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An overview of energy efficiency standards in China's transport sector

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ABSTRACT

China's transport sector is facing severe energy and environmental challenges. Establishing energy efficiency standards is an essential measure to cope with these challenges. This paper comprehensively reviews the energy efficiency standards in China's road, water, aviation, railway and pipeline transport sectors. Based on the review, it is suggested that (1) the integrity of policy framework should be further improved. Energy efficiency standards-based market access qualification mechanism is quite necessary for all transport sectors, especially the aviation, railway and pipeline transport sectors, where such mechanism is absent. (2) Efforts for improving energy efficiency should be balanced among different transport sectors. Priority should be determined by considering each sector's energy consumption, the cost and potential of energy efficiency improvement, etc. Especially, the major energy-consuming sectors, such as heavy-duty vehicles should have similar priority to passenger vehicles in the overall energy efficiency improvement scheme. (3) The scientific basis for the energy efficiency standards should be enhanced. Policies should be proposed with full considerations of China's context, rather than borrowing the experiences of developed countries. Intelligence from the research community should be incorporated to ensure the rationality of the policies.

Contents

Abbreviations: AT, Automatic Transmission; BEV, Battery Electric Vehicle; BP, British Petroleum; CAAC, Civil Aviation Administration of China; CAFC, Corporate Average Fuel Consumption; CAIC, China Automobile Industry Corporation; CCC, China Compulsory Certification; CMIF, China Machinery Industry Federation; COP, Conference of the Parties; DWT, Deadweight Ton; EEDI, Energy Efficiency Design Index; FAW, First Auto Works; FCR, Fuel Consumption Rate; FCV, Fuel Cell Vehicle; FLT, Four-wheel Low-speed Truck; gce, gram of coal equivalent; GDP, Gross Domestic Production; GHG, Greenhouse Gas; GT, Gross Ton; GVW, Gross Vehicle Weight; HVAC, Heating, Ventilation, Air Conditioning; ICCT, International Council on Clean Transportation; IEA, International Energy Agency; kgce, kilogram of coal equivalent; MIIT, Ministry of Industry and Information Technology; MOR, Ministry of Railways; MOT, Ministry of Transport; MPV, Multi-Purpose Vehicle; NDRC, National Development and Reform Commission; NEA, National Energy Administration; NEDC, New European Driving Cycle; NRA, National Railway Administration; OEM, Original Equipment Manufacturer; PHEV, Plug-in Hybrid Electric Vehicle; SAIC, Shanghai Automotive Industry Corporation; STT, Semitrailer Towing Truck; SUV, Sport Utility Vehicle; tce, ton of coal equivalent; tkm, ton kilometer; TLT, Three-wheel Low-speed Truck; tnm, ton nautical mile; VCW, Vehicle Curb Weight; WTVC, World Transient Vehicle Cycle

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1. Introduction

Driven by the flourishing economy, China's energy consumption experienced rapid growth over the past decades, increasing from 0.57 billion tce (ton of coal equivalent) in 1978 to 4.26 billion tce in 2014 [1]. Accordingly, energy-related CO_2 emissions increased from 0.83 billion ton in 1971 to 8.98 billion ton in 2013 [2], as Fig. 1 shows. China's primary energy consumption accounted for 23% of global total in 2014 [3], and energy-related CO_2 emissions accounted for 28% of global total in 2013 [2]. This fast growth in energy consumption has caused great concerns over China's energy security, environmental protection and climate change mitigation. Under such a circumstance, China has made great efforts in reducing energy consumption and CO_2 emissions. In the 15th Conference of the Parties (COP15), China announced the target that CO_2 emissions intensity (measured in CO_2 emissions per GDP output) in 2020 declines by 40–45% compared with the 2005 level [4]. As a decomposition to this target, China set the targets of reducing energy intensity (measured in energy consumption per GDP output) by 20% and 16% in its eleventh and twelfth five-year planning periods, and reducing CO_2 emissions intensity by 17% in its twelfth five-year planning period, respectively [5,6]. The most recent target is from the 'U.S.–China Joint Announcement on Climate Change', in which China promises to peak its total CO_2 emissions before 2030, and to make best efforts to peak early [7].

Transport sector is a major energy-consuming and Greenhouse Gas (GHG)-emitting sector. Globally, transport sector is responsible for around half of total petroleum consumption [8]. As estimated by IEA, CO_2 emissions from transport sector accounted for 23% of total energy-related CO_2 emissions in 2013 [2]. In China, this share is relatively lower at the level of 8.9% [2]. This can be mainly attributed to China's low motorized transport level. For example, China's passenger vehicle ownership level was only 113 vehicles/1000 people in 2014 [9], much lower than the global average, especially compared with the developed countries [10]. With the rapid growth in motorized transport demand, especially the private vehicle transport demand, energy consumption and CO_2 emissions are expected to increase further in the coming decades [11–14].

Reducing energy consumption and GHG emissions can be realized through multiple pathways. In the transport sector, the rationale of reducing GHG emissions is often interpreted by using the 'ASIF' decomposition approach [15]. Under this approach, GHG emissions are decomposed into transport activity (A), transport structure (S), energy intensity (I), and fuel carbon intensity (F). Accordingly, GHG emissions abatement can be realized through reducing transport activity, improving transport structure, reducing energy intensity (or in other words, improving energy efficiency), or reducing fuel carbon intensity. Among all the measures, improving energy efficiency is the most essential one. The essence of energy efficiency improvement is to do the same work by using less energy, which is normally realized through the update of energy utilization facility, and accompanied by higher facility cost and lower energy cost [16,17]. In the 'Twelfth Five-year Plan for Energy Conservation and Emissions Reduction', China specified the energy efficiency targets for major energy-consuming sectors and facilities, including the transport sector, as Table 1 shows [18].

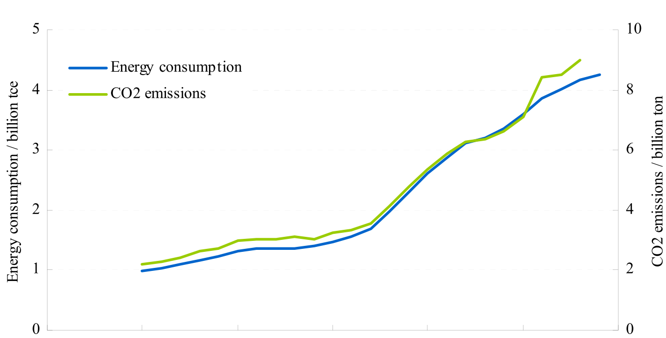

Fig. 1. China's historical energy consumption and energy-related CO_2 emissions.

Establishing energy efficiency standards, or typically fuel consumption, fuel economy or CO_2 emissions standards, is the essential measure to improve energy efficiency in the transport sector. As demonstrated by existing studies, fuel economy standards play a more substantial role in improving fuel economy of new cars, compared with gasoline price [19]. The energy efficiency standards show significant disparity in different regions (China, U.S., EU, Japan, etc.) and sectors (transport, building, industry, etc.) [20–24]. Among all regions and sectors, China's transport sector is quite representative when analyzing the energy efficiency standards. With more and more energy efficiency standards established and updated in China's transport sector, it is necessary to conduct a comprehensive review on the energy efficiency standards and the resulting energy efficiency performances.

