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Study on highway transportation greenhouse effect external cost estimation in China

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Abstract. This paper focuses on estimating highway transportation greenhouse gas emission volume and greenhouse gas external cost in China. At first, composition and characteristics of greenhouse gases were analysed about highway transportation emissions. Secondly, an improved model of emission volume was presented on basis of highway transportation energy consumption, which may be calculated by virtue of main affecting factors such as the annual average operation miles of each type of the motor vehicles and the unit consumption level. the model of emission volume was constructed which considered not only the availability of energy consumption statistics of highway transportation but also the greenhouse gas emission factors of various fuel types issued by IPCC. Finally, the external cost estimation model was established about highway transportation greenhouse gas emission which combined emission volume with the unit external cost of CO$_2$ emissions. An example was executed to confirm presented model which ranged from 2011 to 2015 Year in China. The calculated result shows that the highway transportation total emission volume and greenhouse gas external cost are growing up, but the unit turnover external cost is steadily declining. On the whole overall, the situation is still grim about highway transportation greenhouse gas emission, and the green transportation strategy should be put into effect as soon as possible.

1. Introduction
Climate change is a crucial issue that concerns about the survival and development of human beings. It comes to a consensus gradually that carbon dioxide (CO$_2$), methane (CH$_4$), nitrous oxide (N$_2$O) and hydrogen fluoride (HFCs) eventually led to global climate change that we produced during all production and life activities. Carbon dioxide is the most important factors in greenhouse gases. From global perspective, highway transportation is one of the three main carbon sources of greenhouse gas emissions [1]. According to the 2007 EU Transport Ministers Meeting Report of Carbon Dioxide Emissions Reducing in Transportation, in 2003, greenhouse gases CO$_2$ accounted for 34% of the total emission which was produced by the fuel consumption in the national transportation industry (including the commercial and private transportation) of Organization for Economic Cooperation and Development (OECD). Among 34%, the highway transportation accounted for 23%, and other mode transportations accounted for 11%. It was shown that if the concentration of CO$_2$ in the atmosphere was doubled, the average temperature of the earth would be raised by 2.5°C [2]. The greenhouse effect causes global warming, polar ice and plateau glaciers melting, the sea level rise, the ecological system imbalance in mid-latitude region, frequent sudden climate disasters, diseases and epidemics spreading, and even serious impaction on human beings’ survival and development. According to WHO’s estimation, global climate change led to more than 100 thousand people losing their lives each year, which caused economic losses was equivalent to 5% of global GDP.
The external cost of highway transportation greenhouse effect mainly refers to the economic losses which were caused by the greenhouse gas emissions, such as CO\textsubscript{2} and so on, which brought about the global warming. Due to the large population and rapid economic development in China, the whole volume of energy consumption and greenhouse gas emissions was very large, and was increasing year by year in China. It was eventually replacing the United States as the largest major source of greenhouse gas emissions. With rapid growth of vehicles and huge consumption of fuel, it is more urgent to construct the estimated model on highway transportation greenhouse gas emissions and external cost, and moreover, put forward the management and technical measures of carbon reduction and energy saving. Based on the analysis of the composition and characteristics of highway transportation greenhouse emission gases, the model was presented which estimated the emission volume and external cost in highway transportation. Moreover, an example was concretely executed to confirm presented model which ranged from 2011 to 2015 Year in China. At last, some suggestion is put forward for the further management and technical measures of energy saving and carbon reduction. The research results can provide decision-making references for the highway transportation management department, which includes allocating reasonably the transportation resources and implementing the low-carbon transportation project.

2. Composition and characteristics of greenhouse gases
Greenhouse gases include not only CO\textsubscript{2} but also CH\textsubscript{4}, N\textsubscript{2}O and CFCs, and so on. It was found that the greenhouse effect brought by various types of gases varied very large, which not only related to each type of gas content in the atmosphere, but also with retained time and life of each type of gas in the atmosphere, in other words, greenhouse effect was a function of greenhouse gases content and life. In table 1, it was listed about five type greenhouse gas content, life, sharing ratio and warming potential. Warming potential refers to a ratio of a certain greenhouse gas and CO\textsubscript{2} on the impacts of climate change, regarded as the relative effect index of each type of greenhouse gas [3].

| greenhouse gases | Content (Volume fraction)(10\textsuperscript{-6}) | Content growth rate (%) | Life (year) | Share ratio (%) | Warming potential |
|------------------|-----------------------------------------------|-------------------------|-------------|----------------|------------------|
| CO\textsubscript{2} | 354                                            | 0.5                     | 50-200      | 55             | 1                |
| CH\textsubscript{4} | 1.7                                             | 1.1                     | 11          | 15             | 32               |
| N\textsubscript{2}O | 0.3                                              | 0.3                     | 150         | 6              | 150              |
| CFC-11           | 0.0002                                          | 5                       | 75          |                | 14000            |
| CFC-12           | 0.00032                                          | 5                       | 111         | 17             | 17000            |

