WHITE PAPER

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INTERNATIONAL VEHICLE LABELING PROGRAMS AND RECOMMENDATIONS FOR A HEAVY-DUTY VEHICLE GREENHOUSE GAS EMISSION LABELING PROGRAM IN CHINA

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EXECUTIVE SUMMARY

Reducing transportation-associated greenhouse gas (GHGs) emissions is critical in the race against climate change. Heavy-duty vehicles (HDVs) are responsible for 34% of global transportation carbon dioxide (CO_2) emissions, a disproportionate contribution relative to their numbers in the global vehicle fleet. Regulatory standards and mandatory market requirements are insufficient to decarbonize the HDV sector; complementary policies are required. Vehicle labeling, and more broadly, the various programs of vehicle environmental information disclosure, are powerful complementary measures—and are critical tools for guiding consumer choice over low-carbon HDVs.

Despite the importance of a robust HDV labeling program, only three regions have developed one: the European Union (EU), Japan, and California—a small number compared to the more than 30 labeling programs for light-duty vehicles (LDVs). This paper provides policymakers in China and across the globe with best practices and recommendations for developing and designing GHG labels for HDVs.

The key findings for labeling programs are:

1. Programs to label vehicle GHG emissions or efficiency, or to provide other vehicle environmental information, are key policy complements to regulations and fiscal policies in curbing vehicular GHG emissions and improving their energy efficiency. Nevertheless, experience with HDV labeling programs has been limited.
2. A global review of labeling programs shows that a typical vehicle GHG or efficiency label contains four types of information: vehicle information, GHGs and efficiency, economic performance, and label notes.
3. A literature review of surveys on consumer-focused information reveals that vehicle technical information and data on economic performance are critical in the purchase decisions of private car owners.
4. Further investigation is needed on methodologies for developing an effective HDV GHG labeling program that covers GHG emissions and efficiency, rating system, and economic performance.

Based on our assessment of international vehicle labeling programs, we recommend that policymakers take the following actions to establish a robust HDV GHG emission labeling program for China. The program should

1. Include CO_2, N_2O, CH_4, and HFCs, with total annual GHGs expressed in terms of CO_2 equivalents.
2. Label HDVs by vehicle type, powertrain type, and GVW segment. In particular, it should cover electric and fuel-cell HDVs.
3. Develop labels that reflect regulatory goals and address consumer concerns. Figures ES 1 and ES 2 illustrate the proposed label designs for a diesel straight truck in segment ST8 (GVW 16,000 kg–20,000 kg), and an electric coach in CB9 (GVW 16,500 kg–18,000 kg).

With regard to methodologies, we recommend that program staff:

4. Base measures of CO_2 emissions and energy efficiency values on vehicle testing or simulation, measures of N_2O and CH_4 emissions on vehicle testing, and measures of HFC emissions on the refrigerant's GWP and on the leakage rate of motor vehicle air conditioning (MVAC) systems. Calculations of total annual GHG emissions should be based on measured emissions of CO_2, N_2O, CH_4, and HFC, expressed in CO_2 equivalent, and on assumptions of annual vehicle kilometers traveled (VKT).
5. Rate the performance of GHG emissions and energy efficiency based on the deviation of the benchmark value by vehicle type, GVW segment, and powertrain type, and rate the MVAC system based on a combination of the refrigerant's GWP value and its leakage rate.
6. Estimate cost savings relative to a benchmark (diesel) vehicle of the same vehicle segment. Calculate the cost of a vehicle model by multiplying its certified energy consumption by the energy retail price and a presumed VKT for the vehicle category.
7. Ensure that the label denotes key assumptions regarding environmental and economic variables (such as VKT, energy retail price, etc.) and provides disclaimers regardiing potential discrepancies between labeled value and real-world performance.
8. Allow for the label to provide a QR code that links to external resources with information about the vehicle models' environmental performance if such details do not fit on the label.

