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Real-world fuel consumption and CO_2 (carbon dioxide) emissions by driving conditions for light-duty passenger vehicles in China

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ABSTRACT

The increasing discrepancy between on-road and type-approval fuel consumption for LDPVs (light-duty passenger vehicles) has attracted tremendous attention. We measured on-road emissions for 60 LDPVs in three China's cities and calculated their fuel consumption and CO_2 (carbon dioxide) emissions. We further evaluated the impacts of variations in area-averaged speed on relative fuel consumption of gasoline LDPVs for the UAB (urban area of Beijing). On-road fuel consumption under the average driving pattern is 10 ± 2% higher than that normalized to the NEDC (new European driving cycle) cycle for all tested vehicles, and the on-road NEDC-normalized fuel consumption is higher by 30 ± 12% compared to type-approval values for gasoline vehicles. We observed very strong correlations between relative fuel consumption and average speed. Traffic control applied to LDPVs driving within the UAB during weekdays can substantially reduce total fleet fuel consumption by 23 ± 5% during restriction hours by limiting vehicle use and improving driving conditions. Our results confirmed that a new cycle for the type approval test for LDPVs with more real-world driving features is of great necessity. Furthermore, enhanced traffic control measures could play an important role in mitigating real-world fuel consumption and CO_2 emissions for LDPVs in China.

1. Introduction

The total vehicle population in China has increased dramatically during the last few decades, from 5.5 million in 1990 to 109.4 million in 2012 (excluding motorcycles, electric bikes and rural trucks), due to China's substantial economic growth [37,39]. Nevertheless, total vehicle ownership per thousand people in China is still very low at 80 per 1000 people compared to ownership in developed countries (e.g., ~800 for the U.S., ~600 for Europe and Japan) as of 2011 [24,57]. Many studies forecast that the Chinese vehicle population will continue to increase to 360–540 million by 2030 [10,19,23,52,57]. This rapid growth, however, has brought about a series of problems including concerns about energy security, urban air pollution and traffic congestion. The great surge of oil consumption has caused China to increasingly largely depend on imported oil; the share of imported petroleum to total oil consumption reached 57% in 2011 [38]. On-road vehicles in China are estimated to consume 350–700 million toe (tons of oil equivalent) in 2030 and represent the main driver for China's future oil demand [10,16,19,25,41].

The energy security concern associated with rapid growth of the vehicle population pushed China's government to issue its first FES (fuel economy standard) for LDPVs (light-duty passenger vehicles) in 2004 [48,53]. The Phases I and II of FES implemented in 2006 and 2008 specified fuel consumption limits in liters per 100 km (l/100 km) under the NEDC (new European driving cycle) (i.e., type-approval fuel consumption) according to vehicle curb mass. Ref. [48] estimated that the Phases I and II fuel limits led to a sale-weighted average type-approval fuel consumption of 7.9 l/100 km for China's new LDPVs in 2009, compared to that of 9.1 l/100 km in 2002 [18]. However, the gap of on-road fuel economy between Chinese passenger cars and those in European and Japan apparently remains even though the first two phases of the fuel economy standards have been implemented [4,53]. China has made great efforts to continue tightening the limits of its vehicle fuel economy standard for LDPVs since 2008 [53]. In Jan 2010, the MIIT (Ministry of Industry and Information Technology of the P. R. China) has implemented a labeling policy, which requires each new LDPV to be

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Abbreviations

AQSIQ	Administration of Quality Supervision, Inspection and Quarantine of the P. R. China
Beijing EPB	Beijing Environmental Protection Bureau
BMSB	Beijing Municipal Statistics Bureau
BTRC	Beijing Transportation Research Center
CAERC	China Automotive Energy Research Center, Tsinghua Univeristy
CADC	the common Artemis driving cycles
CAFC	cooperate average fuel consumption
CATARC	China Automotive Technology and Research Center
EEA	European Environmental Agency
FES	fuel economy standard
GPS	global positioning system
GVW	gross vehicle weight
GZTPRI	Guangzhou Transport Planning Research Institute
HFID	heated flame ionization detector
IEA	International Energy Agency
IRF	International Road Federation
LDPV	light-duty passenger vehicle
LPG	liquefied petroleum gas
MIIT	Ministry of Industry and Information Technology of the P. R. China
MLIT	Ministry of Land, Infrastructure and Transport of Japan
NAFC	national average fuel consumption
NBSC	National Bureau of Statistics of P. R. China
NDIR	non-dispersive infrared analyzer
NEDC	new European driving cycle
PEMS	portable emission measurement system
toe	tons of oil equivalent
UAB	the urban area of Beijing
U.S. EPA	Environment Protection Agency of United States
VKT	vehicle kilometers traveled
VSP	vehicle specific power

