

Energy and Environmental Issues for Transportation Sector of North Asia Mega-cities

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1. Introduction

Motor vehicles have played a dominant role in deteriorating urban air quality in the world and a great deal has been learned about their implications for the local, regional and global environment. Vehicles are major sources of hydrocarbon (HC), nitrogen oxides (NO_x), and sulfur dioxide (SO₂), the precursors to both tropospheric ozone and acid rain; carbon monoxide (CO); and toxic air pollutants such as diesel particulate. Vehicles also consume large amount of fossil fuels such as gasoline and diesel, which cause carbon dioxide (CO₂) emitted and become a concern of global warming. Over the past decades, as the vehicle population of Beijing exploding, transport sector has become a large source of CO, NO_x and HC. In densely populated urban areas, vehicles can be a major source of particulates as well. In 1995, vehicles account for about 41% of NO_x emission and 82.5% of CO emission in Beijing (DESE, 1997).

In this paper, a Spreadsheet Model is developed to simulate the future impact of transport sectors on local, regional and global atmospheric environment in Beijing. The spreadsheet model can also be applied to any city in the world provided with the necessary input data. Based on different sets of scenarios, the models provide a year-by-year estimate of fuel consumption and emissions. The object of the model is to develop an effective mathematical tool for projecting the potential environmental impact of transport sector, evaluating the strategies and policies implemented now or in the future, and providing useful information for guiding the development of Beijing's transportation sector. This paper describes the application of this model in Beijing and analysis the outcome of the model.

2. Model Methodology

The model is a multiple-page Excel spreadsheet with table-formatted inputs, calculations, and a graphical display for presenting results. The user can choose parameters that represent the current motorization level, fuel consumption level and emission level. The user can also design different scenarios that represent the future control level of vehicle fuel consumption and emission according to the policy-oriented goals.

The model represented the vehicle fleet in Beijing by 8 different vehicle types:

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1. Light duty gasoline vehicle (LDGV): gasoline cars carrying 12 or less people.
2. Light duty diesel vehicle (LDDV): diesel cars carrying 12 or less people.
3. Light duty gasoline trucks 1 (LDGT1): gasoline trucks whose gross vehicle weight (GVW) is less than 6000pounds, whose gross loading weight is less than 6000pounds, whose basic front windward area is less than 45feet², and satisfying at least one of the followings: (a) carrying more than 12 people; (b) being freight wagons or their derivatives; (c) possessing characteristics of non-street or non-road on design.
4. Light duty gasoline trucks 2 (LDGT2): gasoline trucks whose GVW is between 6001pounds and 8500pounds, and the other characteristics are same with those of LDGT2.
5. Light duty diesel trucks (LDDT): diesel trucks, whose GVW is less than 8500pounds.
6. Heavy duty gasoline vehicles (HDGV): gasoline vehicles whose GVW is more than 8500pounds, or whose gross loading weight is more than 6000pounds, or whose basic front windward area is more than 45feet².
7. Heavy duty diesel vehicles (HDDV): diesel vehicles whose GVW is more than 8500pounds, or whose gross loading weight is more than 6000pounds, or whose basic front windward area is more than 45feet².
8. MC: Motorcycle

The spreadsheet model requires the data of vehicle population, fuel efficiency and emission factors of new vehicles, and vehicle kilometers traveled per year for each vehicle type from 1980 to 2020. The model also need some related parameters about fuel specification during that period. The model chooses 6 pollutants, CO, NO_x, HC, SO₂, PM₁₀, CO₂, the latter one reflects the influence on global climate. The model’s methodology is described in Figure 1. To obtain the successional output which is helpful for analysis, the model also computes the fuel consumption and emission amount in the near past years, from 1995 to 2000. With the data inputted, the model will provide the projected fuel consumed, and total emissions amount for the 6 pollutants in whichever year during 1995 and 2020.