In this review, the energy efficiency standards in China's transport sector, including the road, water, aviation, railway, and pipeline transport sectors are comprehensively reviewed. It should be noted that the scope of this review is limited to the energy efficiency standards for the passenger and freight carrying facilities in the transport sector, including road vehicles, vessels, civil aircrafts, locomotives, and pipelines. The energy efficiency standards for transport infrastructures, such as ports, railway stations and airports, are not covered in this review. This review contributes to (1) empirically summarizing and analyzing the energy efficiency standards in China's transport sector, which to our knowledge has not been conducted before; (2) theoretically establishing the methodology for evaluating and comparing different energy efficiency standards, which can be used to conduct energy efficiency studies in other sectors. The whole paper is organized as follows. After this introduction section, the energy efficiency standards in the road (including passenger vehicles, light-duty commercial vehicles, heavy-duty vehicles, low-speed trucks and motorcycles), water, aviation, railway, and pipeline sectors are respectively reviewed. Following that, policy implications are raised. The final section concludes the whole review.

Table 1
Energy efficiency targets specified in the 'Twelfth Five-year Plan for Energy Conservation and Emissions Reduction'.

Sector	Indicator	Unit	2010	2015	Change
Industry	Energy consumption per industrial added value	%			−21%
	Thermal power generation efficiency	gce/kWh	333	325	−2%
	Thermal power plant auxiliary power ratio	%	6.33	6.2	−2%
	Line loss rate	%	6.53	6.3	−4%
	Steel production	kgce/t	605	580	−4%
	Aluminum ingot production	kWh/t	14,013	13,300	−5%
	Copper production	kgce/t	350	300	−14%
	Crude oil processing	kgce/t	99	86	−13%
	Ethylene production	kgce/t	886	857	−3%
	Synthesis ammonia production	kgce/t	1402	1350	−4%
	Ionic membrane production	kgce/t	351	330	−6%
	Cement clinker production	kgce/t	115	112	−3%
	Plate glass production	kgce/case	17	15	−12%
	Paper and paperboard production	kgce/t	680	530	−22%
	Pulp production	kgce/t	450	370	−18%
	Ceramic production	kgce/t	1190	1110	−7%
Building	Transformed area in northern regions with heating provision	million sqm	180	580	222%
	Green building standards execution rate in new buildings	%	1	15	1400%
Transport	Railway transport	tce/million converted tkm	5.01	4.76	−5%
	Road transport	kgce/100 tkm	7.9	7.5	−5%
	Water transport	kgce/1000 tkm	6.99	6.29	−10%
	Aviation transport	kgce/tkm	0.450	0.428	−5%
Public institution	Energy consumption per unit area	kgce/sqm	23.9	21	−12%
	Energy consumption per capita	kgce/capita	447.4	380	−15%
End-use facilities	Coal-fired industrial boiler	%	65	70–75	12%
	Three-phase asynchronous motor	%	90	92–94	3%
	Air compressor input specific power	kW/(sqm/min)	10.7	8.5–9.3	−17%
	Power transformer loss	kW	No load: 43 Full load: 170	No load: 30–33 Full load: 151–153	No load: −27% Full load: −11%
	Passenger vehicle fuel consumption rate	L/100 km	8	6.9	−14%
	Air conditioner energy efficiency ratio	–	3.3	3.5–4.5	21%
	Refrigerator energy efficiency index	%	49	40–46	−12%
	Gas water heater thermal efficiency	%	87–90	93–97	7%

2. Energy efficiency standards

Currently, most of China's transport sectors have established their own energy efficiency standards or energy efficiency related technical standards. These standards are different in term of rationale, measurements, and enforcement methods, as summarized in Table 2.

2.1. Road transport

2.1.1. Passenger vehicles

In China, passenger vehicles are defined as passenger-carrying vehicles with 9 seats or fewer [25]. By vehicle utility, passenger vehicles can be further categorized into passenger cars, Sport Utility Vehicles (SUV), Multi-Purpose Vehicles (MPV) and cross-over vehicles. China's passenger vehicle market boomed over recent years, with total sales increasing from 1.2 million in 2000 to 21.1 million in 2015 [9]. It was estimated that GHG emissions from China's passenger vehicles accounted for around 5% of China's total GHG emissions in 2014 [26]. Under such a circumstance, regulating the energy efficiency of passenger vehicles is an essential task for China's policy makers. China's fuel consumption standards for passenger vehicles are proposed and enforced by Ministry of Industry and Information Technology (MIIT). Till now, four phases of standards have been implemented [27–30].

2.1.1.1. Fuel consumption standards by MIIT

2.1.1.1.1. Standards. The fuel consumption standards for passenger vehicles are Vehicle Curb Weight (VCW)-based, with the whole VCW range divided into sixteen segments. Each VCW segment is specified with a different Fuel Consumption Rate (FCR) limit or target, measured in L/100 km. Accordingly, the whole FCR limits and targets spectrum shows a ladder pattern. The FCR limits and targets from phase I to phase IV standards are illustrated in Fig. 2. Phase III and phase IV standards are expected to reduce China's fleet average FCR of new passenger vehicles to 6.9 L/100 km in 2015 and 5.0 L/100 km in 2020, respectively. Vehicles with certain configurations, such as Automatic Transmission (AT) and three-row seats, qualify for looser FCR limits and targets.

For phase I and II standards, only FCR limits are specified, which are compared on single vehicle model basis. Since phase III standards, the concept of Corporate Average Fuel Consumption (CAFC) is incorporated. The target CAFC and actual CAFC of a certain Original Equipment Manufacturer (OEM) is calculated and compared by using Eqs. (1) and (2). By specifying both FCR limits and targets, FCR is measured and compared both on vehicle model level and corporate level.

$$T_{CAFC} = \frac{\sum_i T_i \cdot V_i}{\sum_i V_i} \tag{1}$$

$$CAFC = \frac{\sum_i FC_i \cdot V_i}{\sum_i V_i} \tag{2}$$

where T_{CAFC} is the CAFC target; $CAFC$ is the actual CAFC; T_i is the FCR target for vehicle model i; FC_i is the actual FCR of vehicle model i; V_i is the production, import or sales of vehicle model i.

The term 'corporate' here refers to one single OEM. Different domestic OEMs are not allowed to calculate their CAFC as one entity, even if they are oriented from the same foreign OEM, such as First Auto Works (FAW)-Volkswagen and Shanghai Automotive

Table 2
Summarization of China's fuel consumption standards for different transport sectors.