The table reflects that the contribution rate of CO\textsubscript{2} was 55\%, which is the most important greenhouse gas. CH\textsubscript{4}, whose greenhouse effect is 32 times that of CO\textsubscript{2}, has shorter life and the residence time is 11 years in the atmosphere. Chlorofluorocarbons (CFCs) are some synthetic chemicals that are widely used in air conditioning, foaming agent and solvent. Among CFCs, CFC-11 and CFC-12 play a major role in greenhouse effect, with extremely low concentration in the atmosphere, but in recent years they grow rapidly at an annual rate about 5\%, with not only their warming potential as high as 14000 and 17000 but also long survival time.

3. Affecting factors of highway transportation greenhouse effect external cost
To calculate the external cost of highway transportation greenhouse effect, two type data were needed. For one thing, the energy consumption of highway transportation and its corresponding greenhouse gases emissions. For another, the amount of economic and social losses, which were caused by the unit of greenhouse gas emissions, known as the monetization of ecological damage, human health, agriculture, raw materials and ecosystems.

3.1 Energy consumption of highway transportation
In current statistical system in China, there is no direct statistical data of the energy consumption corresponding to highway transportation. In consideration of both the availability of data and using statistical data to improve data quality as possible, it was adopted which included transportation turnover and unit consumption to reckon the total highway transportation energy consumption. The calculated model is shown below in the formula (1).

\[ FQ = \sum_{i=1}^{3} A_i \times TQ_i \]  

Where \( FQ \): Fuel consumption of highway transportation;  
\( A_i \): unit consumption corresponding to mode “i” of highway transportation;  
\( TQ_i \): transportation turnover corresponding to mode “i” of highway transportation;  
\( i \): mode “i” of highway transportation, including highway passenger transport, freight transport, urban public transport.

With the energy consumption data of highway transportation and presented greenhouse gas emission model, it can be calculated about greenhouse gas emission volume from highway transportation. Greenhouse gas emission model can be referred in Section 4.1.

3.2 Unit greenhouse gas external cost

United Nations Framework Convention on Climate Change estimated that each emission ton of CO\(_2\) cost about $5-25 (1990). National Research Council (1991) suggested that the emission cost per ton of CO\(_2\) should be in the range of $10-20 in the United States. According to the latest relevant research, the international market price of carbon emission trading was 17 euros per ton of CO\(_2\) in general [4], while the domestic transaction price was range from 100 to 150 yuan. According to both these reference values and Chinese actual conditions, our research adopted 120 yuan per emission ton of CO\(_2\) to estimate the external cost of Chinese highway transportation greenhouse gas emissions.

4. Estimated method of greenhouse effect external cost

In order to calculate the external cost of the greenhouse effect of highway transportation, two models need to be established. The first one was the greenhouse gas emission model, which could calculate the different greenhouse gas emission according to the energy consumption of highway transportation. The second one was the external cost estimated model of greenhouse effect, which would quantify and monetize the external effects of greenhouse gas emissions from highway transportation.

4.1 Greenhouse gas emission model

There are two kinds of quantification models about highway transportation greenhouse gas emissions: energy consumption statistics and vehicle test. The first model is widely used in the statistics of greenhouse gas emissions in the transportation department, such as the US Environmental Protection Agency greenhouse gas emission estimated methods, the WRI carbon emission model for motor vehicles, the IPCC National Greenhouse Gas Inventories Guide vehicle carbon emission model, and the NEMS model developed by the US Energy Information Administration (EIA). The methods and assumptions among these models varied widely, and the estimated results of greenhouse gas emissions distinguished obviously. In this research, based on these emission models, an improved greenhouse gas emission model was presented which considered not only the availability of energy consumption statistics of highway transportation but also the greenhouse gas emission factors of various fuel types issued by IPCC. The model was shown in equation (2).

\[ GQ_j = \sum_{k=1}^{n} B_{jk} \times FQ_k \]  

Where: \( GQ_j \): emission of greenhouse gas “j”  
\( B_{jk} \): emission factor of greenhouse gas “j” corresponding to fuel “k”  
\( FQ_k \): consumption of fuel “k”
Where emission factor of greenhouse gas $B_{kj}$ can be calculated as follows.

$$B_{kj} = \text{net calorific power} \times \text{carbon content} \times \text{oxygenation efficiency} \times \text{carbon conversion coefficient}$$

Where the net calorific power is the calorific value that per unit fossil fuel is completely combusted, known as the net heating value. The carbon content is the amount of carbon emitted by per unit calorific value of the fuel. The oxygenation efficiency is the carbon oxidized ratio. Carbon conversion coefficient is the carbon conversion coefficient of carbon dioxide, known as $44/12 = 3.67$.

