Scenario Assessment of CO₂ and Air Pollutants Emission Reduction Policies for Private Passenger Vehicles in China

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Abstract. The rapid increase of private passenger vehicles in China has brought about serious problems of CO₂ and air pollutant emissions. It has important practical guiding significance to compare the effects of emission reduction policies. In this paper, the LEAP system is used as a tool with classifying the private passenger vehicles according to the heterogeneity of displacement and fuel economy. The different emission reduction policy scenarios are simulated with respective implementation time and characteristic parameters. It is found that the management target of fuel economy is difficult to be realized by existing policies. Even the most stringent emission standards are all implemented, it is also necessary to cooperate with green travel which is mainly about reducing vehicles' annual travel distance. Although the annual increment of private passenger car is huge, however, there will be a certain downward trend in the discharge of air pollutants. On this basis, it is suggested that a policy goal of maintaining or lowering the emission level can be established. The research suggests that, on the supply side the government should continue to strengthen the management of fuel economy, improve the emission standards, boost the new energy vehicles vigorously, the energy saving vehicles under overall consideration and diesel cars carefully, while on the demand side the green travel should be encouraged at the same time.

1 Introduction

Private Passenger Vehicle (PPV) refers to a passenger car with private property and less than or equal to 9 seats. In the context of China's reality, the minibus is also included.

In the past ten years, China's per capita income has gradually increased, and people's willingness to purchase cars has also been getting higher and higher. The number of PPV reserve increased from 5.78 million in 2002 to 148.66 million in 2016. According to the China Automobile Association's data, the sales volume of passenger cars in 2016 was approximately 24.37 million. Positively PPV brings great benefits to users or owners such as convenient transportation, while the negative externalities of gasoline or diesel consumed by them can bother people's health and daily life. Gasoline or diesel's exhaust contains carbon dioxide (CO₂), which is the representative greenhouse gas that affect climate change, and air pollutants such as carbon monoxide (CO), nitrogen oxides (NO_x), and particulate matter (PM₁₀).

Especially in urban areas, Y.H. Guo, et al. (2014) believe that, due to factors such as vehicle driving performance, fuel quality and road conditions, exhaust pollution has become one of the important sources of air pollution in the city, and the impact on environment is increasing seriously. S.Z. Tian (2016) examines the panel data of the six central provinces and concludes that crude oil consumption is the main factor affecting the severity of smog in China. G.J. Sun (2013) analyzes the

pollutant emission reduction policies of motor vehicles, and proposes to develop public transportation, optimize urban road networks, implement inspection and maintenance systems, speed up the scrappage of old vehicles, and limit the movement of highly polluting vehicles. The above studies do not consider the rapid growth of PPV in recent years as a separate specific research object, and the fuel economy used in pollutant accounting is limited to individual vehicles, or the sample data is small, or non-real-world data. Therefore, they are impossible to accurately and comprehensively reflect the emission of CO₂ and air pollutants from China's PPV. The article overcomes the above shortcomings and uses the advanced LEAP system to explain the effects of China's relevant reduction and control policy scenarios.

2 LEAP system and data collection

2.1 Introduction of LEAP system

The article uses the Long-range Energy Alternatives Planning System (C.G. Heaps, 2016) as the primary analytical tool. It is a software for energy analysis, air pollution and climate change assessment developed by the Stockholm Environment Centre in Sweden. LEAP modularizes and standardizes these fields' research, while providing powerful policy simulation capabilities and energy substitution performance assessment

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capabilities. It can be used to analyze macro energy demand, environmental changes, and allow to focus on the analysis and assessment of micro areas such as electricity, agriculture or households. The article uses the traffic module in this system to evaluate the PPV CO₂ and air pollutant emission control scenarios.

LEAP requires the user to set a few of parameters. For the research questions in this article, it mainly includes the 2016 year PPV reserve data, the existing vehicle use age structure, the 2017-2021 PPV net incremental forecast data, the fuel economy of different displacements, annual mileage, CO₂ and air pollutant emission factors, historical and forecast period policy implementation time and data. For different parameters, some are obtained by statistical analysis, some are predicted, and some are acquired by database or literature.