Category	Sub-category	Competent authority	Effective period	Constraints	Unit	Segment basis	Standards	Measurement
Road transport	Passenger vehicles	MIIT	2005-2007 (Phase I)	FCR Limits	L/100 km	VCW	GB 19578-2004	GB/T 19233-2003
			2008-2011 (Phase II)	FCR Limits	L/100 km	VCW	GB 19578-2004	GB/T 19233-2003
			2012-2015 (Phase III)	FCR limits CAFC targets	L/100 km L/100 km	VCW VCW	GB 19578-2004 GB 27999-2011	GB/T 19233-2003 GB/T 19233-2008
			2016-2020 (Phase IV)	FCR limits CAFC targets	L/100 km L/100 km	VCW VCW	GB 19578-2014 GB 27999-2014	GB/T 19233-2008 GB/T 19233-2008
	Light-duty commercial vehicles	MIIT	2009-2010 (Phase I)	FCR Limits	L/100 km	GVW+engine displacement	GB 20997-2007	GB/T 19233-2003
			2011-2017 (Phase II)	FCR Limits	L/100 km	GVW+engine displacement	GB 20997-2007	GB/T 19233-2003
			From 2018 on (Phase III)	FCR Limits	L/100 km	VCW	GB 20997-XXXX (under discussion)	GB/T 19233-2008
	Heavy-duty vehicles	MOT	From 2008 on	FCR Limits	L/100 km	GVW (trucks) Vehicle length (buses)	JT 711—2008 JT 719-2008	JT 711—2008 JT 719-2008
		MIIT	2012-2014	FCR Limits	L/100 km	GVW	GB/T 27840-2011	GB/T 27840-2011
			From 2014 on	FCR Limits	L/100 km	GVW	GB 30510-2014	GB/T 27840-2011
	Low-speed trucks	CMIF	2008-2015	FCR Limits	L/100 km	GVW	GB 21377-2008 GB 21378-2008	GB 21377-2008 GB 21378-2008
			From 2015 on	FCR Limits	L/100 km	GVW	GB 21377-2015 GB 21378-2015	GB 21377-2015 GB 21378-2015
	Motorcycles	CAIC	1995-2008	FCR Limits	L/100 km	Engine displacement	GB/T 15744-1995	GB 5377-85 GB 16486-1996
		NDRC	From 2008 on	FCR Limits	L/100 km	Engine displacement	GB 15744-2008 GB 16486-2008	GB 14622-2007 GB 18176-2007
Water transport	Vessels	MOT	From 2012 on	FCR limits CER limits	g fuel/tnm g CO_2/tnm	DWT DWT	JT/T 826-2012 JT/T 827-2012	JT/T 826-2012 JT/T 827-2012
		MIIT	From 2013 on	EEDI reference line	g CO_2/tnm	DWT (freight vessel) GT (passenger vessel)	GB/T 30008-2013	GB/T 30009-2013

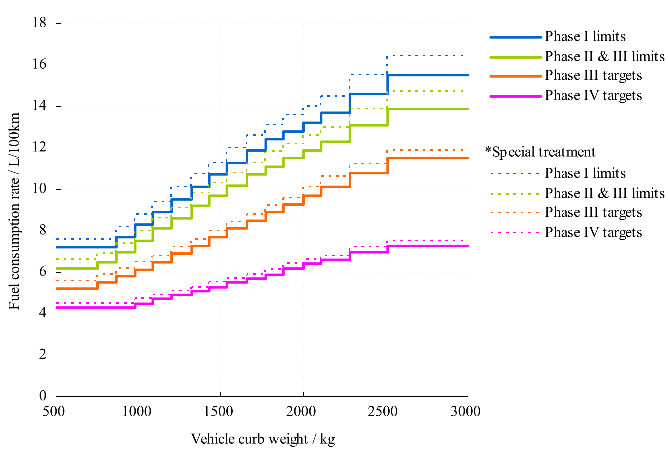

Fig. 2. FCR limits and targets under China's four-phase fuel consumption standards for passenger vehicles. Notes: (1) Special treatment is for vehicles with AT, three or more-row seats under phase I, II and III standards; three or more-row seats under phase IV standards; (2) Phase IV limits are the same with phase III targets.

Industry Corporation (SAIC)-Volkswagen.

As it takes 2–3 years to introduce one new vehicle model, the standards establish a buffer mechanism. OEMs are not required to immediately comply with the CAFC targets. Instead, OEMs are required to comply with a series of actual/target CAFC ratios, which are 109%, 106%, 103% and 100% for the four years of phase III standards implementation, and 134%, 128%, 120%, 110% and 100% for the five years of phase IV standards implementation. The ratios are higher than 100% in the early years of standards implementation, which provides enough buffer time for the OEMs to introduce new vehicle models to comply with the standards.

From phase I to phase IV standards, the FCR limits and targets are tightened with different rates. The average FCR decrease rate is 10.0% from phase I to phase II&III limits, 18.7% from phase II&III to phase IV limits, and 30.1% from phase III to phase IV targets, showing an accelerating update of stringency. The stringencies for different VCW segments also differ a lot. From phase I to phase II standards, the FCR limits for each VCW segment decrease with very similar rates. However, from phase III to phase IV standards, the FCR targets for higher VCW segments decrease with significantly higher rates. For example, the FCR target for the 750 kg or lower segment decreases for 17.3%, while 2510 kg or higher segment for 36.5% from phase III to phase IV standards. In other words, passenger vehicles with higher VCW face higher FCR improvement pressures. This reflects the rationale of the standards to promote vehicle downsizing.

Globally, ten countries have established their own fuel consumption or fuel economy standards for passenger vehicles. These standards are different in terms of rationale and measurement methods. International Council on Clean Transportation (ICCT) compared the stringency of the standards among different countries by normalizing the measurement methods, as Fig. 3 shows [31,32]. It turns out that the stringency of China's fuel consumption standards for passenger vehicles is falling behind the EU, Japan and South Korea standards, but ahead of other major countries.

2.1.1.1.2. Measurement. As specified by the national standards [33,34], FCR of passenger vehicles is tested under the New European Driving Cycle (NEDC), which is borrowed from the EU regulation. On top of the general calculation, credits are available for certain technologies [35]. (1) Energy-saving and new energy vehicles qualify for magnification coefficients. Specifically, Battery Electric Vehicles (BEV), Fuel Cell Vehicles (FCV), Plug-in Hybrid Electric Vehicles (PHEV) with electric range of 50 km or higher are treated as zero fuel consumption vehicles, and are accounted into

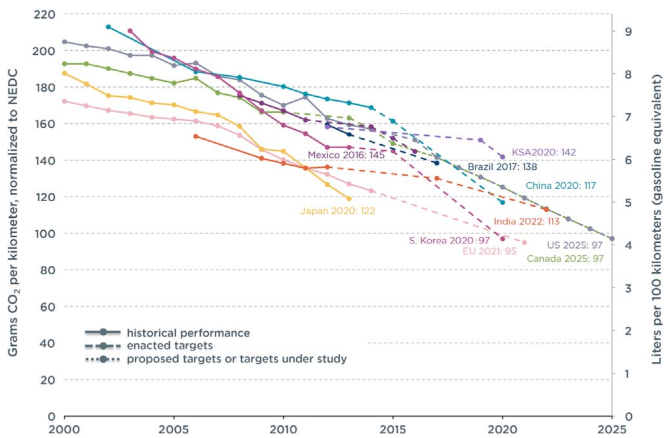

Fig. 3. Comparison of global fuel consumption standards for passenger vehicles (adapted from Ref. [32]).

the fleet with a magnification coefficient of 5; Vehicles with FCR of 2.5 L/100 km or lower are accounted into the fleet with a magnification coefficient of 3. (2) Certain off-cycle technologies qualify for fuel consumption accounting credits. The qualified off-cycle technologies are not specified in the current standards, but will be specified later with other supplementary documents. The accumulated fuel consumption accounting credits should not be higher than 0.5 L/100 km.

