CHINA'S PASSENGER TRANSPORT ENERGY DEMAND AND CO_2 EMISSION SCENARIO ANALYSIS

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ABSTRACT

The energy consumption and CO_2 emission of China's passenger transport have been increasing in recent years. With China's population, economic development level, passenger volume, public transportation share, private car stock, and new energy vehicle (NEV) policies developing year by year, we need a medium - and long-term model to predict the future energy demand and greenhouse gas emissions of China's passenger transport. In this paper, we divide the passenger transport sector into inter-city and inner-city, then establish a bottom-up model using the LEAP (long-term energy planning system) platform to estimate China's provincial passenger transport emissions up to 2050. Four scenarios, namely reference (REF), business as usual (BAU), electric vehicles promoting(EVP) are set to evaluate possible policy alternatives. The results show that the BAU scenario and EVP scenario are efficiently reduce the energy consumption and CO_2 emissions. Under the BAU scenario and the EVP scenario will reduce 45% and 53% energy consumption respectively. Under the BAU scenario and the EVP scenario will reduce 78% and 91% CO_2 emissions respectively. The results show that promoting the development of electric vehicles will help China to achieve the goal of low-carbon transportation.

Keywords: passenger transportation, vehicle stock, energy demand, CO_2 emissions

NONMENCLATURE

Abbreviations	
REF	Reference
BAU	business as usual
CPEG	China Passenger Transport Energy Demand and CO_2 Emissions Analysis
EV	electric vehicle
EVI	electric vehicles improvement
GDP	gross domestic product
ICE	internal combustion engine
ICEV	internal combustion engine vehicle
LEAP	long-term energy planning system
MC	motorcycle
NB	non-urban transit bus
PV	non-taxi passenger vehicle
tce	ton coal equivalent
TV	taxi
UB	urban transit bus
VMT	vehicle miles travele
NEV	new energy vehicle
EI	energy intensity
TTW	Tank-to-Wheels
WTW	Well-to-Wheels
T	inner-city turnover

1. INTRODUCTION

Passenger transportation is divided into inner-city and inter-city, the inner-city traffic consists of private and public transportation, the inter-city traffic including the highway, railway, water transport and shipping. Passenger transportation plays an important role in its contribution in national economy and impact in global warming. Since 2000, with the economic growth, passenger traffic turnover has been growing rapidly. The development of transportation industry consumes a lot of energy, which generates a lot of GHG emissions. CO_2 emissions from China's road transport industry reached 698.3Mt in 2015, accounting for about 8% of China's GHG that year[1] .Passenger transportation total energy consumption in China was about 300Mtce, accounting for 70% energy consumption in the transportation industry in 2015 [2].

The passenger transportation including the inner-city transportation and inter-city transport. The energy consumed by private vehicles, especially in the driving cycle, accounts for the vast majority of inner-city transportation and is an important source of energy consumption. Private vehicle stock in China has risen from 18.2 million in 2005 to 181.3 million in 2017 with an average annual growth rate of more than 12%. According to the recent study that the private vehicle stock may have the potential to reach 508 million in 2050[5]. With the rapid growth of vehicle stock, the energy consumption in inner-city transportation will become a serious challenge in the future. From the point of view of the whole transportation system, the energy consumption China's Per capita transportation energy consumption index increased from 0.16 tce in 2010 to 0.21 tce in 2014, which is still far from the level of 0.6 tce in developed countries[3].Therefore, energy consumption in transportation sector still has great potential for growth.

In terms of energy structure, gasoline and diesel are still the main energy sources for passenger transport in China, while the policy related to promote the use of NEV has been released. According to the "Made in China 2025" and "Energy conservation and new energy industry development planning", the new energy vehicle especially the electric vehicle has set up an explicit development strategy. Meanwhile, a series of research use the specific scenario analysis for NEV promotion has been done including national area and provincial area[4-6,9] .

The rest of the paper is organized as follows: the methodology is presented in second part , the results is
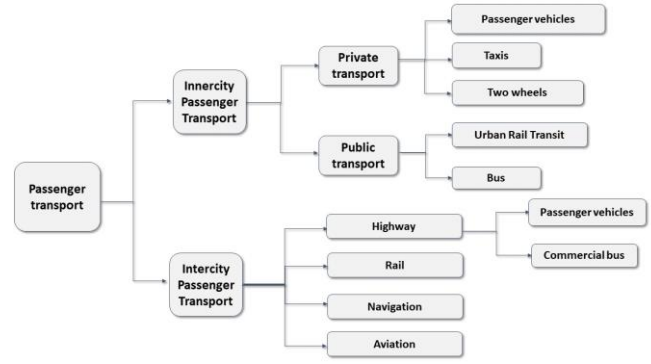

Fig 1 Transportation classification in this study.

presented in third part. And finally, the conclusion is present in forth part.

