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Development and application of China provincial road transport energy demand and GHG emissions analysis model

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HIGHLIGHTS

- A provincial model for road transport energy demand and GHG emissions in China.
- China's vehicle stock will keep increasing and reach 540 million in 2050.
- EV can have great impact on road transport energy demand and GHG emissions.
- Future vehicle ownership and GHG emissions vary among Chinese provinces.

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ABSTRACT

Energy consumption and greenhouse gas (GHG) emissions of China's road transport sector have been increasing rapidly in recent years. Previous studies on the future trends trend to focus on the national picture and cannot offer regional insights. We build a novel bottom-up model to estimate the future energy demand and GHG emissions of China's road transport at a provincial level, considering local economic development, population and policies. Detailed technical characteristics of the future vehicle fleets are analyzed in several up-to date scenarios. The results indicate that China's vehicle stock will keep increasing to 543 million by 2050. The total direct petroleum demand and associated GHG emissions will peak at 508 million tonnes of oil equivalent (Mtoe) and 1500 million tonnes CO_2 equivalent (Mt $CO_{2,e}$) around 2030 in the Reference scenario. Natural gas vehicle diffusion has a large impact on petroleum demand reduction in the short term, with decreases of 41–46 Mtoe in 2050. Compared to the Reference case, battery electric and fuel cell vehicles will reduce petroleum demand by 94–157 and 28–54 Mtoe in 2050, respectively. When combined with decarbonization of future power supply, battery electric vehicles can play a significant role in reducing Well-to-Wheels GHG emissions in 2050 with 295–449 Mt $CO_{2,e}$ more reductions. The spatial distributions of future vehicle stock, energy demand and GHG emissions vary among provinces and show a generally downward trend from east to west. Policy recommendations are made in terms of the development of alternative fuels and vehicle technologies considering provincial differences, expansion of natural gas vehicle market and acceleration of electric vehicle market penetration.

1. Introduction

Road transport plays an important role in transport energy consumption and GHG emissions in the world. Globally, transport sector accounts for about one-fourth of the total fossil fuel CO_2 emissions with about three quarters of the transport sector CO_2 emissions incurred by road transport [1,2]. China has been the largest vehicle producer and consumer from 2008 and its road transport represents about 85% or more of transport sector energy consumption and GHG emissions [3]. Vehicle stock in China has risen from 26.9 million in 2004 to 162.8 million in 2015 with an average annual growth rate of more than 17%, and vehicle sales have risen from 5.1 million in 2004 to 24.6 million in 2015 with an average annual growth rate of 16% [4,5]. With the rapid growth of vehicle stocks, the energy demand and GHG emissions

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Nomenclature

E	elasticity between vehicle growth and GDP growth
EN	direct energy demand of road transport
EN_{WTW}	Well-to-Wheels energy demand of road transport
EM	direct greenhouse gas emissions of road transport
EM_{WTW}	Well-to-Wheels greenhouse gas emissions of road transport
P	population
$PGDP$	per capita gross domestic product
$Sale$	vehicle sale
S	survival ratio
vs	vehicle ownership (in numbers of 1000 people)
VS	vehicle stock

Greek symbol

α, β	curvature parameters related to Gompertz function

Subscripts

i	the studied province
j	vehicle type
k	vehicle fuel type
m	sold time of vehicle
t	calendar year

Abbreviations

AF	alternative vehicle fuel
BAU	business as usual
BD	bio-diesel
BE	bio-ethanol
CM	coal derived methanol
CTL	coal-to-liquids
CNG	compressed natural gas
CPREG	China Provincial Road Transport Energy Demand and GHG Emissions Analysis
$CO_{2,e}$	CO_2 equivalents
EV	electric vehicle
FCR	fuel consumption rate
FCV	fuel cell vehicle
GDP	gross domestic product
GHG	greenhouse gas
HT	heavy duty truck
ICE	internal combustion engine
ICEV	internal combustion engine vehicle
LC	low carbon
LNG	liquefied natural gas
LT	logistics truck
Mt	million tonnes
MT	medium duty truck
NB	non-urban transit bus
NG	natural gas
NGV	natural gas vehicle
PV	non-taxi passenger vehicle
REF	reference scenario
SAE-China	Society of Automotive Engineering of China
ST	sanitation truck
toe	tonne of oil equivalent
TV	taxi
UB	urban transit bus
VMT	vehicle miles traveled
WTW	Well-to-Wheels

associated with on-road vehicles have become a major challenge in China. About 90% of gasoline and 60% of diesel are consumed by road vehicles according to Ou et al. [6] and the growth rates of GHG emissions from road transport in China consistently exceed the rates of economic growth [7]. With sustained economic development and urbanization, China will continue to suffer from great pressure from energy conservation and emission reduction in road transport. The vehicle stock is expected to increase to 500–600 million in 2050 [8–10] from 192 million in 2016 [4] and GHG emissions from China's road transport will accounts for 12% of the national total in 2030 [11].

The Chinese government is seeking more effective policies to curb energy demand and reduce GHG emissions from road transport. To provide relevant recommendations for policy makers, studies estimating the future trends of energy demand and GHG emissions in China's road transport are highly necessary. Due to differences in population and level of socio-economic development, future trends of road transport development will vary significantly between provinces. Several polices at the national level have been introduced by Chinese government to promote energy conservation and emission reduction in road transport sector, including improving vehicle energy efficiency, enhancing the penetration of new energy vehicles and promoting alternative fuel. However, it would be more efficient and effective to provide province-specific policies considering geographical and socio-economic differences.

Bottom-up analysis is a widely used approach to forecasting energy demand and GHG emissions from road transport, by which many important factors such as the growth of vehicle stock, vehicle technology development, vehicle mileage travelled, fuel efficiency improvement and even policy measures can be analyzed in detail. Based on different bottom-up model, several studies have assessed the energy consumption and GHG emissions of road transport in different countries. Aggarwal et al. [12] analyzed the energy demand and CO_2 emissions in the Delhi region for 2021 under various scenarios. Palencia et al. [13] estimated the vehicle market composition and calculated the energy consumption and CO_2 emissions of Japan's passenger light-duty vehicle in the long term. Garcia et al. [14] projected the life-cycle GHG emissions of the Portuguese light-duty fleet by 2030 under four scenarios, especially focusing on the impact of battery electric vehicles.

Also, the energy demand and GHG emissions of China's road transport have been analyzed extensively in previous studies [3,6,10,11,15–20]. For example, He et al. [15] developed a bottom-up model to calculate the historical oil consumption and CO_2 emissions of road transport in China and forecast the future trends of vehicle population using an elasticity method. Hao et al. [16] employed a bottom-up model to project vehicle ownership and simulate energy consumption and GHG emission of the passenger vehicle fleet, and evaluated several key measures to realize fuel conservation and GHG emissions reduction through to 2050. Zhang et al. [17] evaluated the vehicles stocks using an elastic coefficient method and analyzed long-term fuel consumption of vehicles in China based on the LEAP modelling tool. Wu et al. [10] predicted the future vehicle stocks with Gompertz function and calculated vehicle energy demand through to 2050 in China. Ou et al. [6] used a bottom-up model based on future sales projection of all vehicle types to analyze the Well-to-Wheels (WTW) life-cycle energy demand and GHG emissions of China's future road transport. Using the same method, Gambhir et al. [11] calculated the CO_2 emissions of China's on road vehicles and conducted analysis on ways to reduce CO_2 emissions of China's road vehicles during the period of 2010–2050. Several studies conducted analysis of China's road transport using other methods. For instance, Chai et al. [18] studied the relevant factors