2.1.1.1.3. Enforcement. The enforcement of fuel consumption standards for passenger vehicles is mainly based on market access approval. Specifically, one vehicle model can not get the license to enter the market from MIIT if it fails to comply with the FCR limits. On the OEM level, there are a series of punishments for an OEM if it fails to meet its own CAFC target [36], including negative publicity, halting new product license, halting capacity expansion, more stringent supervision on production compliance, etc. The CAFC credit trading system is under discussion and might become an important part of the enforcement system in the coming years.

2.1.2. Light-duty commercial vehicles

In China, light-duty commercial vehicles are defined as vehicles with Gross Vehicle Weight (GVW) of 3500 kg or lower (excluding passenger vehicles). Although the sales of light-duty commercial vehicles are not as high as passenger vehicles, their average use-intensity is much higher. Therefore, the government also put great efforts in improving the energy efficiency of light-duty commercial vehicles. China started to implement the fuel consumption standards for light-duty commercial vehicles in 2008. Till now, phase I and II standards have been implemented, with phase III standards under discussion. The standards are also proposed and enforced by MIIT.

2.1.2.1. Fuel consumption standards by MIIT

2.1.2.1.1. Standards. Different from passenger vehicle standards, the phase I and phase II light-duty commercial vehicle standards are GVW and engine displacement-based, rather than VCW based, as Fig. 4 shows [37]. FCR limits are individually specified for passenger/freight, and gasoline/diesel vehicles. However, during the implementation of the standards, it was found that using GVW and engine displacement as the basis for setting FCR limits might create considerable motivation for the OEMs to manipulate the specifications of their products to comply with the standards. Thus, the phase III standards were intended to become VCW-based, with the same VCW segments as the passenger vehicle standards, as Fig. 5 shows [38]. For all three phases of standards, only FCR limits are specified. The CAFC mechanism in the passenger vehicle standards was not incorporated. Averagely, the FCR

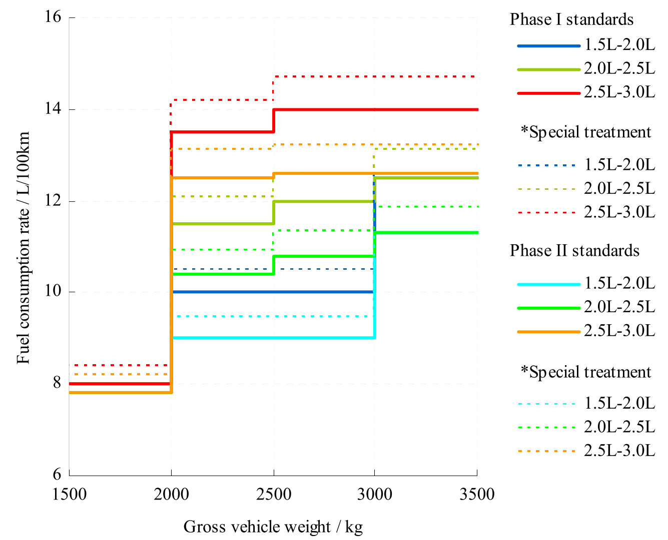

Fig. 4. Phase I and II fuel consumption standards for light-duty commercial vehicles. Notes: (1) Only FCR limits for gasoline freight-carrying light-duty commercial vehicles within three engine displacement segments (1.5–2.0 L, 2.0–2.5 L, 2.5–3.0 L) are illustrated here; (2) Special treatment is for fully closed vans, tank trucks, AT and all-wheel drive vehicles.

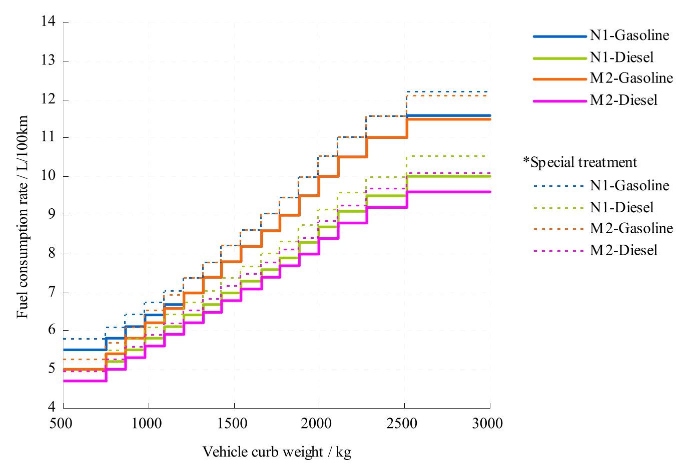

Fig. 5. Phase III fuel consumption standards for light-duty commercial vehicles (under discussion). Notes: (1) N1 vehicles refer to freight-carrying light-duty commercial vehicles; M2 vehicles refer to passenger-carrying light-duty commercial vehicles; (2) Special treatment is for fully closed vans, tank trucks, and all-wheel drive vehicles.

limits are reduced by 7.8% from phase I to phase II standards.

2.1.2.1.2. Measurement. The FCR testing method for light-duty commercial vehicles is the same with the method for passenger vehicles. Currently, no credit is available for advanced vehicle technologies. The actual FCRs of all vehicle models are directly compared with FCR limits on vehicle model basis.

2.1.2.1.3. Enforcement. The enforcement of fuel consumption standards for light-duty commercial vehicles is also based on market access approval [39]. Vehicle models failing to comply with the FCR limits can not get the license to enter the market.

2.1.3. Heavy-duty vehicles

Heavy-duty vehicles are defined as vehicles with GVW of higher than 3500 kg. Most heavy-duty vehicles are used for commercial purposes, such as long-distance logistics, intercity freight/passenger transport, urban transit, etc. Therefore, their FCR and use-intensity are significantly higher than light-duty vehicles. It was estimated that GHG emissions from road freight transport, which are mostly undertaken by heavy-duty trucks, accounted for

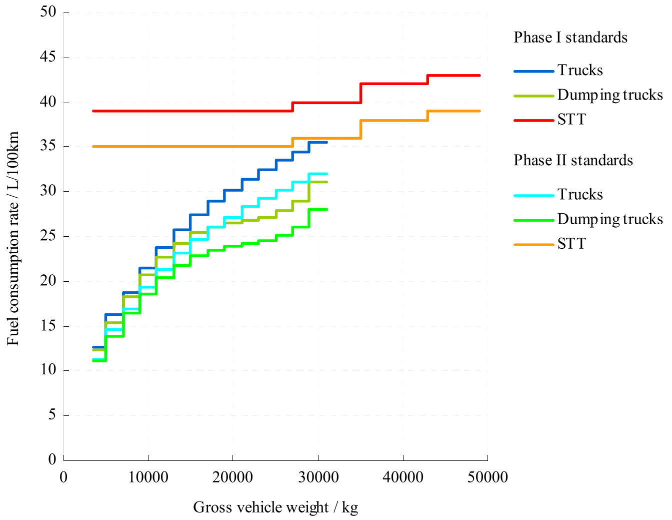

Fig. 6. MOT fuel consumption standards for heavy-duty trucks. Notes: (1) Only FCR limits for diesel vehicles are illustrated here; (2) FCR limits for gasoline vehicles are specified to be 1.15 times the limits for diesel vehicles.