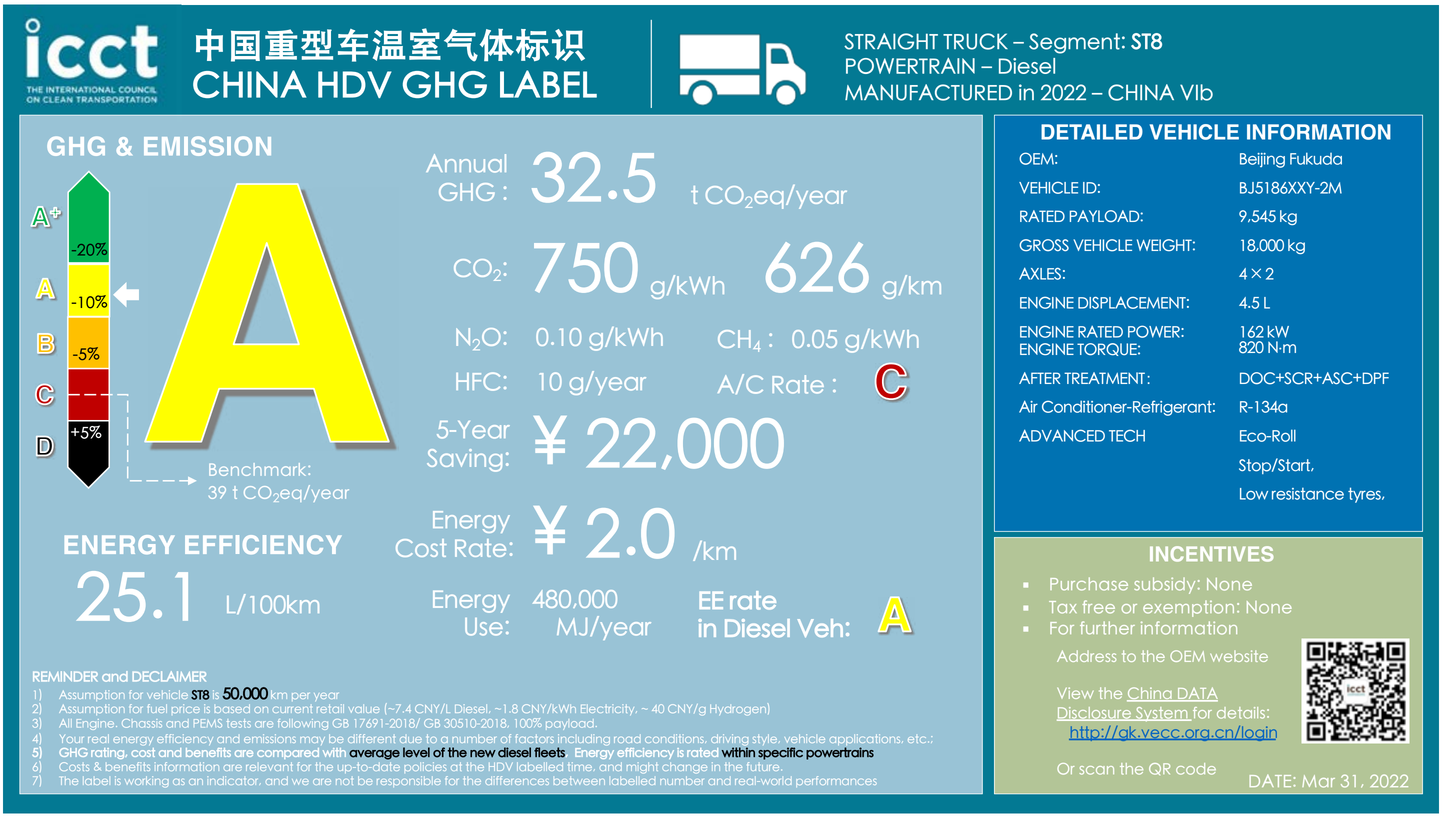

Figure ES 1. China HDV GHG label template – Diesel straight truck

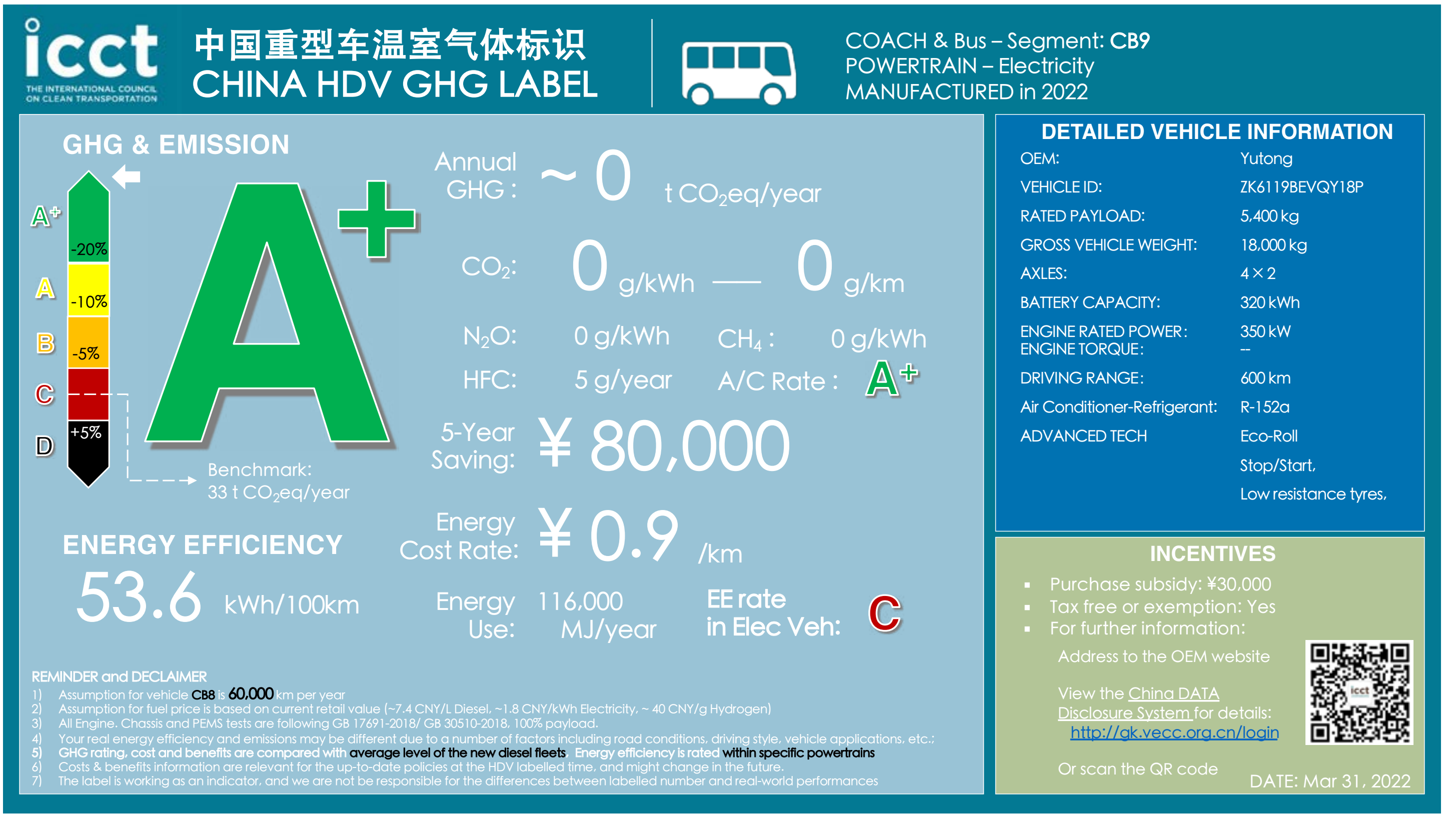

Figure ES 2. China HDV GHG label template – Electric coach

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1. INTRODUCTION

Reducing transportation-associated greenhouse gas emissions (GHGs) is critical in the race against climate change. Heavy-duty vehicles (HDVs) (including trucks, tractors, coaches, and buses with a gross vehicle weight (GVW) greater than 3,500 kg) are responsible for 34% of the carbon dioxide (CO_2) emissions of global transportation, a disproportionate contribution relative to their numbers in the global vehicle fleet (ICCT, 2020). To decarbonize the HDV sector, policymakers globally have introduced regulatory standards for fuel efficiency or CO_2 emissions; mandatory market requirements for low-carbon technology vehicles, especially zero-emission HDVs; and fiscal or other incentive policies. These policies are vital to “push and pull” a market for promoting low-carbon HDVs that are high-efficiency, low-emissions, or both. It is equally critical for policymakers to guide consumer choices regarding low-carbon vehicles. Vehicle labeling, or more broadly, the various programs of vehicle environmental information disclosure, are important and powerful complementary measures to regulatory and fiscal programs.

Despite the importance of robust HDV labeling programs, only 3 markets have developed one—the European Union (EU), Japan, and California—compared to the more than 30 vehicle labeling programs for light-duty vehicles (LDVs) worldwide. This paper provides policymakers in China and elsewhere with the best practices and recommendations for developing and designing GHG labels for HDVs. We focus in particular on design elements and underlying methodologies for providing critical information on the label. To this end, the paper is structured as follows:

Section 2 provides a review of the policy background in China. Section 3 provides a global overview of existing vehicle labeling programs, while Section 4 analyzes information required for HDV GHG labeling based on a 2016 ICCT study, extended from 18 LDV programs to 30 LDV + HDV programs, combined with analysis of information of interest to consumers. Section 4 also provides the design rules and templates for China HDV GHG labeling. Sections 5–7 provide detailed analysis and discussion of underlying methods for key elements including certified emissions and efficiency, rating system development, and economic performance calculations based on reviews of advanced HDV standards and stakeholder interviews. Section 8 concludes with key findings and policy recommendations regarding China HDV GHG labeling.

2. POLICY BACKGROUND

President Xi Jinping announced in 2020 that China aims to peak CO_2 emissions by 2030 and achieve carbon neutrality before 2060 by adopting vigorous policies and measures. In October 2021, China's State Council officially released its *National Action Plan to Peak Carbon Emissions by 2030*, which set overall targets of an 18% reduction in CO_2 intensity and a 13% reduction in energy intensity by 2025, while emphasizing green and low-carbon transportation (State Council of the PRC, 2021). As is true globally, in China, heavy-duty vehicles (HDVs) pose a great challenge for curbing GHG emissions, given their disproportionate 47% contribution to overall GHG emissions from road transport activities, compared to their 11% share of vehicle stock (Ministry of Public Security, 2020).

China has adopted three stages of fuel efficiency standards for new HDVs which set maximum fuel consumption limits for different HDV categories. The current Stage 3 standard took effect in July 2019 and aims to reduce fuel consumption by 14.1%–27.2% across all HDV categories compared to 2015. Meanwhile, a mandatory data disclosure policy aims to monitor compliance of new HDVs on pollutant emissions, which are regulated by the Ministry of Ecological Environment (MEE) under the *Atmospheric Pollution Prevention Law of PRC*. However, the current fuel consumption standard is not sufficient to achieve China's decarbonization targets (Jin et al., 2021), and the data disclosure does not cover non-CO_2 GHGs such as nitrous oxide (N_2O), methane (CH_4) and hydrofluorocarbon (HFC) emissions. Additional regulatory standards and complementary policies are necessary to achieve national targets on GHGs.

The 14th Five-Year Plan period is a key opportunity to develop an HDV GHG labeling program for China, as a complement to existing LDV labeling practices. Such a program in China can help promote low-carbon HDVs, development of the HDV GHG regulatory standards, and decarbonization of the HDV fleet, from 2 perspectives: First, as China is developing HDV GHG standards and regulations, a direct HDV GHG labeling will help to develop or implement future HDV GHG standards and policies, especially in providing robust methodologies on setting limits and creating compliance monitoring schemes. Second, the HDV labeling program could improve the data disclosure system and help consumers by providing valuable data on HDV energy efficiency and emissions of GHGs, including CO_2, N_2O, CH_4, and HFCs. In particular it could include zero-emission HDVs, including battery electric vehicles (BEVs) and fuel-cell electric vehicles (FCEVs).

3. GLOBAL REVIEW OF LABELING AND DATA DISCLOSURE

This section provides an introduction and review of global vehicle labeling programs and data disclosure systems, with detailed analysis and comparisons of 3 HDV labeling programs.

3.1. OVERVIEW

Vehicle labeling for fuel efficiency or GHG emissions is one of a series of measures designed to improve the fuel efficiency of transport fleets that has been introduced by various economies throughout the world since 1978. It is designed primarily to improve vehicle fuel economy. Meanwhile, increasing concern over climate change and pressures to reduce GHG emissions has led many governments to include information on CO_2 emissions in many updated labels. Provision of fuel consumption and CO_2 emission information prior to the purchase of a vehicle is often mandatory and sometimes voluntary, and is expected to motivate consumers to choose low-carbon vehicles by highlighting their benefits. To date, more than 30 markets worldwide have developed or are developing vehicle labeling programs, Figure 1 shows an overview of global markets with existing and proposed labeling programs (Z. Yang et al., 2016; GFEI, 2021); the size of each box represents the share of the 30 markets that have specific labeling programs. We can see that compared with LDVs, only the EU, Japan, and California (CA) have implemented labeling for HDVs.