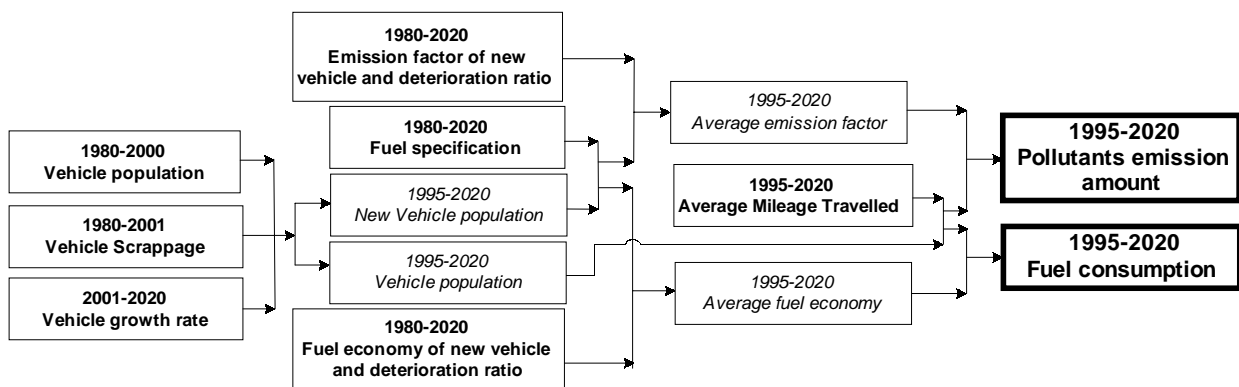


Figure 1. Methodology of the spreadsheet model.

For China hasn't implemented any obligatory standard regarding fuel economy yet, labeled fuel consumption level of new vehicles are used to determine the fuel economy of new vehicles. However, there is much difference between labeled fuel economy and actual level, even for the new vehicles. A concept of *Fuel Economy Deterioration* is introduced in this model to compute average fuel economy of the vehicle fleet. This concept is defined as the ratio of the fuel economy of in-use vehicles to the level when they are new ones. Base on the age distribution of a vehicle fleet in

some year, the fuel economy of new vehicles in each year and the fuel economy deterioration level, the average fuel economy of this vehicle fleet can be computed as following expression:

$$AFE_n = \frac{\sum_{i=1}^{15} (VP_n^i \times NFE_{n-i+1} \times DFE_{n-i+1}^i)}{VP_n} \quad (A)$$

Where, n -year; i -vehicle age; AFE_n -average fuel economy in year n ; VP_n -vehicle population in year n ; VP_n^i -number of vehicles with age of i in year n ; NFE_n -fuel economy of new vehicles in year n ; DFE_n^i -fuel economy deterioration level of vehicles which are initially used in year n and have age of i .

There are a lot of factors that influence the emissions factors like the amount and quality of road infrastructure, age of vehicles, and speeds. But for the sake of keeping things simple enough for the production of a time constrained and manageable set of results, only the effects of age of vehicles on emissions factors are taken into account. Knowing the amount of new vehicles coming in to the fleet and the number that is being scrapped, their new vehicle emission standards and deterioration level for all the types of vehicles, the average vehicle emissions factors can be calculated for each year by a quick rollback method. The method is:

$$AEF_n = \frac{NVP_n \times NEF_n + [VP_{n-1} - NVP_{n-15}] \times AFE_{n-1} + \sum_{i=1}^{15} (VP_n^i \times DEF_{n-i+1}^i)}{VP_n} \quad (B)$$

Where, AEF_n -average emission factor in year n ; NEF_n : emission factor of new vehicles in year n ; DEF_n^i - emission deterioration level of vehicles which initially used in year n .

This formula is used to computed emission factors of NO_x , CO, HC, and PM_{10} . The emission factors of SO_2 and CO_2 is computed based on the fuel economy and fuel specification. The methods are:

$$SO_2 = S \times f \times \frac{64}{32} \quad (C)$$

$$CO_2 = \left[(f - EF_{HC}) \times C - EF_{CO} \times \frac{12}{28} \right] \div \frac{12}{44} \quad (D)$$

where: SO_2 -emission factor of SO_2 , g/km; S -sulfur content of the vehicular fuel; f -fuel efficiency, g/km; 64, 32-molecular weight of $[SO_2]$ and $[S]$ respectively. CO_2 -emission factor of CO_2 , g/km; C -carbon content of the vehicular fuel; EF_{HC} , EF_{CO} -emission factor of HC and CO respectively, g/km; 12, 28, 44-molecular weight of $[C]$, $[CO]$ and $[CO_2]$ respectively.