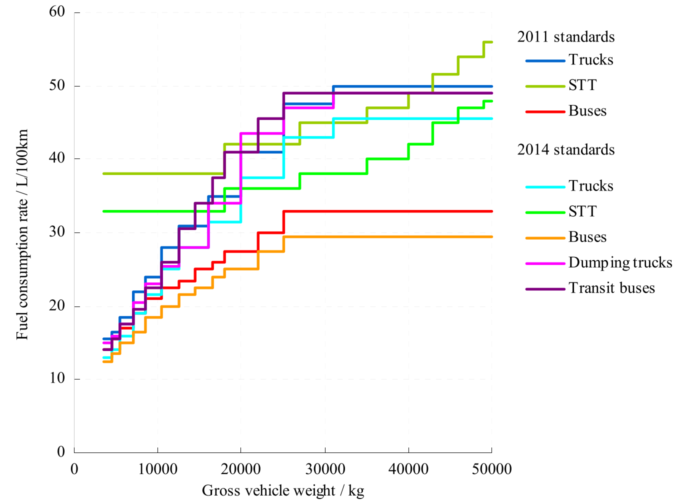

Fig. 8. MIIT fuel consumption standards for heavy-duty vehicles. Notes: (1) Only FCR limits for diesel vehicles are illustrated here; (2) FCR limits for gasoline vehicles are specified to be 1.3 times the limits for diesel vehicles under the 2011 standards, 1.2 times the limits for diesel vehicles under the 2014 standards.

77% of total GHG emissions from China's freight transport sector in 2013 [40]. To address the energy efficiency issues of heavy-duty vehicles, both Ministry of Transport (MOT) and MIIT have announced their own fuel consumption standards for heavy-duty vehicles. These two sets of standards are different in terms of scope, FCR limits, and measurement methods.

2.1.3.1. Fuel consumption standards by MOT

2.1.3.1.1. Standards. MOT implemented the fuel consumption standards for heavy-duty vehicles in 2008 [41,42]. The MOT standards cover only vehicles operating for commercial purposes. The FCR limits are GVW-based for heavy-duty trucks and vehicle length-based for heavy-duty buses, as Figs. 6 and 7 show. The FCR limits are specified for trucks, dumping trucks, semitrailer towing trucks and buses, respectively. The FCR limits for gasoline vehicles are specified to be 1.15 times the limits for diesel vehicles.

2.1.3.1.2. Measurement. As commercial vehicles mainly operate on intercity highways rather than urban roads, the MOT standards employ a series of constant-speed driving conditions to reflect the characteristics of highway drive. Specifically, FCR is firstly tested under several constant-speed driving conditions. The nominal FCR is the weighted average of the tested FCRs, as Eq. (3) shows.

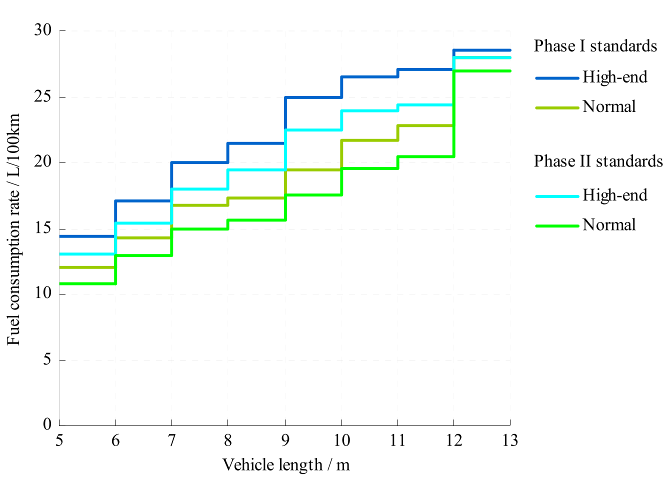

Fig. 7. MOT fuel consumption standards for heavy-duty buses. Notes: (1) Only FCR limits for diesel vehicles are illustrated here; (2) FCR limits for gasoline vehicles are specified to be 1.15 times the limits for diesel vehicles.

$$Q = \sum_i (\overline{Q_{oi}} \cdot k_i) \tag{3}$$

where Q is the nominal FCR (L/100 km); $\overline{Q_{oi}}$ is the adjusted FCR under constant-speed driving condition i (L/100 km); k_i is the weight coefficient for constant-speed driving condition i.

2.1.3.1.3. Enforcement. Different from the MIIT standards, The enforcement of the MOT standards is based on commercial operation approval [43]. Vehicles failing to comply with the MOT standards can not get the license to operate for commercial purposes.

2.1.3.2. Fuel consumption standards by MIIT

2.1.3.2.1. Standards. MIIT established the fuel consumption standards for heavy-duty vehicles in 2011, which was initially treated as recommended industrial standards [44]. The standards are GVW-based, with ladder pattern FCR limits. As Fig. 8 shows, the FCR limits are specified for trucks (excluding dumping trucks), semitrailer towing trucks, and buses (excluding urban transit buses), respectively. The FCR limits for gasoline vehicles are specified to be 1.3 times the limits for diesel vehicles. In 2014, the standards were updated to become compulsory national standards [45]. The major difference between the two standards is that the FCR limits are more stringent with around 10–14% reductions. Besides, the scope of the standards is extended to cover dumping trucks and urban transit buses.

2.1.3.2.2. Measurement. The test cycle employed by the current standards is based on the World Transient Vehicle Cycle (WTVC) with some adjustments [46]. As the WTVC test cycle can not well reflect the actual driving condition of heavy-duty vehicles in China, the government is considering establishing China's own test cycle for heavy-duty vehicles. It should be noted that although the test cycles specified by MIIT and MOT standards are different, these two authorities recognize some common testing bodies. OEMs can choose to have the FCR of their heavy-duty vehicles tested in the common testing bodies using the same sample vehicle with combined testing procedure.

2.1.3.2.3. Enforcement. Same with other MIIT standards, the enforcement of the MIIT fuel consumption standards for heavy-duty vehicles is based on market access approval. Heavy-duty vehicles failing to meet the FCR limits can not get the license to enter the market.