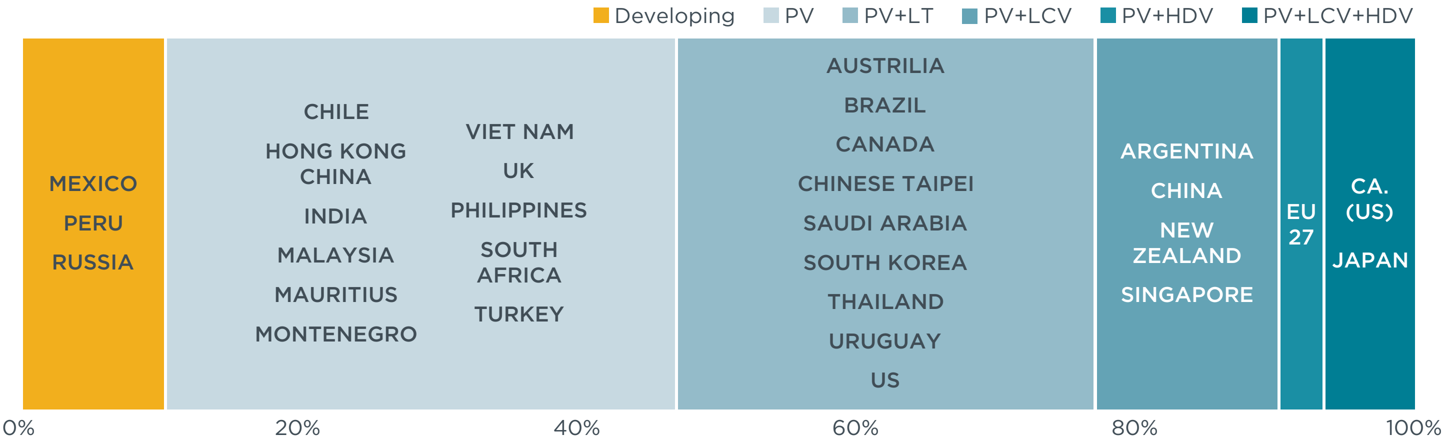


Figure 1. Overview of global markets with vehicle labeling programs

3.2. LIGHT-DUTY VEHICLE LABELING PROGRAMS

Among global LDV labeling programs, those of the U.S. and the United Kingdom (UK) are the oldest, both having started in 1978, followed by Korea in 1988. In 1999, EU member states were required to ensure that relevant information is provided to consumers, including a label showing a car's fuel efficiency and CO_2 emissions, to help drivers choose fuel-efficient cars. China first introduced fuel efficiency labeling for LDVs, including passenger vehicles (PVs) and light commercial vehicles (LCVs), in 2009.

All LDV labeling programs focus primarily on vehicle efficiency, thus energy consumption and economic performance are the most important information and are always displayed in a conspicuous place. This information is sometimes replaced by, or coordinated with, a performance rating that reports energy consumption or GHG emissions on a number or letter scale, or express performance in terms of percentage points above or below the fleet average. Absolute CO_2 emissions, on the other hand, is given as additional information for several labels, including those in the U.S., Canada, EU member states, Singapore, Thailand, Australia, Brazil, Chile, South Korea, and South

Africa. The first five of these also show the performance rating for energy consumption or GHG emissions; consumers may note that higher fuel economy is associated with a better GHG emissions profile. Figure 2 shows label samples from global LDV labeling programs.(GFEI, 2021; Z. Yang et al., 2016)

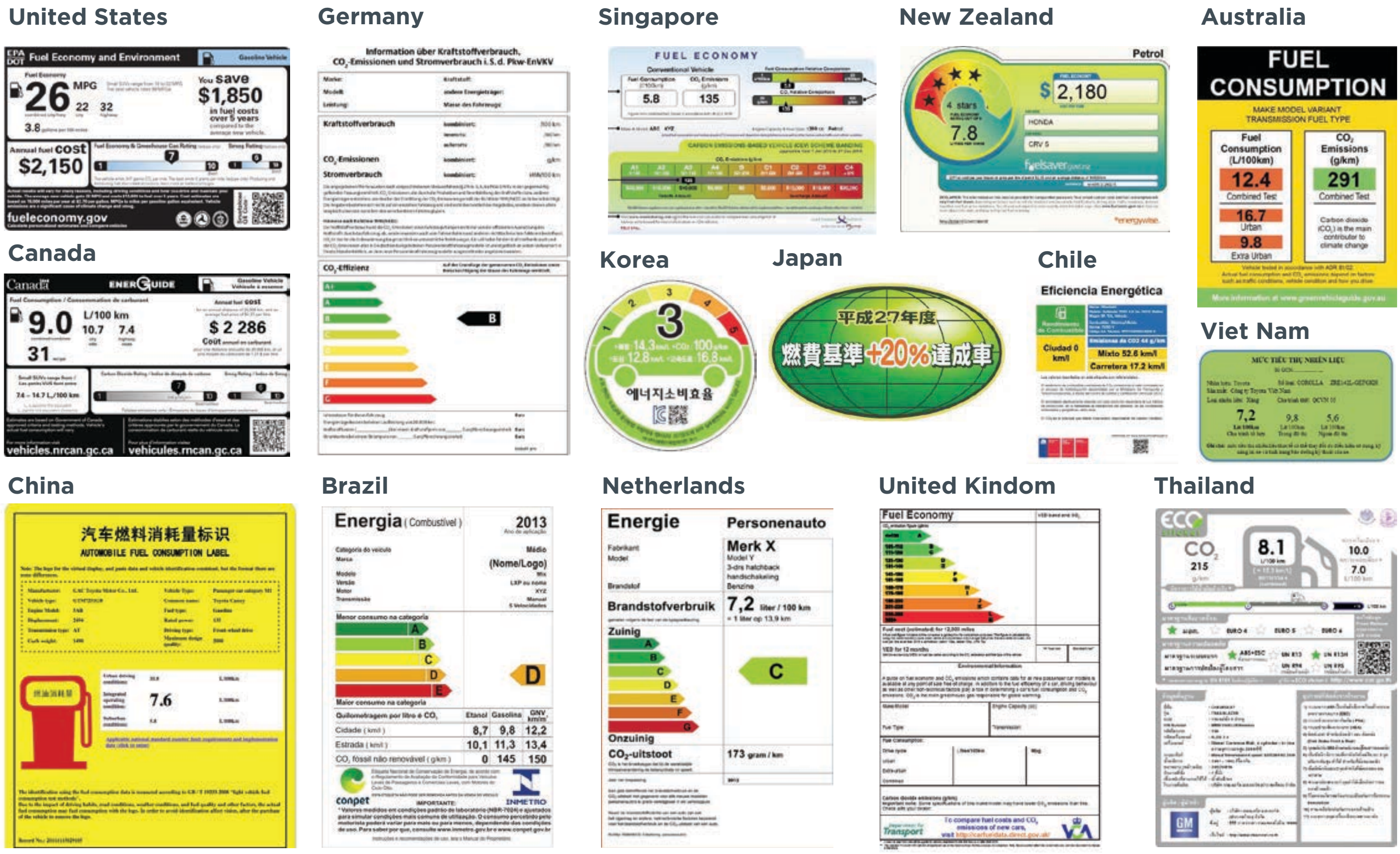
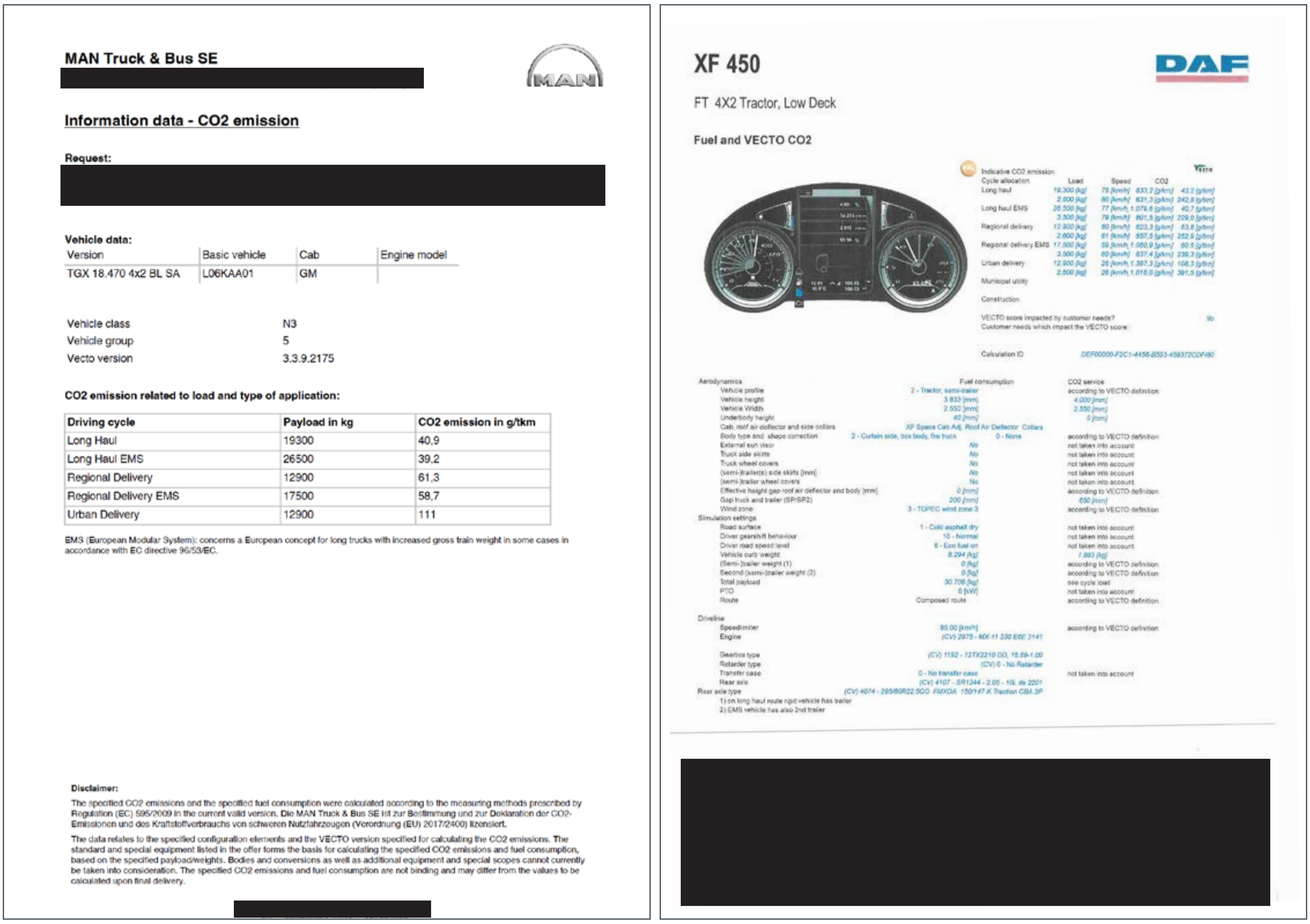


Figure 2. Label samples from LDV labeling programs (multiple sources)

3.3. HEAVY-DUTY VEHICLE LABELING PROGRAMS

To date, only the EU, Japan, and California have implemented HDV labeling.