2.2 Data collection

According to characteristics of PPV and relevant existing policy, the article divides PPV into three groups based on the engine displacement heterogeneity, including 0-1.6L (Liter, L) small vehicle group (including 1.6L), 1.6-2.5L medium group (including 2.5L) and above 2.5L large vehicle group. This classification has following advantages: to make full use of the sales data also based on displacement heterogeneity provided by the China Automobile Association; to be consistent with the environmental protection project of which dividing line is 1.6L; to reflect different consumption levels, as the larger the displacement, the higher the car, the greater the people's expenditure; to link displacement with emissions, as the greater engine displacement, the worse fuel economy following more emissions. In each group, according to technical characteristics, PPV is further divided into gasoline vehicle, diesel vehicle and hybrid electric vehicle. From the accumulated sales data of 2005-2016, the diesel vehicles and hybrid electric vehicles account for a very low proportion, so it is assumed that there are only petrol cars in the beginning.

2.2.1 PPV annual net increment forecast of 2017-2021

The article uses the 2002-2016 PPV reserve (Fig. 1) data combined with the time series model to predict the annual net increment data of 2017-2021 assessment period, then takes the proportion of sales volume in the forecast period unchanged with the base year 2016 to get annual net increment of different displacements of PPV 2017-2021. In fact, this net increase is the black box of summation of PPV's annual domestic sales, scrappage and net import or export.

Fig. 1. China's PPV reserve in year 2002-2016 /10,000

The data in Fig. 1 is a non-stationary time sequence. After taking first-order difference, the annual net increment shows a strong linear trend. Therefore, the regression model of the linear time trend of the year is introduced in the equation (1).

$$dppvr_t = \alpha + \beta \cdot Year + \varepsilon_t \quad (1)$$

Table 1. PPV net increment regression model of the linear time trend.

variable	coefficients	statistic results
Year	155.1*** (Std. Err.=20.98)	Number of obs=14
		F(1, 12) = 440.25
		Prob > F=0.0000
constant	-310697.8*** (Std. Err.=20.91)	R-squared=0.9735
		Adj R-squared=0.9713
		Root MSE=111.51
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$		

Table 1 shows that the explanatory variable and constant terms are significant in the regression results, and the overall regression is also significant. Fig. 2 shows that the fitted curve and the original curve coincide well.

Fig. 2. PPV net increment fitted effect

According to the fitting equation, the net increment forecast data of PPV inspection period 2017-2021 is obtained, as shown in Table 2.

Table 2. 2017-2021 PPV net increment forecast

Year	Xb /10 ⁴	Std	95% Prediction interval
2017	2184.02	128.051	[1905.02, 2463.02]
2018	2339.14	131.422	[2052.80, 2625.49]
2019	2494.27	135.113	[2199.88, 2788.65]
2020	2649.39	139.099	[2346.32, 2952.46]
2021	2804.51	143.357	[2492.16, 3116.86]
Keys:Xb=Linear Prediction ;Std=Standard Error(forecast)			

After predicting the annual net increment of PPV's reserve, we use three displacement groups' sales proportion of 0.7081:0.2706:0.0213 and constant assumption to obtain respective net annual increment, as shown in Table 3.

Table 3. 2017-2021 PPV different displacement annual net increment forecast data /10⁴

Displacement group	2016	2017	2018	2019	2020	2021
0-1.6L	1534.0	1546.5	1656.3	1766.2	1876.0	1985.9
1.6-2.5L	586.3	591.0	633.0	675.0	716.9	758.9
above 2.5L	46.1	46.5	49.8	53.1	56.4	59.7

2.2.2 PPV real-world fuel economy

Fuel economy reflects the amount of fuel consumed by different engine displacements or technologies in exercising the same number of kilometers, or the length of distance using the same amount of fuel. In order to reflect PPV's energy consumption efficiency more accurately, the article has compiled the real-world fuel economy data from Xiao xiong you hao APP (powered by xiaoxiongyouhao.com), which is supplied by PPV owners voluntarily. Table 4 shows the representative real-world fuel economy of the weighted summary of each displacement group.