3. Data

Figure 2 shows the vehicle fleet composition change from 1980 to 2000, which is past data (BSB, 1990-2000; Wang, 2000), and projections for 2001 to 2020 of the spreadsheet model. The retirement age for vehicles is assumed to be 15 years in the spreadsheet model. In 2000 there were slightly more than 1,500,000 vehicles in Beijing and HDGVs made 30% of this. The model's

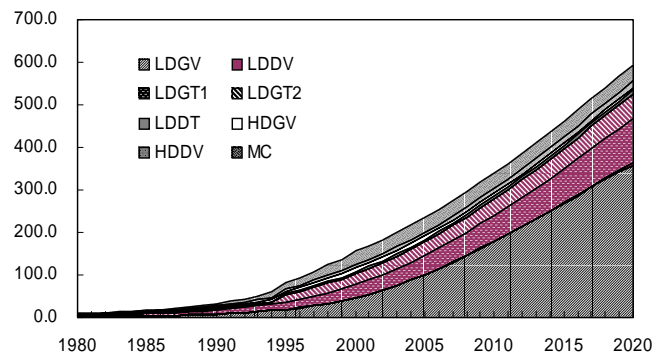


Figure 2. Vehicle population by type

projections show a great increase in the number of HDGVs, from around 46,000 in 2000 to more than 3.5 million in year 2020, reaching almost a 60% of the total vehicle numbers in Beijing. There has been a large number of motorcycles in the past but the future motorcycle population's share is decreasing due to the policies the government is implementing against these vehicles.

The 29th Olympic Games will be held in Beijing in 2008 and the municipal government will implement a series of measures to improve the air quality. Therefore, we design a fairly stringent, even somewhat optimistical scenario in this model. Figures 3-4 demonstrate how the fuel economy and emissions factors of new vehicle change over time for different types of motor vehicles (only the emission factors of HDGV is shown in Figure 4). The methodology determines the fuel economy of new vehicles according to the labeled fuel consumption of the vehicles and determines the emission factors of new vehicles according to the national or municipal emission standards. The projections regarding the fuel economy and emission factors of the future new vehicles are:

1. The fuel economy of some lighter vehicles (including LDGV, LDDV, LDGT1 and LDDT) in 2020 can reach the current level of Japan or Europe, which will be achieved by vehicle fuel economy standards implemented by the Chinese government. The years when the standards are going to implemented are 2003, 2008, 2013 and 2018.
2. The fuel economy of other heavier vehicles (including LDGT2, HDGV and HDDV) will improve 1.0% annually. The fuel economy of MCs will improve 0.8% annually.
3. Four sets of new emission standards, which are respectively equivalent to EURO 2, EURO 3, EURO 4 and EURO 5, will be implemented in 2003, 2007, 2010 and 2015.

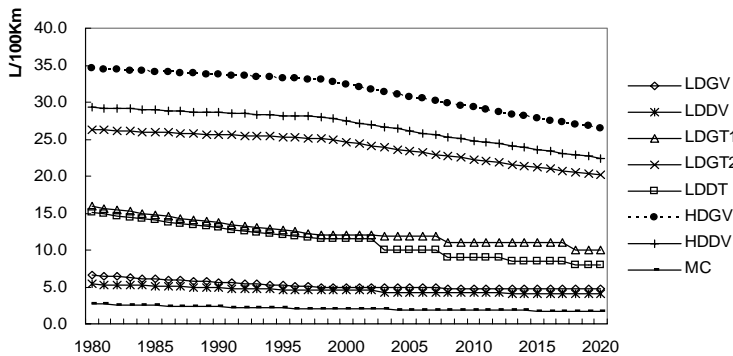


Figure 3. Fuel economy of new vehicles.

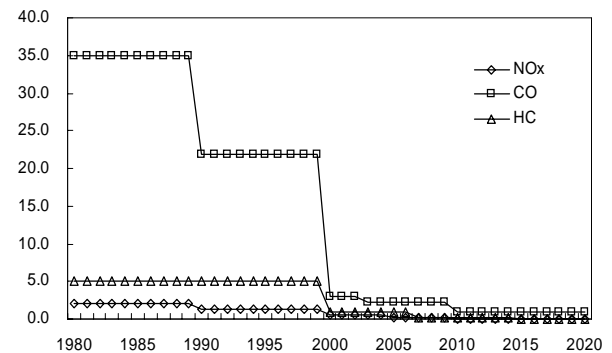


Figure 4. Emission factors of new HDGVs.