The **EU labeling** program is governed by Commission Regulation (EU) 2017/2400 (European Commission, 2017) and was implemented in 2019. It contributes valuable HDV emission and efficiency data to support the EU's first HDV CO_2 standards, which aim to reduce CO_2 emissions from new HDVs by 30% in 2030. Manufacturers are obliged to provide to consumers a customer information file (CIF) that contains certified CO_2 emissions and energy consumption from vehicle simulations, along with other detailed technical information on individual vehicles. The provisions of the CIF currently cover only about 70% of all HDV sales in the EU. While this file differs from the labels shown in Figure 2, the level of detail provided by the CIF warrants its classification as a labeling program in this analysis. Two EU HDV labels are shown in Figure 3; because the regulation only requires a list of information to be disclosed, the design of the label differs by manufacturer. The regulatory methodology for CO_2 emissions is vehicle simulation.



MAN Truck & Bus SE
[redacted]

Information data - CO2 emission

Request:
[redacted]

Vehicle data:

Version	Basic vehicle	Cab	Engine model
TGX 18.470 4x2 BL SA	L06KAA01	GM	

Vehicle class	N3
Vehicle group	5
Vecto version	3.3.9.2175

CO2 emission related to load and type of application:

Driving cycle	Payload in kg	CO2 emission in g/tkm
Long Haul	19300	40,9
Long Haul EMS	26500	39,2
Regional Delivery	12900	61,3
Regional Delivery EMS	17500	58,7
Urban Delivery	12900	111

EMS (European Modular System): concerns a European concept for long trucks with increased gross train weight in some cases in accordance with EC directive 96/53/EC.

Disclaimer:

The specified CO2 emissions and the specified fuel consumption were calculated according to the measuring methods prescribed by Regulation (EC) 595/2009 in the current valid version. Die MAN Truck & Bus SE ist zur Bestimmung und zur Deklaration der CO2-Emissionen und des Kraftstoffverbrauchs von schweren Nutzfahrzeugen (Verordnung (EU) 2017/2400) lizensiert.

The data relates to the specified configuration elements and the VECTO version specified for calculating the CO2 emissions. The standard and special equipment listed in the offer forms the basis for calculating the specified CO2 emissions and fuel consumption, based on the specified payload/weights. Bodies and conversions as well as additional equipment and special scopes cannot currently be taken into consideration. The specified CO2 emissions and fuel consumption are not binding and may differ from the values to be calculated upon final delivery.

[redacted]

[redacted]

Figure 3. EU HDV consumer information files (CIF) for a MAN TGX 4 x 2 truck and a DAF XF 4×2 tractor.

To widen the scope of its HDV CO_2 legislation, the European Commission is currently extending labeling to include buses and coaches, and light and medium lorries (trucks with a GVW < 7.5 t). New powertrain types, including hybrid and fully electric powertrains, will also be covered.

Japan's HDV labeling is regulated under rules governing LDVs that were implemented in 2000, *the Act Concerning the Rational Use of Energy*. The Act is not only an important link to its fuel efficiency standard, but is also effective in raising public awareness and in achieving new energy vehicle (NEV) sales targets (Z. Yang & Rutherford, 2019). The Japanese HDV label shows only the vehicle's fuel consumption performance rating, by confirming that a fuel efficiency benchmark was reached, or by indicating the percentage by which the benchmark was surpassed. Manufacturers are still requested to report more detailed information including model, size, GVW, tires, emission control, and fuel efficiency technologies. A rating of relative performance can be found on the data disclosure website published by Japan's Ministry of Land, Infrastructure, Transport, and Tourism (MLIT). See Figure 4.

Under the rating, called the 'Top Runner' method, a benchmark value for each vehicle segment (classified by vehicle type and weight) was set as the best fuel efficiency in each segment in 2015; this became the standard for the following years. The score for vehicles that reach the benchmark fuel efficiency is 100, which is noted on the HDV label as shown in the first 2 models in Figure 4; if, for example, a vehicle's fuel efficiency is 11% higher than the benchmark, as in the third case in the figure, a rating of 111 will be given and the label will reflect 11% overachievement.

当該自動車の製造又は輸入の事業を行う者の氏名又は名称　三菱ふそうトラック・バス株式会社

トラック等又はトラクタ　　目標年度（平成27年度）

車名	通称名	型式	原動機				変速装置の型式及び変速段数	車両重量 (kg)	車両総重量 (kg)	最大積載量 (kg)又は乗車定員（名）	自動車の構造	燃費値 (km/L)	1km走行における CO_2排出量 $(g\text{-}CO_2/km)$	燃費基準値 (km/L)	主要燃費改善対策	その他燃費値の異なる要因			（参考）低排出ガス認定レベル	燃費基準達成レベル
			型式	総排気量（L）	最大トルク (N-m)	最高出力 (kW)										主要排出ガス対策	車輪配列	その他		
三菱	ふそう	QKG-FU50VY	6R10	12.808	1810	257	7MT	8,765	24,405	15530	トラック等	4.05	639	4.04	P, FI, IC, TC	CCO EGR SCR DF	2-4•4		NOx&PM★	100
		QKG-FU50VY	6R10	12.808	1810	279	7MT	8,765	24,405	15530	トラック等	4.05	639	4.04	P, FI, IC, TC	CCO EGR SCR DF	2-4•4		NOx&PM★	100
	ふそうキャンター	TRG-FBA50	4P10	2.998	300	96	6MT, 5MT	2,652	5,812	2995	トラック等	10.60	244	9.51	P, FI, IC, TC	CCO EGR DF SCR	2-4D	低燃費エンジン	NOx&PM★	111
		TRG-FBA50	4P10	2.998	370	110	6MT, 5MT	2,356	4,521	2000	トラック等	11.60	223	10.35	P, FI, IC, TC	CCO EGR DF SCR	2-4D	低燃費エンジン	NOx&PM★	112

Figure 4. Example of Japan's HDV fuel efficiency label and consumer information file (MLIT, 2020).

Although the U.S. has also adopted HDV GHG standards and has a well-designed LDV labeling program, the federal government is not moving toward HDV labeling. However, **California** has its own medium- and heavy-duty vehicle labeling programs, which are designed to promote more efficient and lower GHG-emitting vehicles to consumers, and to improve vehicle compliance regarding GHG and pollutant emissions. For medium-duty vehicles (MDVs), the CARB Environmental Performance Label Program requires manufacturers to label new MDVs, pick-up trucks and vans (GVW at 8,501 to 14,000 lbs., except for passenger vehicles) manufactured on or after Jan 1st, 2021(CARB, 2021). A GHG rating and a smog rating determined from vehicle testing, and an emission standard to which the vehicle is certified, are provided on the label; an example is shown in Figure 5. The label ratings range from A+ to D, with A+ the highest, cleanest rating. For HDVs, California's Phase 2 HDV GHG standards (CARB, 2018) regulate the labeling of emission control systems for tractors and vocational vehicles (trailers, heavy-duty pick-ups, and vans); the minimum required information list is shown in Table 1.