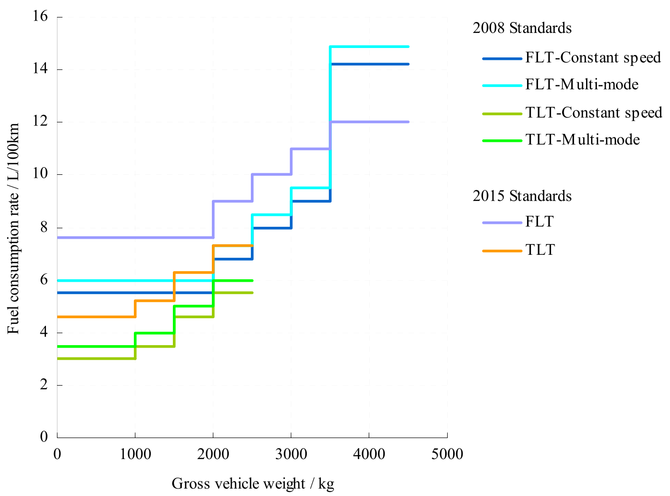

Fig. 9. Fuel consumption standards for low-speed trucks. Notes: (1) Only FCR limits for the certification of multi-cylinder vehicles are illustrated here.

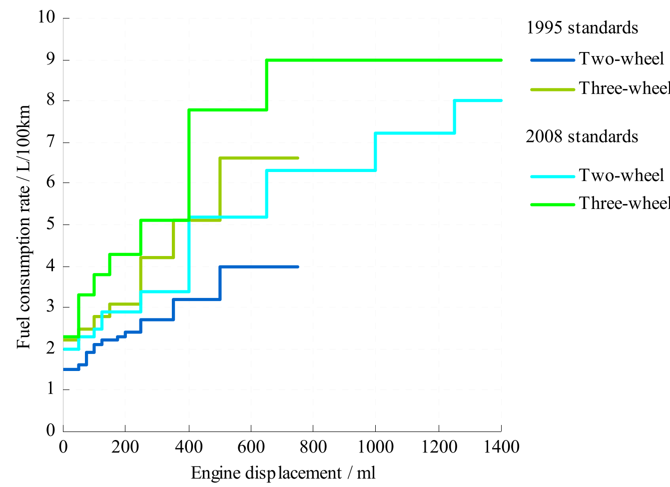

Fig. 10. Fuel consumption standards for motorcycles. Notes: (1) Regarding the 1995 standards, only FCR limits for four-stroke motorcycles are illustrated here.

2.1.4. Low-speed trucks

Low-speed trucks can be further categorized into four-wheel low-speed trucks (with maximum speed of 70 km/h or lower) and three-wheel low-speed trucks (with maximum speed of 50 km/h or lower) [47]. The low-speed trucks are mainly used in China's rural areas, with an estimated stock of 20–25 million in 2014. The energy efficiency of low-speed trucks is under the administration from China Machinery Industry Federation (CMIF).

2.1.4.1. Fuel consumption standards by CMIF

2.1.4.1.1. Standards. CMIF established the fuel consumption standards for low-speed trucks in 2008 [48,49]. The standards are GVW-based, with ladder pattern FCR limits. FCR limits are specified for single-cylinder and multi-cylinder trucks, respectively. Besides, as the FCR is regulated to be tested under two different test cycles, two sets of FCR limits are specified for the two test cycles. In 2015, the standards were updated [50,51]. The major change is that the previous two test cycles are replaced by one new test cycle. Accordingly, only one set of FCR limits are specified in the updated standards, as Fig. 9 shows. Because of the changes of test cycles, the FCR limits in the 2015 standards are generally higher than the FCR limits in the 2008 standards.

2.1.4.1.2. Measurement. In the 2008 standards, FCR is tested under two different test cycles, including one test cycle comprising several constant-speed driving conditions and one multi-mode test cycle. The tested FCRs are compared with the two sets of FCR limits, respectively [48,49]. In the 2015 standards, a new multi-mode test cycle is used, which is required to be tested on the dynamometers [50,51].

2.1.4.1.3. Enforcement. Similar to other standards, the enforcement of fuel consumption standards for low-speed trucks is realized through market access approval [52]. Vehicles failing to comply with the standards can not be licensed to enter the market.

2.1.5. Motorcycles

In China, motorcycles are defined as motor vehicles using handle bar to steer, normally with engine displacement of higher than 50 ml. Motorcycles with engine displacement of 50 ml or lower are normally referred to as mopeds. China has a huge motorcycle stock, which reached 90 million in 2015 [1]. In the early years before the mass penetration of passenger vehicles, motorcycles were the major way of motorized transport. China established the fuel consumption standards for motorcycles in as early as 1995 [53], which is far earlier than the establishment of passenger vehicles standards.

2.1.5.1. Fuel consumption standards by CAIC

2.1.5.1.1. Standards. The 1995 standards were proposed and enforced by the former China Automobile Industry Corporation (CAIC). The standards were designed to be engine displacement-based, with individual FCR limits for motorcycles with different strokes (two-stroke and four-stroke) and structures (two-wheel, regular three-wheel, side three-wheel and scooter). The FCR limits are presented in Fig. 10. The standards were updated in 2008, with very significant changes in the rationale and stringency [54,55]. The engine displacement segments are changed by referring to the fuel consumption standards for motorcycles in Taiwan. Besides, as most of the motorcycle models in China were equipped with four-stroke engines at that time, the FCR limits for two-stroke and four-stroke motorcycles are combined as one set of limits. It should be noted that although the 2008 standards are much more stringent than the 1995 standards, the FCR limits in the 2008 standards are generally higher than the FCR limits in the 1995 standards due to the changes in test cycles.

2.1.5.1.2. Measurement. In the 1995 standards, FCR is tested under a few constant-speed driving conditions. The lowest FCR is chosen as the nominal FCR [56,57]. In the 2008 standards, FCR is tested under one multi-mode test cycle and one constant-speed test cycle. The nominal FCR is the weighted average of the two tested FCRs, as Eq. (4) shows [58,59].

$$FC = 0.6 \cdot FC_I + 0.4 \cdot FC_{II} \quad (4)$$

where FC is the nominal FCR (L/100 km); FC_I is the FCR under multi-mode test cycle (L/100 km); FC_{II} is the FCR under the specified constant-speed driving condition (L/100 km).

2.1.5.1.3. Enforcement. The enforcement of the fuel consumption standards for motorcycles is based on China Compulsory Certification (CCC). To comply with the standards is the necessary condition to apply for CCC [60].

2.2. Water transport

By utility, vessels can be categorized in to bulk carriers, container ships, oil/gas tankers, etc. By operating area, vessels can be categorized into inland waterway, coastal and ocean vessels. The number of vessels in China reached 0.17 million in 2014 [61]. CO_2 emissions by freight shipping were estimated to account for around 12% of total CO_2 emissions from China's freight transport sector in 2012 [62]. Similar to the heavy-duty vehicles, the energy

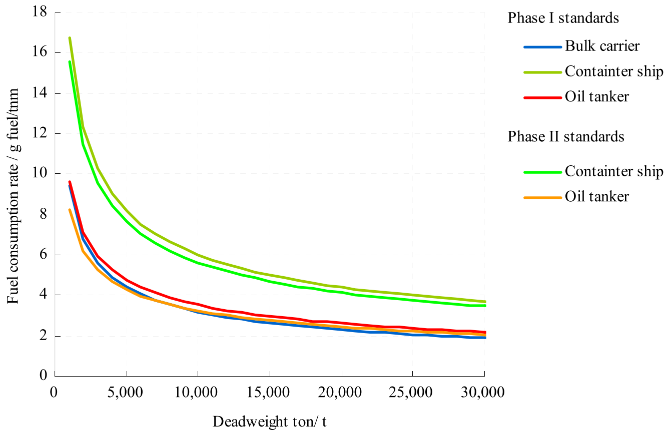

Fig. 11. MOT fuel consumption standards for vessels. Notes: (1) Only FCR limits for coastal vessels are illustrated here; (2) The FCR limits for bulk carriers are the same under phase I and phase II standards.

efficiency of vessels in China is regulated by two competent authorities, MOT and MIIT. These two authorities both established their own fuel consumption standards for vessels.