According to "the Report on Climate Change (2009)", the net calorific power, carbon content and oxygenation efficiency of various types of fuels were shown in Table 2. According to equation (3), the carbon emission factors of gasoline, diesel and natural gas were respectively $2.98 \text{ tCO}_2/\text{t}$, $3.16 \text{ tCO}_2/\text{t}$, $2.18 \text{ tCO}_2/\text{t}$. Furthermore, according to the research [5], the relevant emission coefficients and factors $\text{CH}_4$ and $\text{N}_2\text{O}$ corresponding to other fuels can be calculated and shown in Table 2.

Table 2: the relevant emission coefficients and factors of various types of fuels

|          | net calorific power (kJ/kg) | carbon content $^{(1)}$ (kgCO$_2$/TJ) | oxygenation efficiency $^{(2)}$ | emission factor $(\text{tCO}_2/\text{t})$ | $(\text{tCH}_4/\text{t})$ | $(\text{tN}_2\text{O}/\text{t})$ |
|----------|-----------------------------|-----------------------------------------|----------------------------------|------------------------------------------|---------------------------|--------------------------|
| diesel   | 42650                       | 20.20                                   | 1                                | 3.16                                     | 0.55                      | 0.09                     |
| gasoline | 43070                       | 18.90                                   | 1                                | 2.98                                     | 3.83                      | 0.09                     |
| natural gas | 38931                     | 15.30                                   | 1                                | 2.18                                     | 0.28                      | 0.04                     |

Source: Report on Climate Change (2009). Note: $^{(1)}$ emission factors of each fuel take the 95% confidence limit for each fuel emission factor, data from: 2006 IPCC Guidelines for National Greenhouse Gas Inventories Volume 2 Energy; $^{(2)}$ According to 2006 IPCC Guidelines for National Greenhouse Gas Inventories; $^{(3)}$ The fuel calorific value is based on the low calorific value data.

4.2 Greenhouse effect external cost model

As global climate change has become one of the hot issues of the world, carbon emissions trading has become more popular. The model for estimating the external cost of the greenhouse effect from highway transportation is shown as follows:

$$EC = PC \times \sum_{j=1}^{m} C_j \times GQ_j, \quad (j=1, \ 2, \ ... \ m) \quad (3)$$

Where $PC$: The external cost of unit CO$_2$ emission;

$C_j$: The conversion coefficient of the greenhouse gas “$j$” to CO$_2$, known as the warming potential heating factor of the greenhouse gas “$j$”, referred to Table 1;

$GQ_j$: Emission of the greenhouse gas “$j$”.

5. Application Example

Since 2011, unit energy consumption of highway transportation began to sample statistics in Chinese statistical system. According to the China Statistical Bulletin of Transportation, transport turnover and unit energy consumption were shown in Table 3 about highway passenger transport, freight transport, urban public transport in China during 2011-2015.

Table 3: The energy consumption of highway transportation

| Year | Transport turnover (100 million t·km) | 2011 | 2012 | 2013 | 2014 | 2015 |
|------|----------------------------------------|------|------|------|------|------|
| Freight | 51375                                    | 59535| 55738| 61017| 57956|
| Unit energy consumption (kg standard coal/100 ton·km) | 2.2 | 1.7 | 1.9 | 2 | 1.9 |
| Passenger | Transport turnover | 51375 | 59535 | 55738 | 61017 | 57956 |
Urban public transport turnover (100 million t·km)  
Unit energy consumption (kg standard coal/1000 person·km)  
11.3 11.7 11.6 12.1 12.6  
Transport turnover (100 million person)  
1094 1141 1174 1190 1163  
Unit energy consumption (ton standard coal/10000 person)  
1.4 1.4 1.5 1.4 1.5  
Total ton standard coal (10 thousand ton)  
14728 13879 13656 15332 14110  

Note: 1) urban rail transit is deducted from urban public statistics. It was classified transportation, warehousing and postal services as a whole in the energy consumption statistics system in China. With the total energy consumption of highway transportation, combined with the proportion of gasoline and diesel consumption in the whole energy statistics, the energy consumption of gasoline and diesel from highway transportation can be further calculated, and the results were shown in Table 4.

