Environmental, energy and cost assessment of future technology paths for light-duty passenger vehicles (LDPVs) in Beijing, China

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Introduction

Beijing, the capital of China, has experienced rapid motorization since 1990 and its total vehicle population has surpassed 5 million. Increasingly stringent vehicle emission standards as well as national fuel consumption standards has been implemented in Beijing. Emission controls and operating and use restrictions have been adopted to reduce vehicle pollution, including, in 2003, a restriction prohibiting the registration of diesel cars.

However, in order to mitigate fuel consumption and emissions, additional control technologies beyond the traditional multipoint fuel injection (MPFI) gasoline engine need to be considered such as the gasoline direct injection (GDI) with turbocharging, advanced diesel engines and hybrid technology for the future light-duty passenger vehicles (LDPVs).

It is important to assess the impact of future technology paths for LDPVs in consideration of environment, energy and cost, in order to give more reliable and comprehensive policy suggestions to the government or decision makers.

Methodology

- Use of vehicle emission models and analysis of real-world vehicle datas
  - Emission factors of NOx, $PM_{2.5}$ and CO_2 for the three representative LDPV technologies (MPFI, GDI, and diesel) under the typical driving conditions in Beijing are estimated based on the EMBEV model and the COPERT 4 model.
  - Emission factors of LDPV hybrid technology are calculated by the analysis of real-world vehicle exhaust emissions. Emission factors also include NOx, $PM_{2.5}$ and CO_2.
- Scenario analysis of control technology paths
  - Scenarios of future technology paths for LDPVs are designed based on linear programming model and market estimation. Penetration rates of new LDPVs of different technology paths under three typical scenarios are assessed.
- Cost assessment of control technologies
  - Incremental costs of the four technology paths are evaluated from bottom to up based on the break-down calculation method, to meet tightened emission standards for a typical engine displacement (1.8 liter) relative to the MPFI LDPV complying with the China 4 standard.
- Cost-benefit assessment of control technology paths
  - Through monetary evaluation method, cost-benefits of technology paths are assessed, including the evaluation of PM, fuel consumption, CO_2 and technology costs.

Results and Analysis

China 4 LDPVs are usually equipped with MPFI gasoline engines, when it comes to China 5 and China 6 emission standards, other options of technology paths need to be considered with even more tightened emission standards and fuel consumption standards. GDI and diesel engines and advanced technologies that can reduce fuel consumption but NOx and PM emissions could be higher than MPFI engines, especially diesel vehicles. Hybrid technology has advantage in reducing air pollutant emissions as well as fuel consumption , but the technology cost is still very high.

Emission factors of four technology paths are analyzed from vehicle emission models under typical Beijing driving conditions, as table 1 shown.

Table 1 China 4-6 emission factors of four typical technology paths

Emission Factors(g/km)	NOx	$PM_{2.5}$	CO_2
China 4 MPFI	0.030	0.003	245
China 5 MPFI	0.017	0.003	211
China 6 MPFI	0.017	0.003	196
China 4 Diesel	0.666	0.052	189
China 5 Diesel	0.819	0.013	163
China 6 Diesel	0.286	0.013	152
China 5 GDI	0.029	0.007	179
China 6 GDI	0.024	0.002	167
China 5 HEV	0.009	0.002	137
China 6 HEV	0.009	0.002	127

Technology cost calculation is based on break-down method, includes direct cost (manufacturing cost) and warranty cost. Costs of aftertreatment devices are estimated individually, as they are mainly about platinum group metals (PGM) loadings and catalyst systems.

Long-term costs of new technologies (e.g. DPF\LNT\SCR) will be reduced by learning process and volume production.

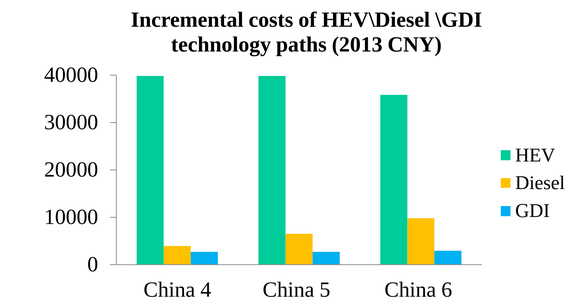

Fig 1 Incremental costs of technology paths

Incremental costs of HEV and diesel and GDI technology paths are estimated compared to China 4 MPFI LDPVs. Technology cost of HEV is highest, diesel comes next, and incremental cost of GDI is lowest. Technology costs of China 5 and China 6 MPFI LDPVs are slightly higher than China 4 MPFI because of the improvement of three-way catalyst (TWC) system.