2.2.1. Fuel consumption and CO_2 emissions standards by MOT

2.2.1.1. Standards. MOT established fuel consumption and CO_2 emissions standards for commercial vessels in 2012 [63,64]. The standards use Deadweight Ton (DWT) as the basis for calculating FCR/CO_2 emissions rate (CER) limits, which are measured in g fuel/tnm (ton nautical mile) and g CO_2/tnm, respectively. Different from the standards in the road transport sector, the fuel consumption standards for vessels do not use ladder-pattern FCR/CER limits. Instead, a power function is employed to describe the relationship between FCR/CER limits and DWT, as Eq. (5) shows. Figs. 11 and 12 illustrate the FCR and CER limits specified by the standards. It should be noted that, as the measurement of FCR/CER uses freight transport volume (measured in tnm) as the denominator, the FCR/CER decreases as DWT increases. This is different from the standards using distance as the denominator to measure FCR. The standards specify different parameters for vessels with different utilities and operating areas.

$$LimitFC = a \cdot DWT^{-c} \tag{5}$$

where *LimitFC* is the FCR limit for the vessel (g fuel/tnm); *DWT* is the deadweight ton of the vessel (t); *a* and *c* are the parameters determined by vessel type.

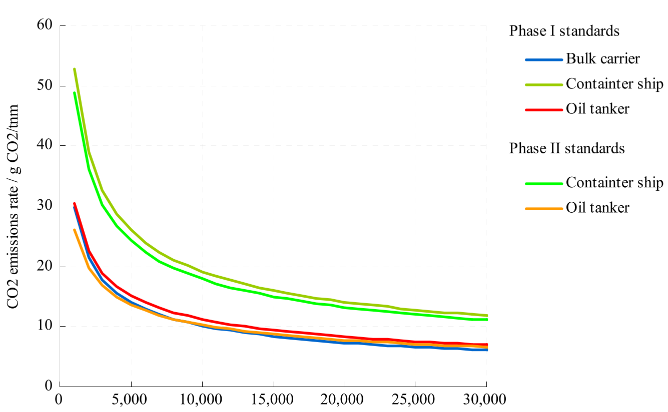

Fig. 12. MOT CO_2 emissions standards for vessels. Notes: (1) Only CER limits for coastal vessels are illustrated here; (2) The CER limits for bulk carriers are the same under phase I and phase II standards.

2.2.1.2. Measurement. The FCR/CER of vessels is calculated by using Eqs. (6) and (7). The physical implications behind these two equations is the FCR/CER of vessels operating under the conditions of maximum draft, 75% maximum continuous rating of the main engines, and smooth water state. The calculated FCR/CER is used to be compared directly with the limits to determine whether the vessels comply with the standards.

$$I_{FC} = \frac{\left(\sum_{i=1}^{n_{ME}} P_{ME(i)} \cdot SFC_{ME(i)} \cdot R_{ME(i)}\right) + \left(P_{AE} \cdot SFC_{AE} \cdot R_{AE}\right)}{Capacity \cdot \upsilon_{ref}} \tag{6}$$

$$I_{CO_2} = \frac{\left(\sum_{i=1}^{n_{ME}} P_{ME(i)} \cdot SFC_{ME(i)} \cdot C_{FME(i)}\right) + \left(P_{AE} \cdot SFC_{AE} \cdot C_{FAE}\right) - \sum_{i=1}^{n_{eff}} f_{eff(i)} \cdot P_{eff(i)} \cdot SFC_{ME} \cdot C_{FME} - \sum_{i=1}^{n_{eff}} f_{eff(i)} \cdot P_{AEff(i)} \cdot SFC_{AE} \cdot C_{FAE}}{Capacity \cdot \upsilon_{ref}} \tag{7}$$

where I_{FC} is the FCR index (g fuel/tnm); I_{CO_2} is the CO_2 emissions index (g CO_2/tnm); n_{ME} is the number of main engines; n_{eff} is the number of energy efficiency technologies employed on the vessel; $P_{ME(i)}$ is 75% of the difference between maximum continuous rating of the main engine *i* and shaft generator power (kW); $P_{eff(i)}$ is the main engine power reduction through employing energy efficiency technology *i* (kW); $SFC_{ME(i)}$ is the FCR of main engine *i* under 75% maximum continuous rating (g fuel/kWh); $R_{ME(i)}$ is the reference oil conversion factor for the fuel used in main engine *i*; $C_{FME(i)}$ is the CO_2 emissions conversion factor for the fuel used in main engine *i*; P_{AE} is 50% of the maximum continuous rating of the auxiliary engine (kW); $P_{AEff(i)}$ is the auxiliary engine power reduction through employing energy efficiency technology *i* (kW); SFC_{AE} is the FCR of the auxiliary engine under 50% maximum continuous rating (g fuel/kWh); R_{AE} is the conversion factor for the fuel used in the auxiliary engine; C_{FAE} is the CO_2 emissions conversion factor for the fuel used in the auxiliary engine; *Capacity* is the DWT; υ_{ref} is the vessel speed under designed draft, 75% maximum continuous rating of main engines, and smooth water state; $f_{eff(i)}$ is the availability coefficient of energy efficiency technology *i*.

2.2.1.3. Enforcement. The enforcement of the MOT standards is limited to commercial vessels. Vessels failing to comply with the standards can not get the license to operate for commercial purposes.

2.2.2. Energy efficiency standards by MIIT

2.2.2.1. Standards. MIIT established the energy efficiency standards for vessels in 2013, one year later than the MOT standards [65–69]. The standards incorporate the concept of Energy Efficiency Design Index (EEDI), which measures vessel energy efficiency by calculating its nominal CER. The higher one vessel's EEDI is, the less energy efficient the vessel is. The standards specify an EEDI reference line, which is used to compare with one vessel's actual EEDI. Similar to the FCR/CER limits in the MOT standards, the EEDI reference line is also power function-based. The MIIT standards cover not only freight vessels, but also passenger vessels. The EEDI reference lines for freight vessels and passenger vessels are based on DWT and Gross Ton (GT), respectively. The standards also specify different EEDI reference lines for vessels with different utilities and operating areas.

2.2.2.2. Measurement. the measurement of EEDI uses a similar approach to the MOT CO_2 emissions standards, which is not elaborated here.

2.2.2.3. Enforcement. The MIIT standards are established as recommended standards rather than compulsory standards. Therefore, the standards can not be used to determine market access

Table 3
Energy efficiency related technical standards in the pipeline transport sector.