2. METHODOLOGY

2.1 Overview of the CPEG model

In order to analyze and forecast the energy consumption and CO_2 emissions related to passenger transport sector under different scenarios in 2015-2050, we use the LEAP modelling platform to develop a passenger transport structure CPEG model. The CPEG model is in a bottom-up tree based structure including four activity levels: sector, sub-sector, end-use, and device, respectively. In this paper, we divide the passenger transport sector into inter-city passenger transport and inner-city passenger transport. The inter-city passenger part further subdivided into railway, highway, navigation and civil aviation[2] [3]. The inner-city passenger transport was divided into private transport and public transport. The private transport including non-taxi passenger vehicle, taxi, motorcycle and mopeds, while the public transport including subway and urban bus. The model includes four modules: input module, vehicle inventory module, turnover module and energy module.

Calculation of energy consumption and emissions
2.2.1 Vehicle stock projection
2.2.1.1 non-taxi passenger vehicle stock and sales projection.
In this paper, future PV stocks are projected with Gompertz function relating vehicle ownership to per-capita GDP[5].

$$v_{s_{i,t}} = v_{s_i} \times e^{\alpha e^{\beta PGDP_{i,t}}}$$
$$Vs_{i,t} = v_{s_{i,t}} \times P_{i,t}$$
$$Vs_{i,t} = \sum_{m \leq t} sale_{i \cdot m} \times S_{i,m,t}$$

Where the $v_{s_{i,t}}$ denote the PV ownership in province i in year t; α and β are related to the curve shape which could be calculated by the historical data, $Vs_{i,t}$ represent the PV stocks in year t. $PGDP_{i,t}$ is the per capita GDP in province i in year t. $sale_{i \cdot m}$ is the vehicle sales in province i at year t; S is the survival ratio of PV.

2.2.1.2 Taxi and Urban bus stock projection
The stock of TV, UB are calculated based on urban population density as they increasing with the travel demand of people. Therefore, according to the urban taxi and bus ownership per 1,000 people in the base year, assuming the growth trend of the ownership per 1,000 people in the future, combined with the future urban population distribution and city size, the urban taxi and bus ownership in different city is obtained. The TV and UB stock in each province is calculated through the sum of all the cities in the province. The values of ownership per thousand people in base year and future are shown in table 1.

Table 1　Vehicle ownership assumption per 1,000 people by city category

Urban population (million)	2015		2020		2030		2050	
	UB	TV	UB	TV	UB	TV	UB	TV
>100	1.24	2.4	1.3	2.4	1.4	2.4	1.4	2.4
5-100	1.09	2.0	1.2	2.0	1.3	2.0	1.3	2.0
3-5	1.02	2.0	1.2	2.0	1.3	2.0	1.3	2.0
1-3	0.6	1.2	0.7	1.2	0.9	1.2	1.2	1.2
0.5-1	0.76	2.5	0.9	2.5	1.0	2.5	1.1	2.5
<0.5	0.82	4.1	0.8	4.1	0.9	4.1	1.0	4.1

2.2.1.3 Mtorcycle and mopeds stock projection
As for the prediction of future MC and Mopeds stock, we adopt the calculation outcomes from GAINS, and calculate the sales in each province based on the survival rate of two wheels.

2.2.2 Passenger traffic turnover and vehicle miles traveled

Passenger traffic turnover($T_{i,t}$) including the inner-city turnover($Tv_{i,t}$)and inter-city turnover($T\omega_{i,t}$). The $Tv_{i,t}$ is calculated by the population, per capita number of daily trip(DP) and the per capita annual daily average distance(ADD)[7,10]. There is a good linear fitting relationship between the $T\omega_{i,t}$ and per capita GDP[1], therefore, we calculate $T\omega_{i,t}$ based on the historical data of each province. The VMT calculated by the vehicle

traffic turnover, average load capacity, actual load traffic turnover share of passenger transportation[8].