labeled with the fuel consumption as obtained during testing under the NEDC in a laboratory. At the end of 2011, the Phase III limits of the FES for LDPVs were formally released [33]. These require a manufacturer to reduce its CAFC (cooperate average fuel consumption) of LDPVs by 3% annually from 2012 in order to achieve the goal of a NAFC (national average fuel consumption) that is 6.9 l/100 km (equivalent to ~165 g CO_2/km) by 2015 [2].

However, it is crucial to clarify that previous studies in Europe and China have identified the discrepancy between the type-approval fuel consumption over the NEDC and real-world fuel consumption [14,21,36,55] (see Table 1). Large-sample sets of data regarding on-road fuel consumption for LDPVs in Europe indicate that the average discrepancy between them rose from below 10% around 2000 to ~25% in 2011 [36]. Ref. [36] reported that increasing application of technologies that have higher benefits in type-approval tests than real-world conditions, increasing use of flexibility and tolerance in type-approval tests and increasing use of air conditioning over the past decade are most likely to be the main factors in that increased discrepancy. Furthermore, fuel consumption and CO_2 (carbon dioxide) emission factors of LDPVs become extremely high under low-speed congested traffic conditions [49]. This is important since in some of China's cities traffic congestion occurs with increasing frequency in the urban areas associated with the recent surge of LDPVs. In particular, the average speed during the rush hours within the urban areas is about 20 km/h for several highly vehicle-populated cities like Beijing and Guangzhou [8,15]. However, driving conditions are rarely noted in most of the previous estimates of fuel consumption by LDPVs [10,16] and [17,41,51]. Therefore, it is very necessary to address the impacts from driving conditions on real-world fuel consumption in a quantitative way.

This study aims to evaluate real-world fuel consumption and CO_2 emission factors for LDPVs in China, discuss the impacts from on-road driving conditions and further stress the importance of reducing fuel consumption through effective traffic measures. We collected on-road tests by a PEMS (portable emission measurement system) for 41 gasoline LDPVs, 16 diesel LDPVs and 3 LPG (liquefied petroleum gas) LDPVs. We conducted those tests on designed typical routes in three of China's cities, Guangzhou, Beijing and Macao. Our results can improve policy-makers' understanding of the role of real-world traffic conditions in influencing fuel consumption and CO_2 emissions of LDPVs.

2. Methodology

2.1. Experimental section

We tested 41 gasoline LDPVs, 16 diesel LDPVs and 3 LPG-fueled LDPVs on-road in this study. We conducted those on-road measurements in Guangzhou, Beijing and Macao between 2009 and 2011 (see Table S1 for detailed vehicle specification). Given that fuel consumption of vehicles in Mainland China operated over the NEDC improved as the fuel economy standard becomes more stringent, we further divided gasoline LDPVs tested in Guangzhou and Beijing into several groups according to the model year (see Table 2). It should be pointed out that, as one of the two Special Administrative Regions in China, China's national emission and fuel economy standards are not implemented for vehicles in Macao [20,54].

Table 1
Summary of the discrepancy between type-approval and on-road fuel consumption for LDPVs reported by previous studies.

Source	Type of on-road data	Country/region	Model year/fleet year	On-road fuel consumption vs. type-approval values over NEDC	Number of sampled vehicles
[21]	Drivers' online voluntary report	China	2009	115.5% on average (101–148%[a])	63,115
[36]	Record of leased vehicles	Germany	2006–2011	121% in 2006 to 133% in 2011	~15,000 per year
	Record of leased vehicles	Netherlands	2004–2011	111% in 2004 and 127 in 2011	~15,000 per year
	Drivers' online voluntary report	United Kingdom	2000–2011	103% in 2000 to 127% in 2011	~3000 per year
	On-road PEMS	United Kingdom	2011–2012	125% on average	134
	On-road fuel consumption measurement vs. laboratory test	Switzerland	1996–2012	100% in 1996 to 122% in 2012	~20 per year
[55]	On-road PEMS	Italy	2007–2012	124 ± 15%	7
[14]	Vehicle dynamics model and CO_2 monitoring database	Europe	2010	~120 to 125%	

[a] Discrepancy for 10 typical vehicle models representing 10% of China's car sales in 2009.

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