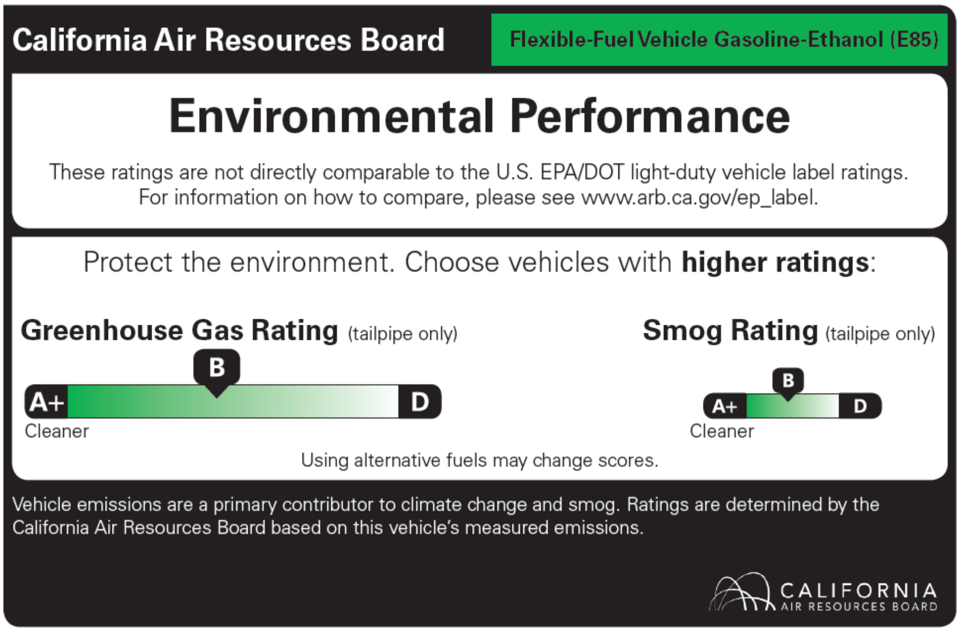


Figure 5. Example of the CARB Environmental Performance Label for MDVs

Table 1. Minimum required emission control identifiers for tractor and vocational vehicles in CA's Phase 2 standard

Number	Information required	Explanation	Tractor	Vocational vehicle
1	IRT	Engine shutoff system	✓	✓
2	LRRA	Low rolling resistance tires (all) (if is labelled, NO. 3 and 4 are not required)	✓	✓
3	LRRD	Low rolling resistance tires (drive)	✓	✓
4	LRRS	Low rolling resistance tires (steer)	✓	✓
5	TPMS	Tire pressure monitoring system	✓	✓
6	ATI	Automatic tire inflation system	✓	✓
7	ATS	Aerodynamic side skirt and/or fuel tank fairing	✓	✓
8	ARF	Aerodynamic roof fairing	✓	✓
9	ARFR	Adjustable height aerodynamic roof fairing	✓	✓
10	AFF	Aerodynamic front fairing		✓
11	AREF	Aerodynamic rear fairing		✓
12	TGR	Gap reducing tractor fairing	✓	

3.4. VEHICLE DATA DISCLOSURE SYSTEM IN CHINA

In China, which lacks an HDV labeling program, the current measure for consumers to explore HDV information is the data disclosure system. The data disclosure system was developed under the environmental data disclosure policy (MEE, 2016) and managed by Vehicle Emission Control Center (VECC) since 2016 to improve the compliance and public awareness of vehicle pollutant emissions. Consumers or the public can access that information from the data disclosure website[1] or from an accessory information inventory (accompanying documentation) when buying the vehicles. It is an important intermediate step for a comprehensive labeling program in China. A unique ID is set for each HDV model, which allows consumers to explore the vehicle on the data disclosure system (VECC, 2016a).

Compared with a labeling program, information in the data disclosure system is much more detailed regarding vehicle technical elements. Manufacturers are required to provide comprehensive vehicle and engine information, including details regarding manufacturer, model, vehicle type, powertrain, dimensions (L × W × H), curb mass, GVW, tires, axles, and driving mode. For engine and transmission, required information includes manufacturers, model, displacement, power, speed, torque, cylinder information, coolant, aftertreatment components, gears, and speed ratio. Environmental and energy efficiency performances are also regulated in China VI (GB 17691-2018) and fuel efficiency standards, including CO, THC, and NO_X measured in g/kWh; PN emissions in #/kWh from HDV engine and PEMS tests, and energy consumption in L/100km or kWh/100 from chassis and PEMS tests. Additionally, CO_2 emissions in g/kWh are reported. See Table 2 for a summary.

Table 2 also compares key information in China's data disclosure system with the EU's consumer information file. Similar information is required in the two systems for most items, but the EU CIF pays more attention to information related to vehicle simulation (highlighted in blue), while China's system has more information related to air pollutant emission control (highlighted in red), as the data disclosure system is tied to the *Atmospheric Pollution Prevention Law of PRC*. The pollutant information in China's system is worth considering for the China HDV GHG label, as is EU information such as the HDV sub-group classification, advanced energy efficiency technology like tires, and eco-roll, which may also attract consumers.

Although the China data disclosure system provides comprehensive information to consumers, it is not very convenient or easy to use. Consumers must go through a registration process to access the website, or they receive a long list of vehicle information. By contrast, the EU and Japan both developed HDV labeling programs based on their vehicle data disclosure, as a more effective way to deliver a subset of the most specific and critical information to consumers. Meanwhile, China's data disclosure system does not cover pollutants and GHGs like N_2O, CH_4, and HFCs, and is not applied to clean and low-carbon technologies like ZEVs. In sum, an HDV GHG labeling system can be very effective in improving consumer awareness and in bringing great benefits to existing data disclosure and future standards. The well-developed data disclosure system in China is a strong foundation from which to develop a GHG program.

1 Website link: http://gk.vecc.org.cn/login

Table 2. Open vehicle information comparison between the EU's consumer information file and the Chinese data disclosure system

Item List	EU	China Data disclosure
Vehicle data	• Manufacturer • Model • VIN • Category (N1, N2, ...) • Application (Urban, regional, long-haul, etc.) • GVW • Axle configuration • Sub-group class • Curb mass • Vocational (Y/N) • Powertrain • Vehicle dimensions	• Manufacturer • Model • VIN • Category (N1, N2, ...) • Application (delivery, sanitation, logistic, etc.) • GVW • Axle configuration • Emission standard • Curb mass • Vocational (Y/N) • Powertrain • Vehicle dimensions
Engine	• Engine model • Engine rated power • Engine capacity • Engine torque • Engine speed • Cylinder	• Engine model • Engine rated/max power • Engine capacity • Engine torque • Engine speed • Cylinder
Transmission	• Transmission values • Transmission type • Number of gears • Retarder (Y/N)	• Transmission values • Transmission type • Number of gears • Speed ratio
Other vehicle components	• Axle ratio • Average rolling resistance coefficient (RRC) of all tires • Average fuel efficiency labeling class of all tires	• Axle ratio • Aftertreatment system components, models, and manufactures (DOC, SCR, ASC, DPF, noise elimination) • OBD supplier
Advanced driver assistance system	• Stop-start (Y/N) • Eco-roll with engine stop-start (Y/N) • Eco-roll without engine stop-start (Y/N) • Predictive cruise control? (Y/N)	• N/A
Test or simulation files	• Simulation mission profile • Ave load and speed of testing cycle • Software tool version	• Testing cycle and standard • Testing facility
Fuel consumption and emission results	• Fuel consumption (L/100km, L/t-km) • Specific CO_2 emissions (gCO_2/t-km)	• Fuel consumption (L/100km, kWh/100km) • Pollutants and CO_2 emissions (PN in #/kWh, others in mg/kWh)
Identifier and notes	• Cryptographic hash of the manufacturer's records file • Notice and disclaimers	• Unique ID for vehicle • Notice • Photos

4. INFORMATION AND DESIGN FOR HDV GHG LABELING

A well-designed labeling program requires intelligent information selection and effective visualization. This section analyzes the information required for HDV GHG labeling, combined with analysis of information of interest to consumers. This section also provides design rules and templates for China HDV GHG labeling.

4.1. TYPICAL INFORMATION IN EXISTING LABELING PROGRAMS

While label designs differ widely across national programs, key commonalities exist regarding the information shown on labels. Table 3 shows typical information from 30 labeling programs and their frequency of use; the labeled information is highlighted in orange. It is based on 18 vehicle labeling programs reviewed in a 2016 ICCT study (Z. Yang et al., 2016), with 12 additional programs investigated for this study from various sources (GFEI, 2021; UNEP, 2017; Saudi Standards, Metrology and Quality Organization, 2017; Mock, 2016).

Four types of information are identified, focusing on **vehicle information, GHG emissions and energy efficiency, economic performance, and label notes.** Vehicle information such as brand and model name, and powertrain type, are found in more than 65% of labels, while engine information, GVW, and vehicle segment are featured in advanced programs (the EU and US) to certify energy efficiency and CO_2 emissions more accurately.

Certified GHG and fuel efficiency are always presented to document vehicle compliance, but to motivate consumers, ratings on environmental and economic performance are often offered. Twenty percent of the programs have both rating and cost-related information; the most consumer-targeted labels are those designed by the United States and Canada, which display ratings on emissions and economic benefits prominently, in large numbers. Finally, more than 80% of labels offer additional information such as explanations and disclaimers, and more than half explain how to access additional vehicle details from sources like a data disclosure website or a QR code.

4.2. CONSUMER INFORMATION

To double-check whether the identified elements do in fact attract consumers, and whether any information of interest to consumers is not considered, we conducted research from ICCT studies, relevant literature, and investigation of consumer concerns regarding low-emission vehicles, especially BEVs (Esposito, 2014; Li & Yang, unpublished; Tian et al., 2021; Wang et al., 2021; Xiong & Wang, 2020). The study analyzed 25 cases and summarized 40 important elements identified in the cases; the frequency for each element is summarized in Figure 6.