Table 4. Representative real-world fuel economy of each displacement group

Representative fuel economy /L/100km	Displacement group	Accumulated sales from 2008-2016
7.9457	0-1.6L	97812883
10.0593	1.6-2.5L	39568027
12.4529	>2.5L	1341866

2.2.3 Other data

The article sets the annual mileage of the PPV to 16,000 km based on following researches, X.L. Lin (2009), H. Hao (2011), J.H. Chen, et al. (2014), C. Hou (2014). It

should be pointed that the annual mileage level will affect total amount of CO₂ and air pollutant emissions, meaning if it changes, not only existing vehicles but also new added ones need to adapt new mileage number. According to the parameters provided by the National Development and Reform Commission Energy Institute, the carbon emission trading network calculates the CO₂ emission of 1L gasoline to 2.251484kg without distinguishing the gasoline label, and the vehicle-km emissions corresponding to each displacement group are 178.896g, 226.484g and 280.375g.

Table 5 shows the emission factor of pollutants and the execution time of emission standards. The emission factor mainly relies on the research of H. Cai, S.D. Xie (2010). It is worth noting that only the factors of those different emission standards were investigated in their study. There was no separate explanation for specific displacement vehicle pollutant emission factor. The gasoline and diesel vehicles of their study were in the 1.4-2.0L displacement range. The article uses this data as the emission factor of air pollutants in all displacement ranges. Moreover, unlike the CO₂ emission factor, the air pollutants emission factors were not derived from the unit energy conversion, but a fixed value per unit distance in their study. So, when the total amount of pollutant emissions is sought, the annual mileage is made the same scale adjustment when the fuel economy changes.

Table 5. Emission factor, national standard and execution time

	National emission standard	Emission factor /g/vehicle-km			Emission standard execution time
		CO	NO _x	PM ₁₀	
Gasoline vehicles	I,II	9.5	0.6	0.02	2002-2006
	III	4.6	0.15	0.02	2007-2012
	IV	1.4	0.08	0.02	2013-2016
	V	1	0.06	0.004	2017-2020
Diesel vehicles	IV	0.3	0.8	0.08	2015-2016
	V	0.3	0.6	0.02	2017-2020

LEAP provides a year of use age structure module to suit different emission standards for vehicle analysis at different ages. The article uses the 2002-2016 annual change in the amount of PPV as the corresponding year's PPV increment data to determine the age of that part vehicle in year of 2016, and its share in 2015 is the proportion of reserve in this age structure. We set the age value of incremental part in 2016 as 0. The proportion of the PPV use age structure is shown in Fig. 3.

Fig. 3. PPV use age structure

3 Emission reduction policy scenario simulation and results analysis

3.1 Scenario introduction

The article sets BAU (Business as Usual, BAU) scenario with base year 2016's condition, and under BAU the assessment period (2017-2018) maintains its characteristic. In order to evaluate the effects of different CO₂ and pollutant control policies, we simulate Improved Fuel Economy (IFE), Increased market penetration of Energy Saving Vehicle (IESV), Increased market penetration of New Energy Vehicle (INEV), Increased market penetration of Diesel (IDSL), Decreased Annual Travel Distance (DATD), and PC (Policy Combination, PC) scenarios.

China's "Energy Conservation and New Energy Vehicle Industry Development Plan (2012-2020)" sets targets for the average fuel economy of passenger vehicles in 2015 and 2020 to fall to 6.9L/100km and 5.0L/100km respectively. Under the IFE scenario, the article incorporates the improvement ratio of 27.54% as a target into LEAP realized linearly from 2016-2021.

Under the IESV scenario, the article assumes that the annual net increment of the 0-1.6L displacement interval (China stipulates this range of vehicles as energy saving vehicles) gradually increases from 70.81% in 2016 to 75.81% in 2021, while the proportion of 1.6-2.5L displacement decreases to 22.06%, and the displacement above 2.5L interval does not change.

Under the INEV scenario, it is assumed that the proportion of new energy vehicles in 2016-2021 will increase linearly from 0 to 5%. Since it is limited to CO₂ and air pollutants emission at the PPV end use, not the whole life cycle, the emissions of pure electric vehicles in this scenario are 0, and the different displacement groups' fuel economy of plug-in hybrids are obtained according to different interval vehicles' weight from Xiao xiong you hao APP, which are 6.386L/100km for 0-1.6L group, 8.0847L/100km for 1.6-2.5L and 10.0085L/100km for above 2.5L group. The article assumes a fixed sales ratio of pure electric and plug-in hybrid during the evaluation period according to 2016 ratio number of 0.7635:0.2365.