$$Tv_{i,t} = T_{i,t} - T\omega_{i,t}$$
$$Tv_{i,t} = POP \times ADD \times DP$$
$$VMT_{i,t} = \left(\frac{Tv_{i,t}}{Vs_{i,t} \times LF_{i \cdot t}} \right)$$

2.2.3 Energy consumption

The energy demand of vehicles is determined by vehicle stock, fuel type, fuel consumption rate (Fc) and vehicle and vehicle miles traveled(VMT). Energy demand of other transportation is based on the traffic turnover and the unit traffic turnover of energy consumption(EI) in each mode of transport.

$$E_{i,t,vehicle} = \sum (Vs_{i,t} \times VMT \times Fc)$$

$$E_{i,t,others} = \sum (T\omega_{i,t} \times EI)$$

Where the E represents the energy consumption; the Fc represents the fuel economy of vehicles, we obtain the Fc in 2015 from Jun-ling Liu[11], according to the "Evaluation method and index of passenger vehicle fuel consumption", the Fc is expected to reach 5.0L/100km in 2020, 4.5L/100km in 2025, we use this standard as the Fc value for PV and TV in our paper.

2.2.3 CO₂ emissions

The total direct CO_2 emissions of passenger transport are the product of total direct energy demand and the CO_2 emission intensity of each mode of transport.

$$EM_{i \cdot t} = \sum E_{i,t} \times EF$$

Where the EM represents the CO_2 emission; the EF represents the CO_2 emission intensity.

2.2 Scenario design

The Ministry of Transport has already proposed the CO_2 decreasing goal, Meanwhile, each province is making its own policies. This paper considers three policies, including improving fuel economy, promoting electric vehicles and improving public priority, and sets the policies already issued by various provinces as the BAU scenario. In addition, we further strengthen the basis of each policy to find out the emission reduction potential of different policies. (see Table 2)

Table 2 Scenarios design in this paper

Scenario	Description

REF	All policies to promote low-carbon transport have not been implemented, and the share of EV was frozen in 2015.
BAU	All policies that encourage fuel economy improvements , EV promotion and public transport priorities are considering in this scenario.
EVI	EV production capacity will increase significantly compared to BAU.

Fig 2 BAU energy structure

Fig 3 EVP energy structure

2.3 Results and discussion

2.3.1 Vehicle stock projection

The PV stock is estimates increased rapidly from 137 million in 2015 to 378 million in 2030 and reach the saturation point at 465 million in 2050. The results show that under the BAU scenario, the private car stock in China will increase a large number of EV in the vehicle composition. It can be seen from the results that the electric vehicle ownership in all regions has shown a sustained growth, the EV stock only account for 1% in 2015, after the promotion policy release by each government, the EV stock of proportion rise dramatically into 24% in 2030 and maintain a strong growth trend until 2050. In terms of the ICE vehicles, except for a small number of underdeveloped regions, the majority of regions showed a decline in the ownership of ICE vehicles. CNG and FCV are two other NEV. Their promotion is not as intensive as that of EV. Few provinces have issued special policies to promote them. However, due to their cleaner fuel structures, in 2050, CNG and FCV accounted for 13% and 8% respectively.

During 2015-2020, various regional EV promoting policy cause the different EV stock projection presents in each province. Hainan will become the province with the largest number of EV in China by 2030 because of its aggressive EV promotion policy. Sichuan, Zhejiang and Guangdong provinces will have more than 5 million vehicles by 2030 due to their large vehicle base and advanced EV promotion policies. In the future, EV promotion policies will continue to be issued in all regions. So we hypothesized different scenarios to compare the greenhouse gas emissions of passenger traffic under different EV market share scenarios in the future.

2.3.2 Energy demand

Under the BAU scenario, the energy demand of the passenger sector in 2050 was about 230 Mtoe, and the EVI scenario was about 195 Mtoe. Both BAU and EVP showed effective reduction to the REF scenario, and the REF scenario was about 420 Mtoe. In the scenario of BAU and EVP, the passenger energy demand is at the peak in 2027, while in the scenario of REF, the energy demand in 2015-2050 will increase and cannot reach the peak.

