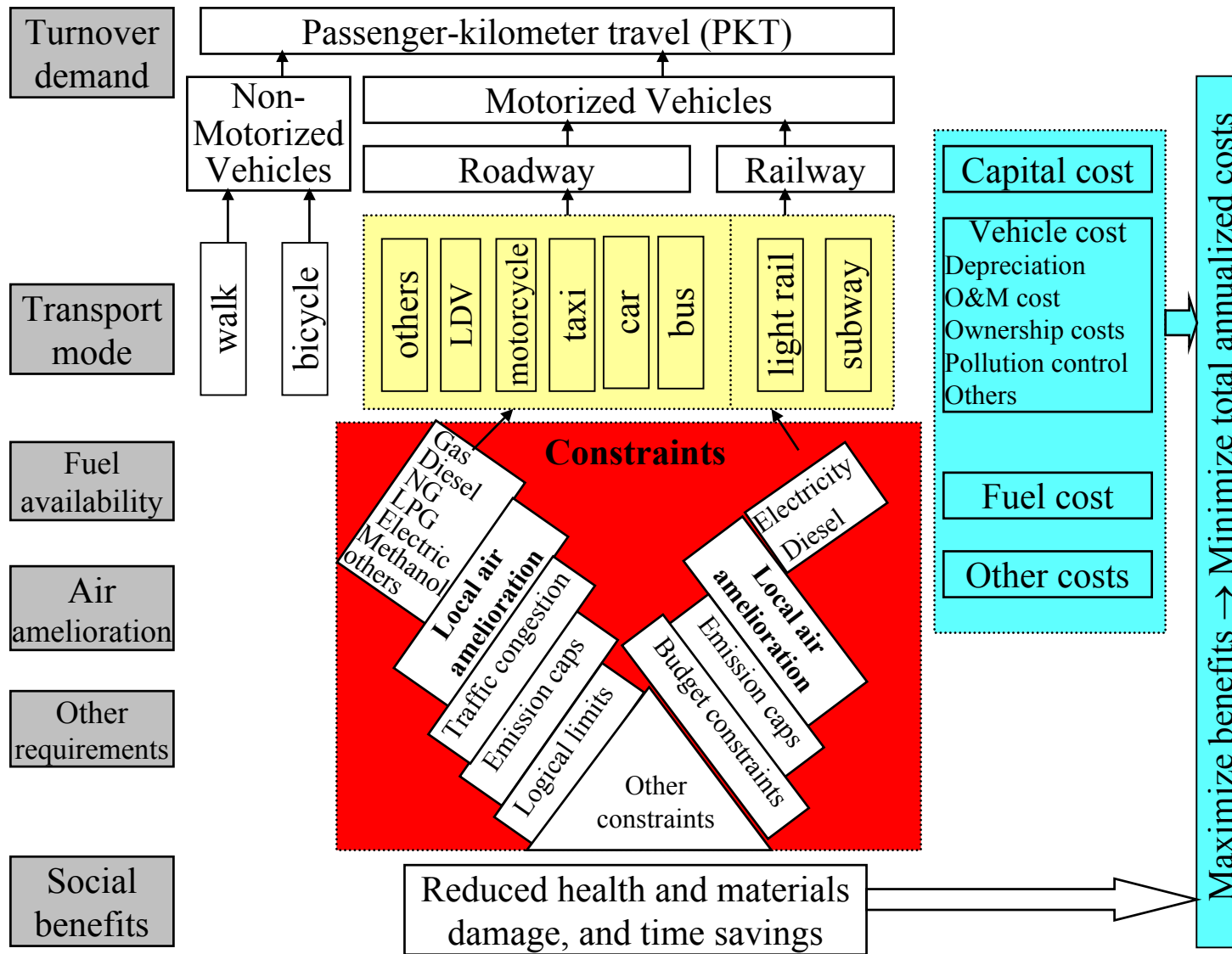
In traffic time each hour may be assumed to be worth 50% of your wage

Increase in concentration of pollutants due to mobile sources emissions result in health and materials damages.



Types of Results from The Model

- * *Optimization of urban transportation systems for minimum overall cost and least environmental damage meeting all economic, technical, and policy constraints will yield the following information:*
 - Obtain trade-off curves for cost, emissions, and pass-km demand
 - Average vehicle emission factors, fuel efficiencies, vehicle population (type, age, fuel), land use patterns, fuel consumption
 - Breakdown of turnover (% of pass-km demand and VKT being satisfied by each mode)
 - Cost breakdown (%) of the optimal system over the model time horizon: vehicle costs, O&M costs, fuel costs, infrastructure investments, fuel switching costs, costs of control options utilized
 - Investment into different control options each year
 - % of fuel switching of vehicle v from fuel type f to f_1 and extent of control options utilized each year and over the total model time horizon
 - Total emissions of pollutant p from mobile sources exhaust emissions from each vehicle type v
 - Resulting concentrations from these emissions and health impacts
 - Social costs: health and materials damages from air pollution caused by vehicle emissions and value of time spent in traffic
 - Energy consumption by each mode
 - Shadow prices of constraints
 - Vehicle growth rates, mode choice, road area, number of vehicles per km of road, average road speeds



The transportation system should emphasize the movement of people, not vehicles.

ADVANTAGES

- Simulation vs Optimization
- Extensive list of control options
- Passenger-km demand as the driving force
- Time frame (annual) evaluation - not one step future
- Valuation of future costs and accounting on social costs
- User friendly design at the fingertips of the decision maker
- Visual representation of final optimal set of options (GIS)