Under the IDSL scenario, we set that the sales ratio of every year's new diesel vehicle increment in LEAP

will increase linearly from 0 to 5%. In addition, combined with the research of Min Jiang (2014), diesel vehicle's fuel economy is improved by 35% compared to gasoline vehicle. And the vehicle-km CO₂ emission factor of each displacement group is 139.48g, 176.582g and 218.6g respectively.

DATD is different from others because it mainly reflects the PPV users' actions for emission reduction of CO₂ and air pollutants on the demand side, while IESV, INEV and IDSL represent government's regulation on the supply side. Moreover, DATD can be taken as the most important contribution to green travel. In LEAP, we set 1% as each year's decreasing rate for PPV user's travel distance.

PC scenario is the combination of IFE and DATD. It is an ideal reference and objective to achieve for government and PPV users.

3.2 Results

The emissions of CO₂ and air pollutants in the base year and the assessment period under BAU are shown in Table 6. Among them, CO₂ has increased from 468 million tons in 2016 to 799 million tons in 2021, almost doubled. Due to the out-flow of low pollutant emission standard vehicles in the historical years such as 2002-2006, which are just scrapped after 15 years in the assessment period of 2017-2021, and the in-flow of low emission factor vehicles of 2017-2021, the change of air pollutants does not always maintain a growth trend, but initially decreased. Especially, it can be seen that the air pollutants of 2017 decreases significantly compared with the base period in 2016, for the reason that the vehicles in the historical year of 2002 with high emission factor accounts for a large proportion and exits in 2017. This decline trend will disappear due to the compressing space to enhance emission standard. If no measures are taken, it will eventually become an upward trend for the sharp rise in PPV new vehicles. This also gives an idea of PPV air pollutant control, that whether emissions can be contained at current or even lower levels in the context of a sharp rise in PPV.

Table 6. CO₂ and air pollutants emission of base year and assessment period /10⁶ t

	2016	2017	2018	2019	2020	2021
CO ₂	467.8	517.4	583.1	653.5	725.9	799.4
CO	8.585	8.056	8.099	8.164	8.117	7.911
NO _x	0.402	0.367	0.369	0.371	0.367	0.353
PM ₁₀	0.0475 73	0.047 121	0.047 920	0.048 813	0.049 517	0.0499 35

3.2.1 CO₂

Due to the low CO₂ emission factor of diesel vehicles, Table 7 takes IDSL scenario as reference, then let other scenarios' emission minus it. It shows that each improvement scenario can be more efficient in reducing CO₂ than IDSL, and the emission reduction effect is

ranked as PC>DATD>IFE>INEV>IESV>IDSL>BAU. If the IFE is compared as a target, only DATD can approach the target, and IDSL, INEV, and IESV are far from IFE.

Table 7. CO₂ emission difference vs. IDSL /10⁶ t

	2017	2018	2019	2020	2021
BAU	0.149	0.469	0.981	1.705	2.664
DATD	-5.024	-11.191	-18.624	-27.332	-37.304
INEV	-0.400	-1.255	-2.624	-4.563	-7.128
IDSL	0.000	0.000	0.000	0.000	0.000
IFE	-3.583	-11.257	-23.533	-40.918	-63.921
PC	-8.719	-22.683	-42.402	-68.250	-100.559
IESV	-0.017	-0.053	-0.111	-0.194	-0.303

3.2.2 CO

Since the diesel vehicle also has an advantage in CO emission factor, Table 8 is still based on IDSL. BAU and IESV both have a positive number because their CO emission factors of the gasoline vehicle is greater than IDSL. In IESV, the emission factor is the same in each displacement group, and the change in displacement group ratio cannot affect the emission result. Therefore, the CO emission is just equal to BAU, and the same situation also occurs in NO_x and PM₁₀, which will not be explained below.

INEV behaves well in fuel economy, and therefore it has a slight advantage over IDSL. The CO emission reduction effect of DATD is most ideal of all, because the annual mileage reduction of DATD is applied to all vehicles, especially the historical year vehicles with high emission factor. Although IFE has a great improved economy, it only works for new vehicles. Consequently, the effect of DATD is much better than IFE. As the number of years closer to 2021, the higher the proportion of new vehicles becomes, the advantage of low emission factor will become more and more, following the gap with DATD also decreasing. However, the reduction of CO by IDSL, IESV and INEV is still far from the reference in IFE.