Year	Standards	Code
1994	The method of efficiency test for crude oil pipeline transport system	SY/T 6066-94
2003	The method of energy consumption test and calculation for crude oil pipeline transport system	SY/T 6066-2003
2003	Code for energy saving & economical operation of natural gas transmission pipeline system	SY/T 6567-2003
2005	The method on energy consumption measurement and calculation for natural gas pipeline	SY/T 6637-2005
2008	Specification for economical operation of crude oil pipeline	SY/T 6723-2008
2010	Specification for economical operation of natural gas transmission pipeline system	SY/T 6567-2010
2012	The method of energy consumption test and calculation for crude oil pipeline transport system	SY/T 6066-2012
2012	The method of energy consumption test and calculation for natural gas pipeline transport system	SY/T 6637-2012

qualification. Instead, the standards are used as references to identify energy efficient vessels under the subsidy and tax incentive policies.

2.3. Aviation transport

There are 2370 civil aircrafts in China in 2014, distributed in 51 airline companies [70]. The energy efficiency of aircrafts is managed by Civil Aviation Administration of China (CAAC). Although energy efficiency standards for civil aviation have not been established yet, they are alleged to be under discussion [71]. Currently, energy efficiency in the civil aviation sector is mainly promoted through setting sector-level energy efficiency targets.

2.3.1. Energy efficiency targets

In the ‘Instructions on Accelerating Energy Conservation and Emissions Reduction’ released in 2011, CAAC set the targets that FCR, measured in g fuel/tkm (ton kilometer), and CER, measured in g CO_2/tkm, of China's civil aircrafts decline by 11%, 15% and 22% in 2012, 2015, and 2020, compared with the 2005 levels [72].

2.4. Railway transport

China has the world's largest railway network, with 0.11 million km railway and 21,100 locomotives in service in 2014 [73]. The CO_2 emissions from railway freight transport were estimated to account for 4% of total CO_2 emissions from China's freight transport sector in 2013 [40]. In China, railway transport is under the administration of the National Railway Administration (NRA), or the former Ministry of Railways (MOR). The operation of the railway transport sector is mostly administration driven, rather than market driven. As a result, energy efficiency in the railway transport sector is mainly promoted through administrative orders, with energy efficiency target decomposition and technical standards as the main instruments.

2.4.1. Energy efficiency target decomposition

NRA and former MOR considered energy efficiency a priority in railway transport, and set the target that the energy consumption rate (measured in tce per million converted tkm) should decline by 5% from 2010 to 2015 [74,75]. This overall target is stepwise decomposed to the sub-administration units. On the sub-administration levels, the actual energy efficiency performances are captured and compared with the decomposed targets. Achieving the targets or not is an important indicator in the overall performance appraisal of the sub-administration units. The incentive is strong as the appraisal result potentially affects the promotion of the sub-administration unit leaders.

2.4.2. Technical standards

The former MOR announced the ‘Codes for Energy-Saving Design of Railway Engineering’ in 1986 and updated the codes for two times in 2002 and 2006, respectively [76,77]. The codes comprehensively specify the energy efficiency orientated technology requirements in railway design, including railway network mapping, motive power determination, railway station and infrastructure building, Heating, Ventilation, Air Conditioning (HVAC) design, locomotive maintenance, electrification, power supply, water supply and drainage, communication, information and signal, etc. Especially, in the 2006 update, it is specified that the design of all railway projects should take energy efficiency as a core consideration, and should evaluate the energy efficiency performance of the railway projects during the design procedure. The actual energy efficiency performance of the railway projects should also be tested after their establishments.

2.5. Pipeline transport

In China, pipelines are mainly used to transport bulk gaseous and liquid freights, most of which are petroleum and natural gas. China's petroleum and natural gas pipeline network reached a total length 105,700 km in 2014 [1]. The energy efficiency of petroleum and natural gas pipelines is currently under the administration of the National Energy Administration (NEA).

2.5.1. Technical standards

Since 1994, several industrial standards regarding pipeline transport energy efficiency have been established, as Table 3 summarizes [78–85]. Especially, the ‘Specification for economical operation of crude oil pipeline (SY/T 6723–2008)’ and ‘Specification for economical operation of natural gas transmission pipeline system (SY/T 6567-2010)’ specify the principles, measures and indicators in maintaining and evaluating the energy efficiency of pipeline transport system.

3. Policy implications

First, the integrity of policy framework should be further improved. Currently, the road transport and water transport sectors have basically established energy efficiency standards-based market access qualification mechanisms. However, the railway, aviation and pipeline transport sectors have only established energy efficiency-related technical standards, which are far less effective in addressing the energy efficiency issues. The energy efficiency standards in these sectors should be timely established, especially for the aviation sector, where international energy efficiency standards are available as reference [86]. The energy efficiency standards for the railway and pipeline transport sectors are relatively more complicated, which should be proposed with full consideration of China's context.

Second, efforts for improving energy efficiency should be balanced among different transport sectors. Currently, efforts for improving energy efficiency of the passenger vehicles are the strongest, followed by other road transport sectors. The efforts in water, aviation, railway and pipeline transport sectors are generally weaker. This can be mostly attributed to the fact that passenger vehicle fleet is prominent in energy consumption. Besides, the technology nature and utilization pattern of passenger vehicles are less complicated than other transport sectors, which is easier for the policy makers to regulate. Under such a circumstance, comprehensive analysis is needed to determine the priority of efforts among all the transport sectors. Factors that should be taken into consideration include energy consumption, cost and potential of energy efficiency improvement, etc. Especially, the major energy-consuming sectors, such as heavy-duty vehicles should have similar priority to passenger vehicles in the overall energy efficiency improvement scheme.

Third, the scientific basis for the energy efficiency standards should be enhanced. The energy efficiency standards in China's road and water transport sectors have borrowed considerable experiences from developed countries. Taking the fuel consumption standards for passenger vehicles as an example, the VCW-based, ladder-pattern FCR limits and targets are similar to the Japanese regulation. The test cycles are generally based on the EU regulation. These borrowed policy features might not work well in China's context. As demonstrated by Hao et al., the ladder-pattern FCR limits and targets have weakened OEM's motivation for vehicle light-weighting [87]. Instead, smooth FCR limits and targets could have better overall effects. The rationale of energy efficiency standards should be reconsidered for better effect in China's context. Besides, the intelligence from the research community should be incorporated to ensure the rationality of the policies.

4. Conclusions

In this review, the energy efficiency standards in China's transport sector, including the road, water, aviation, railway, and pipeline transport sectors are comprehensively reviewed. On top of this review, more efforts are needed to further the understanding of energy efficiency in the transport sector. One possible further step is the international comparison of energy efficiency in the transport sector. The energy efficiency level and policy framework show significant disparities in the transport sectors of different countries. By conducting international comparison, the energy efficiency gaps among different countries can be observed. They can be utilized to highlight the improvement potential for the latecomers. Besides, the energy efficiency policies in one country can be good reference for other countries. Another possible step is a quantitative analysis of the impact of the policies on energy efficiency in the transport sector. This is especially needed in China, where lack of such studies is affecting the quality of policy making.

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