Table 3. Typical information from 30 labeling programs, and usage frequency

Economy	Labeling program	Vehicle information						GHG emission & efficiency					Economic attractiveness			Label note	
		Manufacturer & Model	Powertrain Type	Engine Power or Displacement	GVW or Segment	Emission Standard*	Battery or Range*	Energy Efficiency	Energy Efficiency Rating	CO_2 Emission (g/km)	CO_2 Emission Rating	Pollutant Emission Rating	Total Energy Use	Total Energy Cost	Cost Saving	Reminder & Supporter	Access to broader information
Argentina	PV	■	■					■	■	■						■	■
Australia	PV & LT		■				■	■		■						■	■
Austria	PV	■						■		■	■			■		■	
Brazil	PV & LT	■	■					■	■	■						■	■
California	HDV		■								■	■				■	
Canada	PV & LT		■		■		■	■		■	■	■	■			■	■
Chile	PV	■	■	■		■		■		■						■	■
China	PV	■	■	■	■		■	■								■	■
Chinese Taipei	PV	■	■		■			■	■				■			■	■
EU 27 MS	HDV	■	■	■	■	■	■	■		■						■	
Germany	PV	■						■		■	■			■		■	
Hong Kong, China	PV	■	■	■		■		■					■			■	■
India	PV	■	■	■	■			■	■						■	■	
Japan	PV								■								
Japan	HDV								■								
Mauritius	PV	■	■	■				■		■						■	■
Montenegro	PV	■		■				■		■	■					■	
Netherlands	PV	■						■	■	■						■	
New Zealand	PV & LCV	■			■		■	■	■					■		■	■
Philippines	PV	■				■		■	■	■							
Saudi Arabia	PV	■	■	■	■			■	■								
Singapore	PV & LCV	■	■	■	■			■	■	■	■			■	■	■	■
South Africa	PV	■						■		■						■	
South Korea	PV & LT		■					■	■	■							■
Thailand	PV & LT	■	■	■	■	■		■	■	■						■	■
Turkey	PV	■	■	■				■		■	■					■	
UK	PV	■	■	■				■		■	■			■		■	■
Uruguay	PV	■						■		■						■	■
US	PV & LT		■		■		■	■	■	■	■	■		■	■	■	■
Viet Nam	PV	■	■					■								■	
Frequency		77%	67%	40%	33%	17%	20%	90%	47%	67%	30%	10%	10%	20%	10%	83%	53%

*__Emission Standard__ is for conventional vehicles only, **Battery or Range** is for BEVs, FCEVs and PHEVs.

Figure 6. Word cloud of consumer areas of interest regarding purchase of NEVs

The figure shows that vehicle technical information like battery specifications, driving range and charging time, and economic performance including purchase price, energy consumption, and cost savings, are critically important to private car owners considering a purchase. Among these variables, driving range, purchase price, energy consumption, and cost savings are of interest to HDV buyers as well, in our view. In particular, accurate information on energy consumption and economic data could be a deciding factor for buyers seeking to control the total cost of ownership (TCO) of their HDVs (Mao et al., 2021). Thus, these elements should be given high priority in the design of an HDV label.

4.3. PROPOSAL FOR HDV GHG LABELING

Based on the typical information in labeling programs and on information of interest to consumers, a final HDV GHG labeling information list file is proposed in Table 4, including the information we proposed to label, the data samples or descriptions, and a criteria importance value for each type of information. The criteria importance gives priority levels to the design of the visual label, rated from low (1) to significant (5) in importance. The criteria importance values are determined by the frequency of appearance in existing labeling programs and consumer interest surveys; information with higher frequency and consumer interest scores tend to have high importance.

Table 4. Proposed HDV GHG labeling information list

Group	Information	Samples and descriptions	Criteria Importance
Vehicle information	Manufacturer and model	Name of manufacture or vehicle model Vehicle model code VIN number	3
	Standard vehicle Category	N1, N2, N3, M1, M2, M3 Urban, non-urban	2
	Vehicle segment	HDV segment by vehicle type and weight, e.g., ST8, CB2, TT5	4
	Vehicle size	Length, height, width; color Curb mass, GVW	1
	Technical information	Year of production Powertrain Emission standard (for ICE) Driving range (for BEV and FCEV)	5
	Engine information	Model, code, displacement Rated power, rated speed	2
	Advanced efficiency technology	Low-resistance tires, Eco-roll, stop/start	3
GHG emissions and energy efficiency	CO_2 emissions	Value, in g/km and g/kWh	5
	Energy Efficiency	Value, e.g., in L/100km, kWh/100km	5
	Total annual GHG emissions	Value, in t CO_2e/year	5
	Total annual energy consumption	Value, in MJ / year	4
	GHG emission rating	Rated on a scale of **A^+ A B C D**	5
	Energy efficiency rating	Rated on a scale of **A^+ A B C D**	4
	Refrigerants for MVAC	Refrigerant name	3
	MVAC rating	Rated on a scale of **A^+ A B C D**	4
	Air pollutant emissions	Value, in g/kWh	2
	Certification information:	Driving Cycle; Average speed in km/h; Average Payload (%)	1
Economic performance	5-year saving/spending	Values, "save/spend **X,XXX CNY in** fuel costs"	5
	Energy cost rate	**X,X** CNY / km	3
	Annual fuel costs	**X,XXX** CNY / year	1
	Purchase subsidy	"**X,XXX CNY** direct price reduction"	4
	Tax free and exemptions	"**X,XXX CNY** tax free for VAT/ Excise Tax/ Purchasing Tax/ Annual Automobile Tax/ Emission Tax/…"	3
	Further city-specific incentives	'Allowed to urban area', 'XX% toll fee reduction', 'exempted from plate number restriction', etc.	1
Label notes	Reminder & disclaimer	Includes contextual information, for example: 1. 'Vehicle category, AA is assumed to be driven xx,xxx km/year; 2. 'The price of energy is assumed to be X' 3. 'Your fuel economy and emissions may be different due to a number of factors' 4. 'GHG emissions, costs, and benefits are compared with the averages for a new diesel vehicle; the energy efficiency rating is compared to specific powertrains' 5. 'All cost and benefit information is based on policies current at the HDV labeled time, and are subject to change' 6. 'This label is an indicator only. We are not responsible for any difference between values found here and real-world performance.'	5
	Access to further information	To support the consumer with additional details on vehicles or to customize information, e.g.: 1. the **Unique ID** and the **address to China Data Disclosure System** (http://gk.vecc.org.cn/login) 2. **QR code** to a specific information platform or to the manufacturer's site	4
	Labelled date	Indicates the labeled date, YY/MM/DD	2

Note that all information including values, ratings, and texts must comply with the fuel efficiency standard, emission standard, and other policies and regulations.

4.4. DESIGN OF CHINA HDV GHG LABELING

To improve focus and readability, the design of the HDV GHG label should follow the criteria importance values listed in Table 4. For the China HDV GHG labeling program, we proposed the following rules for design: Information with a criteria importance level of 5 or 4 should be labeled and perhaps highlighted, information at level 3 or 2 should be labeled accordingly, and all unlabeled information should be reported on the data disclosure system or other platform. In this way, consumers can still have access to extensive vehicle information if they are interested.

According to this rule, we designed two China HDV GHG label templates for a diesel straight truck in segment ST8 (GVW 16,000 kg–20,000 kg), and an electric coach in CB9 (GVW 16,500 kg–18,000 kg), shown in Figure 7 and Figure 8.

Some interesting findings align with our expectation for HDV labeling:

1. Energy efficiency ratings of ICE HDVs are always in line with GHG ratings
2. ZE-HDVs are 100% rated ‘A+’ for GHG emissions but will differ in energy efficiency
3. A high GHG rating is always linked with high total energy cost savings compared to diesel vehicles
4. Higher energy efficiency ratings can also help consumers save money by reducing total energy consumption and energy costs; however, ZEVs always have higher energy cost savings in each segment.
5. MVAC system ratings are independent and varied.