In terms of the fuel structure, Fig2 shows fuel structure under the BAU and Comparison with REF scenario values. Fig 3 shows fuel structure under the EVI and Comparison with REF scenario values, The EVI greatly reduced dependence on gasoline while the electric become the more important in energy supply. EVI can meet the needs of more electricity per unit of passenger transport turnover. Therefore, it is necessary to take full life cycle CO_2 emissions into consideration in the study and comprehensively evaluate the potential of greenhouse gas emission reduction brought by the promotion of electric vehicles. In 2.3.3, we extended the research stage from TTW(tank-to-wheels) to WTW (well-to-wheels), and studied the difference of CO_2 emission of China's passenger transportation from transportation sector to power sector under different scenarios
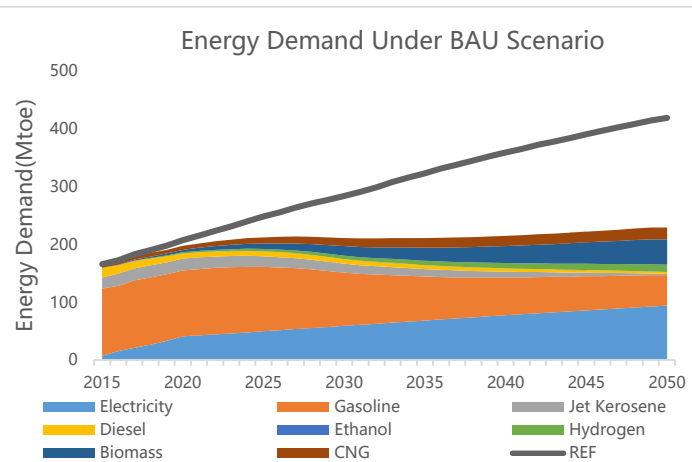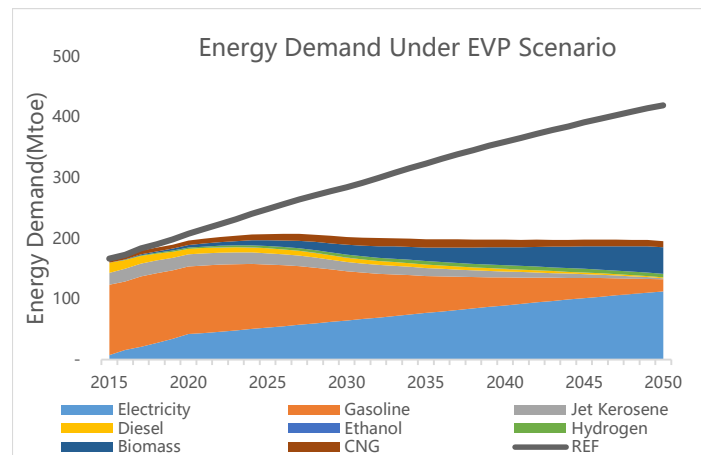
2.3.3　CO_2 emissions

The CO_2 emissions on the TTW of passenger transportation is about reach 972Mt at 2050 under REF scenario, while BAU and EVP can reduce the CO_2 emissions 78% and 91% respectively. Meanwhile, EVP scenario can improving the energy structure of the passenger transport sector to make it more "electrification" . On the other hand, optimize the energy demand structure will turn to the great demand of electricity power structure. This poses great challenges to China's power sector. According to the results in figure 5, in the WTW stage of China's passenger transport sector in 2015,2030 and 2050, the emission of BAU and EVP was far lower than that of REF scenario. The CO_2 emissions on the WTW of passenger transportation is about reach 1664Mt at 2050 under REF scenario, while BAU and EVP can reduce the CO_2 emissions 47% and 52% respectively. It can be seen that the emission reduction potential of EVP in WTW stage is much smaller than that in TTW stage, because a lot of emissions have been transferred to the power sector, but the development of electric vehicles is still a low-carbon transportation policy with great emission reduction potential.
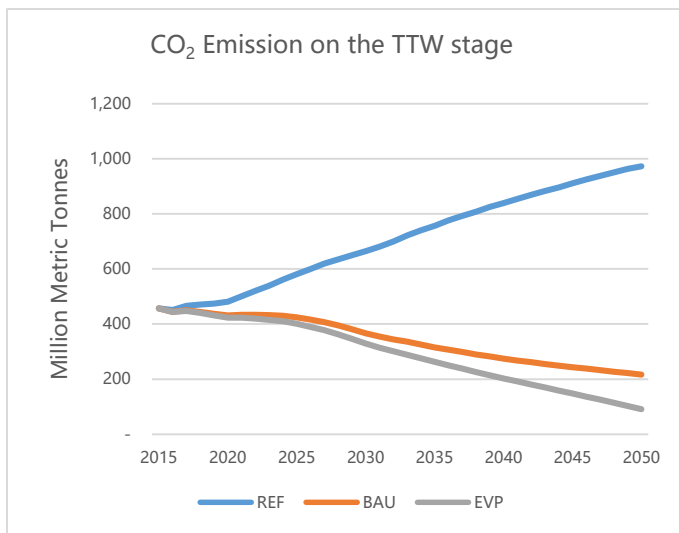