Using formula (B), average emission factors of certain year should be known. This model use 1998 as the base year to get the final emissions factors trend and past emission factors. Table 1 shows the average emission factors in 1998 (DESE, 2001).

Table 1. Average emission factors in Beijing in 1998.

	NO _x	CO	HC	PM ₁₀
LDGV	1.900	46.700	5.420	0.023
LDDV	2.455	2.506	1.089	0.251
LDGT1	2.380	41.930	6.380	0.025
LDGT2	4.160	64.180	9.480	0.139
LDDT	2.639	2.534	1.170	0.269
HDGV	5.580	148.460	11.000	0.152
HDDV	20.440	10.630	3.410	0.785

MC	0.080	16.060	5.900	0.027
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Figure 5 provides the current fuel economy deterioration level of some vehicle types during vehicles' life-cycle (DRC, 2001). In the future, with the improvement of traffic conditions and I/M programs, the deterioration level will decline. We assume that this decline is 0.5% per year during 2000 and 2010 and 0.4% per year during 2010 and 2020. Figure 6 provide the current emission deterioration level of HDGVs (DESE, 2001). We assume that the deterioration level will not vary a lot and will stabilize at the current level.

According to (C), SO₂ emission is closely associated with S content of the fuel, so lowering S content is an effective way to reduce SO₂ emission from vehicles. Besides, low S content is a necessity of implementation of more stringent emission standards. In the future, the sulfur content of vehicular fuel in Beijing will decrease greatly. The Yanshan Petrochemical Group, the largest petrochemical enterprise in China, will provide clean vehicular fuel with very low S content for Beijing. The S content will be 200ppm in gasoline and 300ppm in diesel in 2003, will be 100ppm and 80ppm in 2006, and will be 30ppm and 30ppm in 2011.

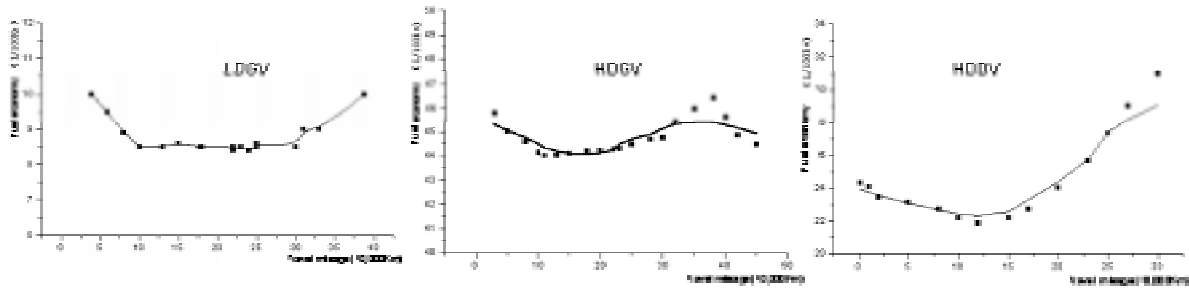


Figure 5. Deterioration level of fuel economy of some vehicle types.

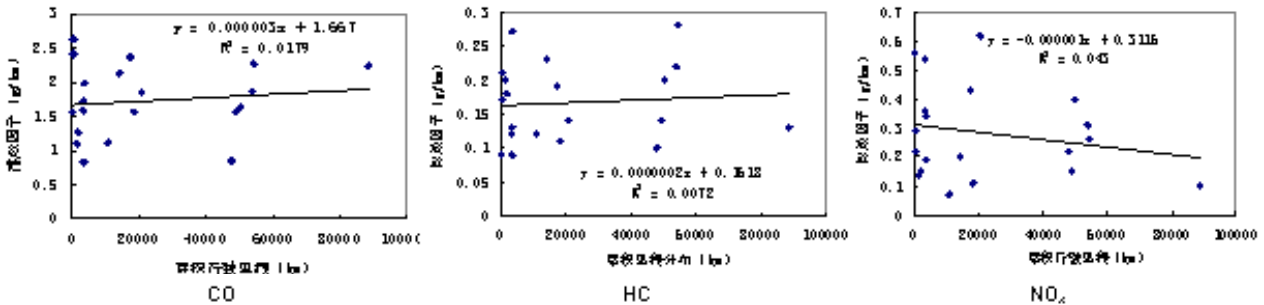


Figure 6. Deterioration level of emission of HDGVs.