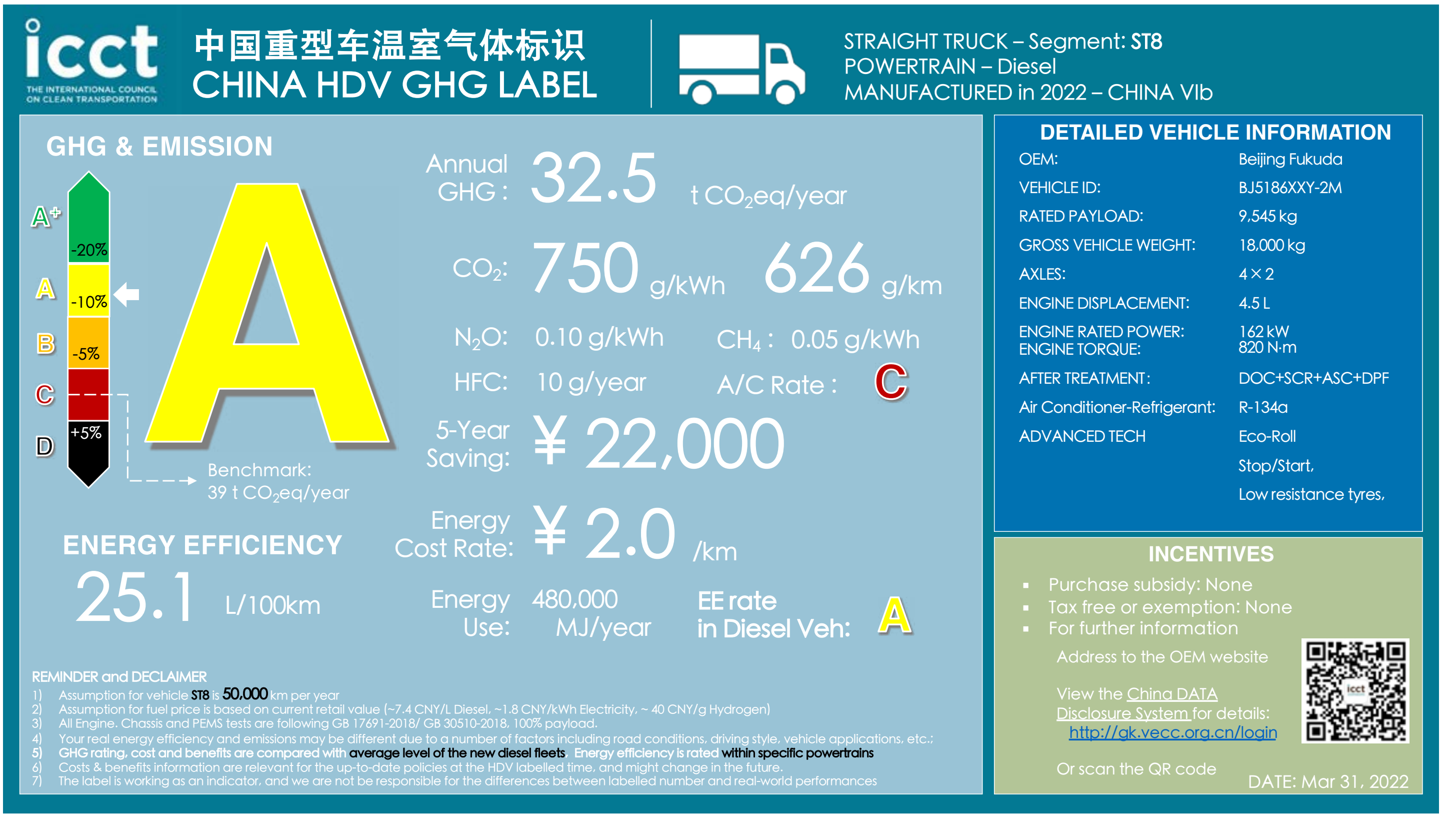


Figure 7. China HDV GHG label template—Diesel straight truck

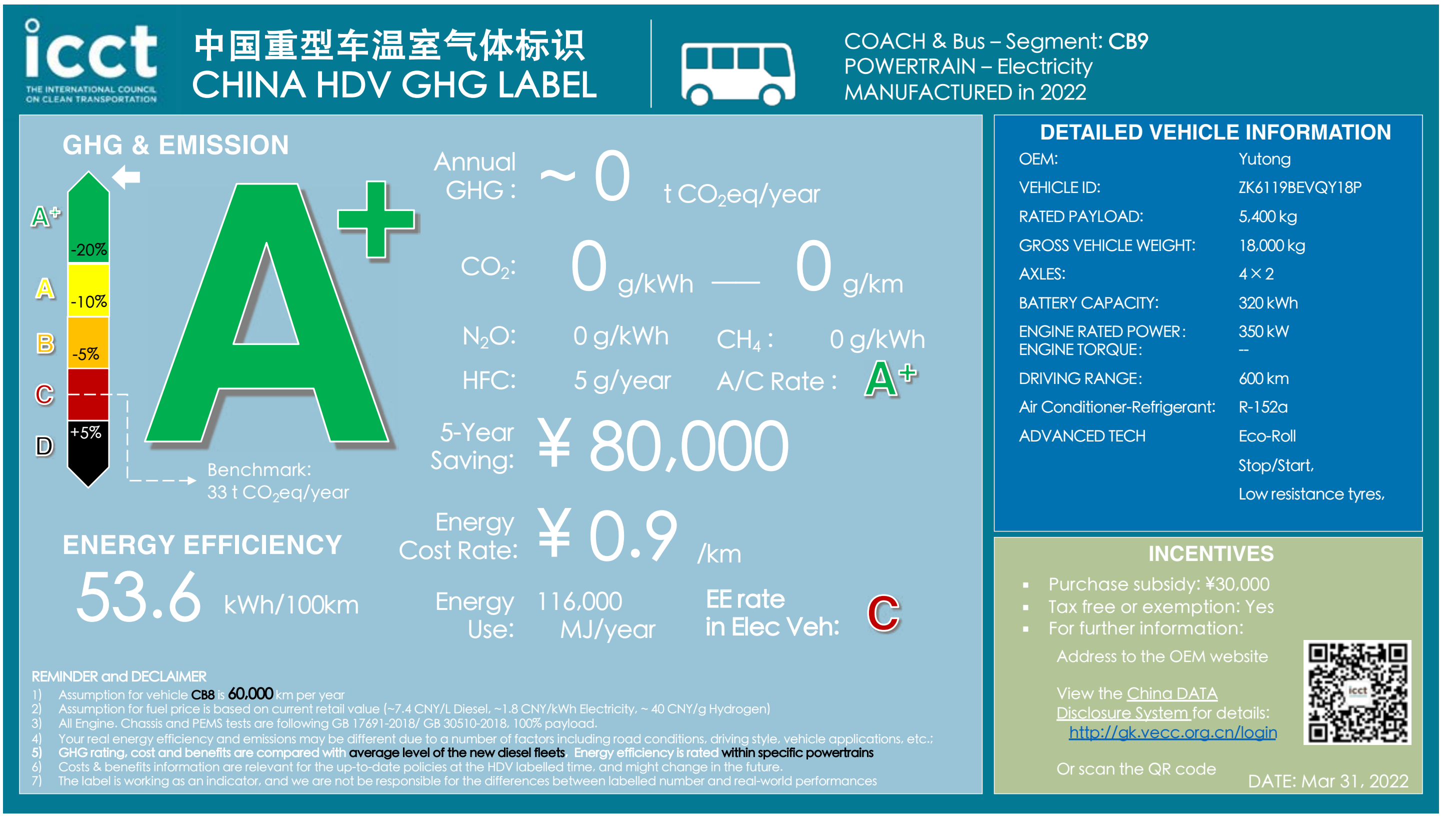


Figure 8. China HDV GHG label template—Electric coach

5. METHODOLOGY FOR MEASURING GHG EMISSIONS AND ENERGY EFFICIENCY

CO_2 emissions and energy efficiency performance are at the core of HDV GHG labeling, and various methods for measuring them are feasible. In addition, labeling CO_2, and the non-CO_2 GHG emissions (N_2O, CH_4, and HFCs) in China can be challenging, because they are not officially regulated. This section provides suggestions for measuring GHGs and energy efficiency, as well as a method for estimating vehicle annual GHG emissions.

5.1. CO_2 EMISSIONS AND ENERGY EFFICIENCY

CO_2 emissions and energy efficiency can always be measured together, and two methods—vehicle testing and simulation–are typically used to certify the vehicle's CO_2 emissions and energy efficiency across worldwide regulations.

Chassis dynamometer tests and portable emissions measurement system (PEMS) tests are reliable vehicle testing methods for assessing the emissions and energy consumption behavior of HDVs (Sharpe & Lowell, 2012). In China, chassis testing is regulated under fuel consumption standards to measure the energy consumption (in L/100km or kWh/100km) of vehicles, while distance-based CO_2 emissions (in g/km) can be estimated from fuel consumption. PEMS testing is used in China VI mainly for measuring pollutant emissions; according to the data disclosure regulation, work-based CO_2 emissions (in g/kWh) from PEMS should also be reported.

Vehicle simulation has also become a well-established and cost-effective methodology in several regions (Rodriguez, 2018). Vehicle simulation tools can be used to accurately estimate fuel consumption and CO_2 emissions (in g/kWh, g/km, g/t-km) under different driving cycles. At the global level, the EU's Vehicle Energy Consumption Tool (VECTO) and the U.S. Greenhouse gas Emissions Model (GEM) are two of the most comprehensive simulation tools. Korea's HES (Heavy-duty Vehicle Emission Simulator), developed by the Korean Ministry of Environment and the National Institute of Environment Research, along with Japan's tool developed by MLIT, have also been successfully used in regulatory programs (Korean MOE & NIER, 2020; Kajiwara, 2011; Sharpe, 2019). In China, potential simulation methods for certifying CO_2 and energy efficiency are being explored. The review of regulatory documents and the interviews with Chinese Automotive Technology and Research Center (CATARC) and VECC offer a glimpse into the capabilities of current simulation tools and their development, details are presented in Annex II. Figure 9 shows the available graphic user interfaces of four simulation tools.