Fig 4　CO_2 Emission Under different scenario on TTW stage

2.5 Conclusions

The promotion of electric vehicles has the positive effect on direct CO_2 emission reduction in the whole country. Compare to the REF scenario, the BAU and EVP scenario can reduce the green house gas emission to 45% and 51% respectively in 2030 and can reduce the green house gas emission to 78% and 91% respectively on TTW stage in 2050.
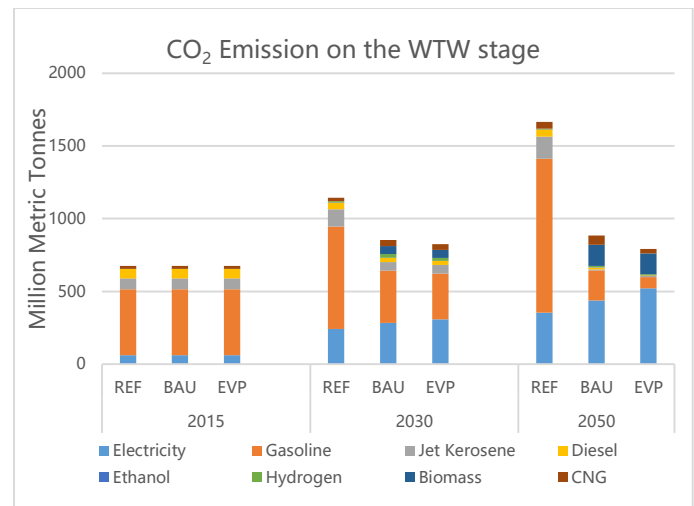

Fig 5　CO_2 Emission Under different scenario on WTW stage

REFERENCE

[1] Zhang L, Long R, Chen H, Geng J,A review of China's road traffic carbon emissions[J],Journal of Cleaner Production, 2019, Volume 207, Pages 569-581.

[2] Liu L , Wang K , Wang S , et al. Assessing energy consumption, CO2 and pollutant emissions and health benefits from China's transport sector through 2050[J]. Energy Policy, 2018, 116:382-396.

[3] Yi W, Zhu Y, Tian Z. Potential path and implementation effect of remaking energy in China's transportation sector [J]. China energy, 2017(1).

[4] Peng B , Du H , Ma S , et al. Urban passenger transport energy saving and emission reduction potential: A case study for Tianjin, China[J]. Energy Conversion and Management, 2015, 102:4-16.

[5] Peng T , Ou X , Yuan Z , et al. Development and application of China provincial road transport energy demand and GHG emissions analysis model[J]. Applied Energy, 2018, 222:313-328.

[6] Xianchun T , Yuan Z , Baihe G , et al. Scenario Analysis of Urban Road Transportation Energy Demand and GHG Emissions in China—A Case Study for Chongqing[J]. Sustainability, 2018, 10(6):2033-.

[7] A. Sadri, M.M. Ardehali, K. Amirnekooei,General procedure for long-term energy-environmental planning for transportation sector of developing countries with limited data based on LEAP (long-range energy alternative planning) and EnergyPLAN[J]. Energy, 2014, Volume 77, Pages 831-843.

[8] Wang H, Ou X, Zhang X,Mode, technology, energy consumption, and resulting CO2 emissions in China's transport sector up to 2050 [J]. Energy Policy,2017, Volume 109, Pages 719-733,

[9] Fan J L , Wang J X , Li F , et al. Energy demand and greenhouse gas emissions of urban passenger transport in the Internet era: A case study of Beijing[J]. Journal of Cleaner Production, 2017, 165.

[10] Peilin Li, Pengjun Zhao, Christian Brand,Future energy use and CO2 emissions of urban passenger transport in China: A travel behavior and urban form based approach[J].Applied Energy, 2018, Volume 211, Pages 820-842.

[11] Junling Liu, Xirui Chen, Haiwei Zhou, Ke Wang, Ji Zou, Ying Kong,A practical methodology to evaluate internationally consistent energy data for China's transport sector[J].Journal of Cleaner Production, 2019, Volume 239.

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