### Table 4: The classified energy consumption of highway transportation

| Year | Diesel (10000-ton) | Gasoline (10000-ton) | Natural gas (100 million m³) | Proportion of conversion standard coal, diesel | Proportion of conversion standard coal, gasoline | Proportion of conversion standard coal, natural gas | Total (10 thousand ton) |
|------|-------------------|---------------------|-----------------------------|---------------------------------------------|---------------------------------------------|---------------------------------------------|------------------------|
| 2011 | 9485              | 3374                | 138                         | 68%                                         | 24%                                         | 8%                                          | 14728                  |
| 2012 | 10727             | 3753                | 154                         | 68%                                         | 24%                                         | 8%                                          | 13879                  |
| 2013 | 10920             | 4381                | 176                         | 65%                                         | 26%                                         | 9%                                          | 13656                  |
| 2014 | 11746             | 5035                | 200                         | 63%                                         | 27%                                         | 9%                                          | 15332                  |
| 2015 | 12635             | 5786                | 228                         | 62%                                         | 29%                                         | 9%                                          | 14110                  |

Note: 1) according to the energy ratio, 1 ton gasoline is equivalent to 1.4714 tons standard coal, 1 ton diesel is equivalent to 1.4571 tons standard coal, 10000 m³ natural gas is equivalent to 12.143 tons standard coal.  
2) The consumption fuels of highway transportation are mainly diesel, gasoline and natural gas. Kerosene and other fuels account for less, and are combined into the aforementioned three types during calculation.  
3) In current energy consumption statistics, the proportions of energy consumption were released only to 2013, so the proportions after 2013 were calculated based on the existing proportion trend.  
According to the model presented in the previous section and greenhouse gas emission factors, with the energy consumption of highway transportation, the greenhouse gas emissions could be estimated including CO₂, CH₄ and N₂O from commercial vehicles during 2011-2015, as is shown in Table 5. The warming potentials of CH₄ and N₂O are 32 times and 150 times of CO₂ respectively.

### Table 5: The greenhouse gas emissions of highway transportation Unit: 10⁴ ton

| Year | Fuel type | Fuel consumption | CO₂ emission | CH₄ emission | N₂O emission | Conversation CO₂ emission |
|------|-----------|------------------|--------------|--------------|--------------|-------------------------|
| 2011 | diesel    | 6827             | 21575        | 3755         | 614          | 233908                  |
|      | gasoline  | 2429             | 7237         | 9302         | 219          | 337680                  |
|      | natural gas | 99              | 1408         | 181          | 26           | 11067                   |
| Year | Conversion transport turnover (100 million ton·km) | Greenhouse gas external cost (100 million RMB) | Unit turnover external cost (RMB / ton·km) | Proportion in GDP (%) |
|------|--------------------------------------------------|------------------------------------------------|------------------------------------------|----------------------|
| 2011 | 53051                                            | 6992                                            | 0.13                                     | 1.44                 |
| 2012 | 61382                                            | 6558                                            | 0.11                                     | 1.23                 |
| 2013 | 56863                                            | 6709                                            | 0.12                                     | 1.14                 |
| 2014 | 62225                                            | 7677                                            | 0.12                                     | 1.21                 |
| 2015 | 59030                                            | 7201                                            | 0.12                                     | 1.06                 |

Note: Conversion transport turnover = Freight turnover + Passenger turnover/10

As a whole of highway transportation, the external cost of greenhouse effect was growing up in 2011-2015, but the external cost of unit transport turnover steadily declined. The results indicated that the growth rate of greenhouse effect external cost caused by highway transportation was less than that of conversion transport turnover. So it can be seen that the highway transportation was gradually developing into low-carbon transport in China. At the same time, with the rapid development of national economy and the obvious growth of the economic scale, the proportion of the external cost of greenhouse effect from highway transportation in GDP will decrease year by year in the future.

6. Conclusions

According to the research above, the current greenhouse gas emissions from highway transportation are in a steady and good trend, but the overall situation is still grim. Thus the green transport strategy should be put into effect as soon as possible. First and foremost, carrying out the clean energy vehicle project, which will strengthen the access management of transport market, lay down strict vehicle emission standards, and accelerate the use of clean fuel transport. Secondly, adjusting highway transportation energy consumption structure, which may encourage to increase the proportion of diesel vehicles in large and medium vans, and improve continuously the ratio of clean energy consumption to...
reduce environmental pollution and greenhouse gas emissions from the origin. Thirdly, developing integrated transport, which will play comparative advantages of various transport modes. Compared with road transport, waterways and railways are more environmental-friendly and have unique advantages in per unit traffic energy utilization. More attentions should be paid attention to the joints among various modes of transport, and play combination advantages of transport modes. Finally, but not least, public transport should be developed actively. Non-commercial vehicles account for a large proportion in vehicle ownership in China. Along with the popularization of private cars, greenhouse gas emissions from non-commercial vehicles and their external costs are increasing year by year. Therefore, it should be actively promoted and encouraged about public transport.

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