Table 8. CO emission difference vs. IDSL /10³ t

	2017	2018	2019	2020	2021
BAU	2.519	8.074	17.209	30.502	48.562
DATD	-78.043	-153.907	-227.722	-294.179	-346.987
INEV	-0.311	-0.819	-1.381	-1.821	-1.931
IDSL	0.000	0.000	0.000	0.000	0.000
IFE	-16.728	-52.403	-109.212	-189.312	-294.823
PC	-97.098	-213.174	-350.350	-505.200	-673.203
IESV	2.519	8.074	17.209	30.502	48.562

3.2.3 NO_x

Different from CO₂ and CO analysis, we now take BAU as a reference to compare effects of NO_x control policy.

The results are shown in Table 9. Under IDSL, since the diesel vehicle's NO_x emission factor is too high compared to gasoline vehicles, the increase in the proportion of new diesel vehicles has led to an increase in the pollutants compared to BAU emissions. The effect of DATD is the best in the first four years of the assessment period, but it is reversed by IFE in 2021. IDSL, IESV and INEV's emission reductions for NO_x are also far from the IFE ideal reference.

Table 9. NO_x emission difference vs. BAU /10³ t

	2017	2018	2019	2020	2021
BAU	0.000	0.000	0.000	0.000	0.000
DATD	-3.671	-7.372	-11.144	-14.685	-17.635
INEV	-0.170	-0.534	-1.115	-1.939	-3.030
IDSL	1.740	5.153	10.110	16.418	23.821
IFE	-1.155	-3.629	-7.585	-13.189	-20.603
PC	-4.814	-10.928	-18.501	-27.346	-37.208
IESV	0.000	0.000	0.000	0.000	0.000

3.2.3 PM₁₀

Increasing smog air pollution have caused the public to pay more and more attention to the emission reduction control of inhalable particulate matter-PM₁₀. The national V standard has significantly increased the PM₁₀ emission limit. Table 10 shows that the diesel vehicle has a too much high emission factor such that the number of PM₁₀ emission of IDSL increases over BAU. Due to the overall impact of annual driving mileage, DATD still has the best effect, followed by IFE. INEV is still far behind IFE.

Table 10. PM₁₀ emission difference vs. BAU /t

	2017	2018	2019	2020	2021
BAU	0.000	0.000	0.000	0.000	0.000
DATD	-471.2	-958.4	-1464.4	-1980.7	-2496.7
INEV	-11.32	-35.57	-74.36	-129.29	-201.97
IDSL	51.019	149.824	291.099	467.440	669.347
IFE	-76.99	-241.90	-505.68	-879.26	-1373.5
PC	-547.4	-1195.5	-1954.9	-2824.8	-3801.6
IESV	0.000	0.000	0.000	0.000	0.000

4 Conclusions

Through the above scenario assessment of CO₂ and air pollutants emission control policy, we first conclude that there are differences in policy effects. The best solution is to encourage PPV owners to actively reduce the use of PPV, as this will have an impact on all vehicles. As a simulation of the government's fuel economy management objective, it is unlikely that the IFE emission reduction effect will be achieved by only INEV, IESV and IDSL. In the reduction of NO_x and PM₁₀, IDSL has a counter-productive effect. Its advantages are

mainly reflected in the control of CO₂ and CO. The scenario assessment shows that the proportion of new energy vehicles added by 5% is very limited to help achieve emission targets. If displacement heterogeneity does not result in differences in air pollutant emission factor, IESV has little effect on air pollutants control. Moreover, it is found that with the continuous withdrawal of vehicles in the historical year of high emission factor, the decline trend of PPV emission occurs during the assessment period. Therefore, an idea is put forward, that whether this trend will continue, or the existing emission levels can be maintained through various measures.

On the topic of policy recommendation to reduce PPV CO₂ and pollutant emissions, we suggest the government continue to strengthen the fuel economy management and improve emission standards on the supply side, while encourage the owners to travel green in the use side. Scenario simulations show that we should continue to vigorously develop new energy vehicles and increase their sales proportion. For the development of energy saving vehicles, we should make a comprehensive decision after weighing the upgraded PPV consumer demand and air pollutants emissions, because the article found that although the increase in the proportion of energy saving vehicles is effective in reducing CO₂ emission, but for the control of air pollutants, it needs to meet some prerequisites. The most controversial is the development of diesel vehicles. The government can make short-term and long-term arrangements according to the priorities of controlling air pollution and greenhouse gas emissions.

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