4. Results and analysis

4.1. Fuel consumption

Figure 7 illustrates how average fuel efficiencies vary during 1995 and 2020 for different types of vehicles in Beijing. According to Figure 7, for heavier vehicles (HDGV, HDDV and LDGT2), improvements in technology of new vehicles are not sufficient to overcome the adverse effect of old vehicles with high oil consumption degree before 2010, which is due to the future number of the heavier vehicle increase

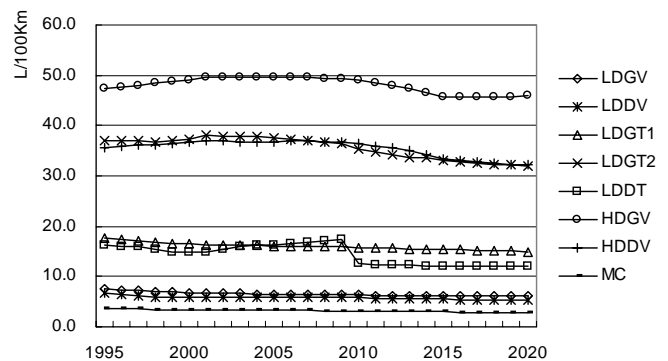


Figure 7. Average fuel economy by vehicle types.

slowly, even decrease for some type such as HDGV. After 2010, with the retirement of old vehicles, the average fuel economy will begin to improve. Whereas, for LDGT, LDDT, LDGT1, LDDT and MC, because large number of new vehicles will add into the fleet in the future year, the technology improvements are able to overcome the adverse effects from old vehicles. Using average fuel economy, number of vehicles, and vehicle kilometers traveled, the amount of fuel consumption can be calculated. The amount of fuel consumption (figure 8) has increased by 3.6 times from 1995 to 2020 (from 3,460 million tons/year to 12,470 million tons/year). China became a net oil importer in 1993 and it will have a very hard time keeping up with the demand for oil consumption to feed its growing transportation sector. Figure 9 gives the information of fuel consumption by type in 2020. The largest consumer is LDGT2 for its higher fuel consumption level and longer travel mileage and during the objected years its percentage doesn't vary a lot. Because the number of LDGT2 only occupies about 10% of the total, this result maybe give the hint that LDGT2 is a key object for oil saving in transport sector. The percentage of fuel consumption for LDGVs increased from 9% in 1995 to 20% in 2020 even with a large decrease in both of travel mileage and fuel economy, which is due to a much more rapid increase in number of this fleet. In the far future, this percentage will continue to increase, so LDGV is also a key control object.

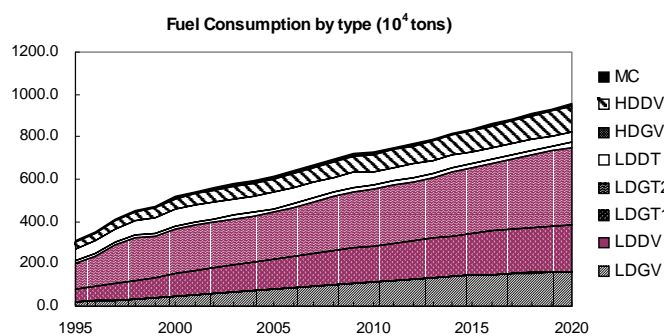


Figure 8. Fuel consumption (10^4 tons).

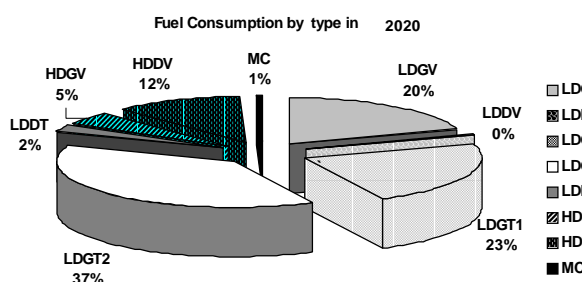


Figure 9. Fuel consumption by type in 2020.

Additionally, SO_2 and CO_2 emissions factors are calculated based on fuel efficiencies and fuel characteristics of diesel and gasoline. Therefore, the effects of reduced emission from the improved fuel efficiencies should be observed in the future, which will be discussed in the following section.