Scenarios are designed in three typical years (2015\2017\2020) . Under Scenario A (i.e., the reference scenario), we assume that all new LDPVs in Beijing would adopt MPFI engines. Scenario B is based on market estimation of technology adoption. Under Scenario C, penetration rates of technology paths are estimated by linear programming model to meet China's emission reduction targets, which shows that diesel technology path is not suitable for LDPVs in Beijing because on-road exhaust emission factors are too high, the estimated penetration rate is nearly zero.

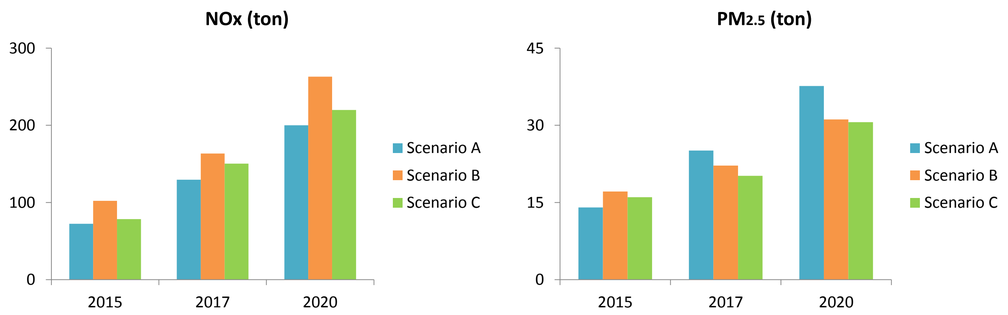

Fig 2 Exhaust emissions of three scenarios in typical years

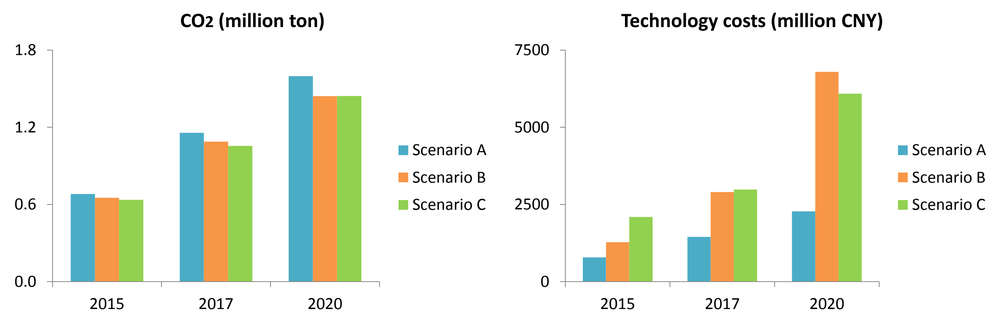

Fig 3 CO_2 emissions and technology costs of three scenarios in typical years

Economic evaluation includes the monetary analysis of PM, cost, CO_2 and fuel consumption. Social costs of China 5 (MY 2013) and China 6 (MY 2017) LDPVs are estimated in a 20-year full use cycle.

Table 2 External costs of PM\CO_2\FC

Objects	$PM_{2.5}$ (million CNY/ ton)	CO_2 (CNY/ ton)*	FC (CNY/ L)
External costs	3.27	400	8

*: Given external cost of CO_2 is for 2020, climate impact varies through the time period of 20 years.

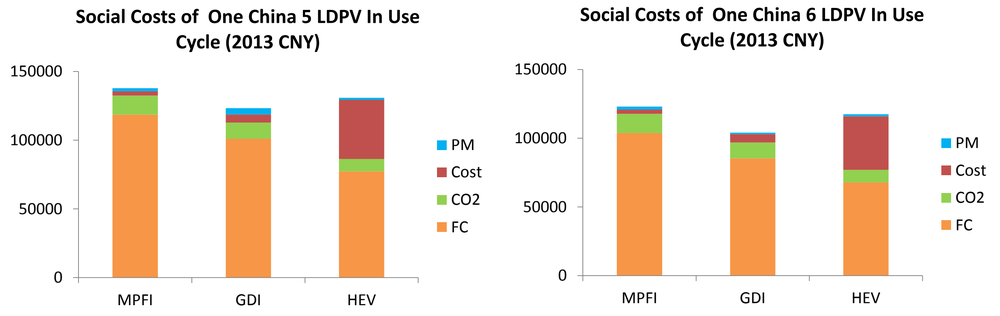

Fig 4 Social costs of one LDPV of MPFI\GDI\HEV technology paths in use cycle

Conclusions

1. Diesel technology path is not appropriate for LDPVs in Beijing, as real-world PM and NOx emissions are much higher, which offsets fuel-saving benefit.
2. Compared to Scenario A, emissions under Scenario C are generally lower than those under Scenario B, especially $PM_{2.5}$ and CO_2 emissions are even lower than Scenario A; but both Scenario B and C cost higher than Scenario A.
3. Social costs of GDI technology path is lowest in 20-year economic evaluation of one LDPV, HEV technology comes next and MPFI technology is the highest.