4.2. Vehicular emissions

Figure 10 and 11 respectively give the average emission factors and emission amount of each vehicle types. The average emission factors basically decline over time. However, as the average fuel economy, the CO and HC emission factors of heavier vehicles decrease very slowly because of the adverse effects from old vehicles before 2010. This phenomenon doesn't occur on NO_x emission factor for their deterioration ratios approximately equal to zero. From Figure 11, we can clearly observe that the pollutant emission amount of LDGVs increase rapidly and LDGVs become to be the largest contribution of CO emission and HC emission in all the fleets since 2010. With these model predictions, LDGVs will produce 39% of CO emission and 40% of HC emission in 2020.

Emissions of NO_x , CO, and HC have increased by 15%, 26%, and 49% respectively from 1995 to 2020 based on the model projections (see figures 12). At the same time total vehicle kilometers traveled is expected to increase by about 8 times. This shows that the increase in emissions relative to the increase in travel mileage from 1995 to 2020 is lower because of the strict standards implemented and the advanced technologies applied. However, the situation projects itself to an unfavorable environment in the future that even with such stringent control standards, the amounts of emissions from the transportation sector is still higher than that of 1995. For these three pollutants, the largest emission

amount occurs during 2000 and 2010, which is probably due to that the old vehicles with bad emission condition still occupy a certain percentage in the fleets. The above conclusions indicate that only controlling new vehicles is not enough, therefore, if Beijing wants to actually reduce the pollutants emission amount from vehicles, it must make great efforts on in-use vehicles, especially the vehicles initially used before 1999 in which year the EURO 1 standards were implemented. PM_{10} emission seems to gradually increase during 1995 and 2020, which become a concern of air quality. According to the model projections, HDDVs occupy 54% of the total emission amount, LDGVs occupy 9%, and LDGT2s occupy 18%, indicating that the key for transport PM_{10} emission is on the heavier vehicles. On the other hand, because the emission data for PM_{10} are not easy to find or project, so this part of research need further scrutinies. For CO_2 emission is most relative to the fuel consumption and basically independent to other factors, so the variation trend of CO_2 emission is similar with that of fuel consumption. For the low S content in the fuel in the future, SO_2 emissions are greatly reduced with a decrease rate as much as 88% during the period.

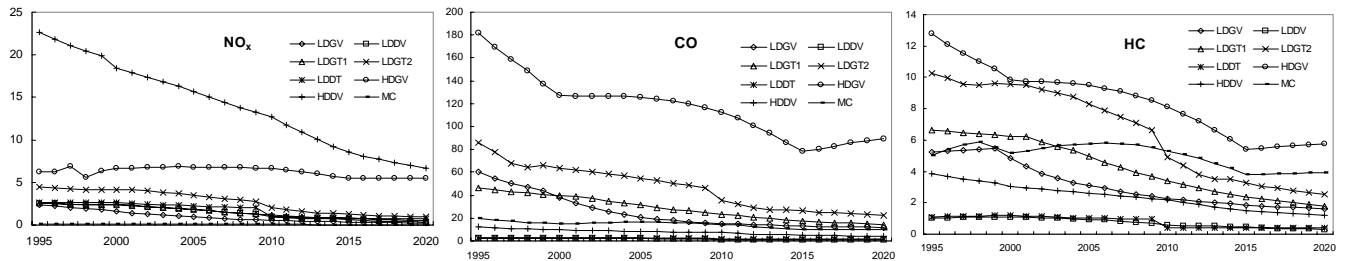


Figure 10. Average emission factors (g/km).

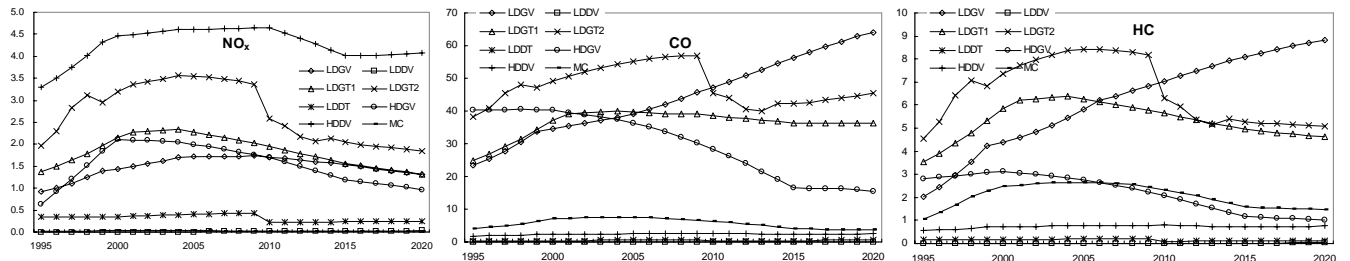


Figure 11. Pollutant emission amount by vehicle types (10^4 tons).

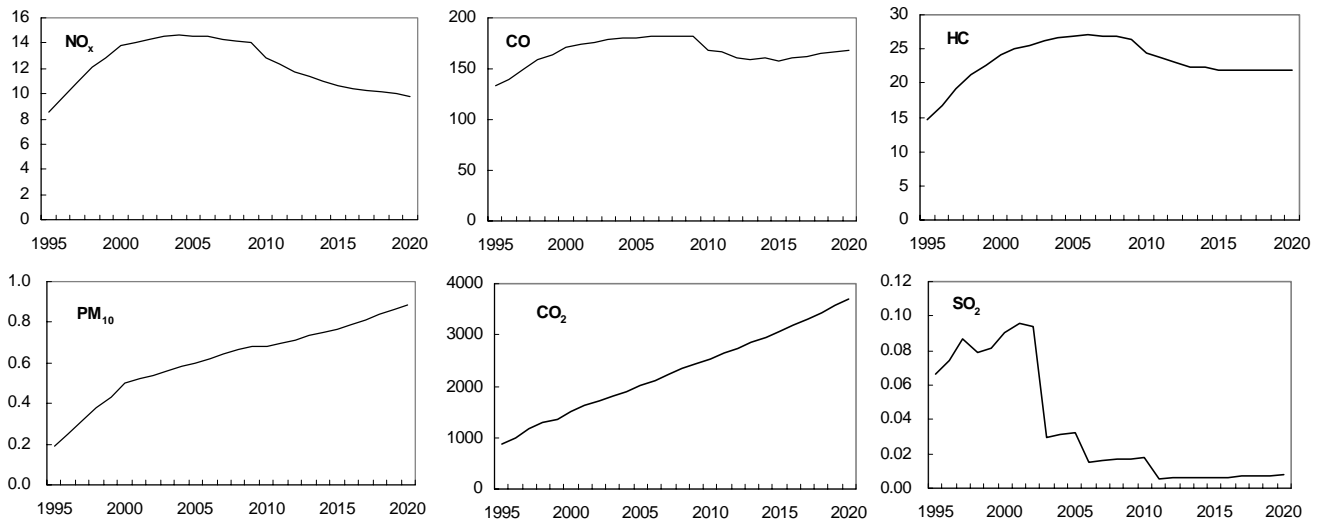


Figure 12. Total pollutant emission amount (10^4 tons).

5. Discussions

The vehicle population is rapidly increasing in Beijing, especially for LGDVs. According to the model's results, the contribution of LGDVs on the total fuel consumption and pollutant emission become larger and larger and LGDV is potentially the largest contributor of all the fleets for deteriorating the urban air quality. In the future, the travel mileage of LGDVs should be further reduced. Therefore, the aim of transportation planning should be directed at efficient passenger transport rather than private vehicle transport because that efficient passenger transport system will attract more passenger volume and this is the only way the city will be able to meet the growing transportation demand in a sustainable manner. For this purpose, energy use per passenger-km and emissions per passenger-km will be good parameters to consider in order to frame the action plan that will enable the city's future transportation system meet the demand. Mass rapid transit systems such as buses, subway and light rail systems are the most efficient modes of transport to meet low levels of these parameters.

Stringent standards and advantaged technology on new vehicles are useful for decreasing the vehicle emission, but they alone are not enough for control the increase trend of transport pollution. Great effort should be made on in-use vehicles, such as enhancing I/M programs and accelerating vehicle retirement programs.

From the results of the model, the situation in Beijing demonstrates the need for a broad, systematic but practical assessment of transport sector in Beijing. We plan, therefore, to develop this model that can project the potential environmental impact of the transport sector, evaluating the strategies and policies implemented at present and in the future, and providing useful information for guiding the development of Beijing's transportation sector.

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