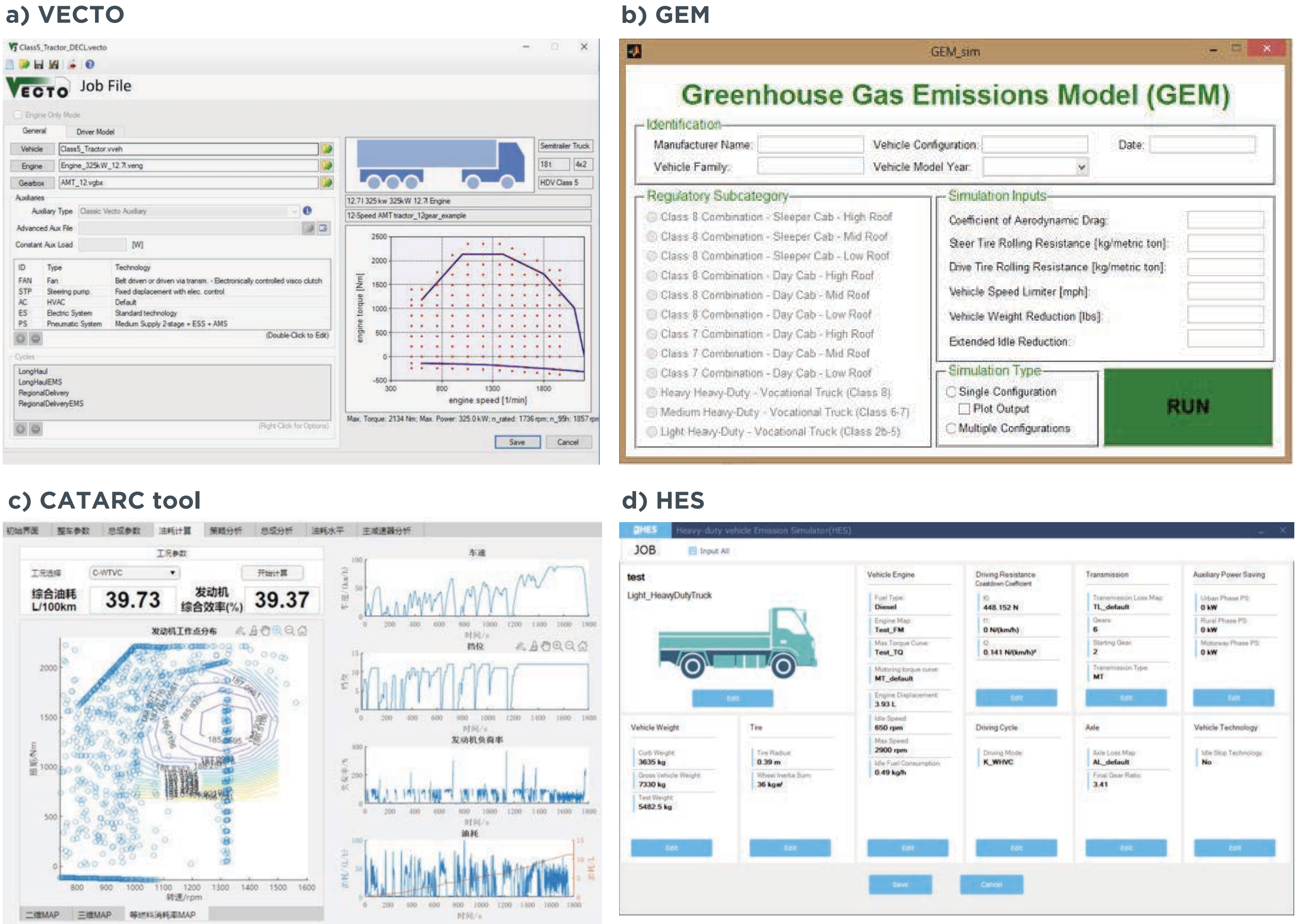


Figure 9. Graphic user interfaces for VECTO, GEM Phase 1, the CATARC tool, and HES

In sum, vehicle PEMS testing and simulation tools can both be used to label CO_2 emissions and energy efficiency of HDVs. China can regulate one or both methods according to their development standards and real implementation.

5.2. NON-CO_2 GHG EMISSIONS

Given that GHG emissions beyond CO_2 are covered under China's national targets and will also be relevant to the development of standards, inclusion of N_2O, CH_4, and HFC emissions is recommended in a comprehensive GHG labeling system. Table 5 gives a review of regulatory documents in major markets on the current measurement methods for non-CO_2 emissions. It shows that the U.S. has a comprehensive regulatory system for other vehicle GHG emissions, while China still has large gaps in all non-CO_2 emissions.

For example, there is currently no specific standard regulating N_2O emissions in China, and only China VI regulated CH_4 for the standard cycle WHTC (positive ignition) for engine tests. It's expected that China VII will add N_2O and CH_4 standards for real-road PEMS testing. At the global level, the U.S. has regulated the testing methods and limits for both gases in medium- and heavy-duty vehicle GHG emission standards, both the previous Phase 1 and the current Phase 2, as shown in Table 5. EU has regulated engine testing for HDV CH_4 emissions in Euro VI but not for N_2O, although a stricter limit for CH_4 and an introduction of N_2O testing method and limits are expected in Euro VII.

No regulation for HFC emissions from motor vehicle air conditioners (MVAC) is found in China, either; however, a specific national standard is expected to regulate MVAC refrigerant emissions (like R-134a) based on two vehicle air conditioner standards, GB/T 21361-2017 and GB/T 37123-2018 (Yang et al., 2022). Worldwide, both the EU and the U.S. adopted regulations and standards to estimate the HFC emissions from MVAC by setting limits on refrigerants' Global Warming Potential (GWP) value, and the leakage rate in grams per year or percentage of total refrigerant per year (EC, 2006; U.S EPA, 2016). EU Regulation No. 517/2015 and the U.S. Greenhouse Gas Reporting Program (GHGRP) require manufacturers of HFCs or HFC facilities (including MVAC) to report and label the leakage weight and CO_2 equivalent (CO_2e) emissions of their products according to the refrigerant's GWP and leakage rate (U.S. EPA, 2010)fuel and industrial gas suppliers, and CO_2 injection sites in the United States. Approximately 8,000 facilities are required to report their emissions annually, and the reported data are made available to the public in October of each year.

Table 5. Regulation, with testing methodology, for vehicle non-CO_2 GHG emissions, by region

Market	Item	N_2O	CH_4	HFC leakage
China	**Regulation**	Likely in China VII	China VI	NO
	Methodology	-	Engine test	-
	Reported?	-	Yes	-
	Limit value	-	0.5 g/kWh	-
EU	**Regulation**	Likely in Euro VII, under development	Euro VI	Yes
	Methodology	-	Engine dyno	Standard value for refrigerant's GWP and leakage rate
	Reported?	-	-	Yes
	Limit value	-	0.5 g/kWh	Refrigerant's GWP ≤ 150, or Leakage rate ≤ 40 g/year (single evaporator); 60 g/year (dual evaporator)
US	**Regulation**	Phase 2 M/HDV GHG regulation	-	Phase 2 M/HDV GHG regulation
	Methodology	Engine and chassis test	Engine and chassis test	Set standard refrigerant's leakage rate
	Reported?	No	No	Yes
	Limit value	Tractors & vocational: 0.01 g/bhp-hr Pick-ups and vans: 0.05 g/mi	Tractors & vocational: 0.01 g/bhp-hr Pick-ups and vans: 0.05 g/mi	Refrigerant GWP ≤ 150; Larger A/C (capacity > 733g): 1.5% of total refrigerant per year Smaller A/C (capacity < 733g): 11.0 g/year

Overall, vehicle testing is the only feasible regulated method for measuring N_2O and CH_4; for HFC emissions, refrigerant GWP and MVAC leakage rates are requested. It is worth considering whether manufacturers should be required to label non-CO_2 GHG emissions even before there is a standard. Labeling can be effective to collect HDV non-CO_2 GHG emissions data and evaluate the measuring methods for the standards development.

5.3. ESTIMATION OF TOTAL VEHICLE GHG EMISSIONS

With the inclusion of non-CO_2 emissions, total GHG emissions will be an important common metric on labels to compare overall GHG emissions by vehicle, rather than individual emissions of each GHG. As the emissions data may come from different methods with different units, we developed an integrated methodology to merge CO_2 and non-CO_2 GHG emissions together for HDV GHG labels.

The methodology for estimating total annual GHG emissions in gCO_2e is illustrated in Figure 10, using a typical straight truck as an example. Note that all emissions data are estimated from ICCT's vehicle testing program. 100-year GWP (GWP-100) for N_2O, CH_4 and typical refrigerant R-134a are used to calculate annual GHG emissions (in g CO_2-equivalent) in the example (IPCC, 2014), which are 298, 28, and 1430, respectively. 20-year GWP (GWP-20) is an alternative metric, according to the regulator. Note that the total GHG emissions here represent only tailpipe CO_2, N_2O, CH_4 emissions and vehicle A/C HFC emissions; upstream emissions are not considered.

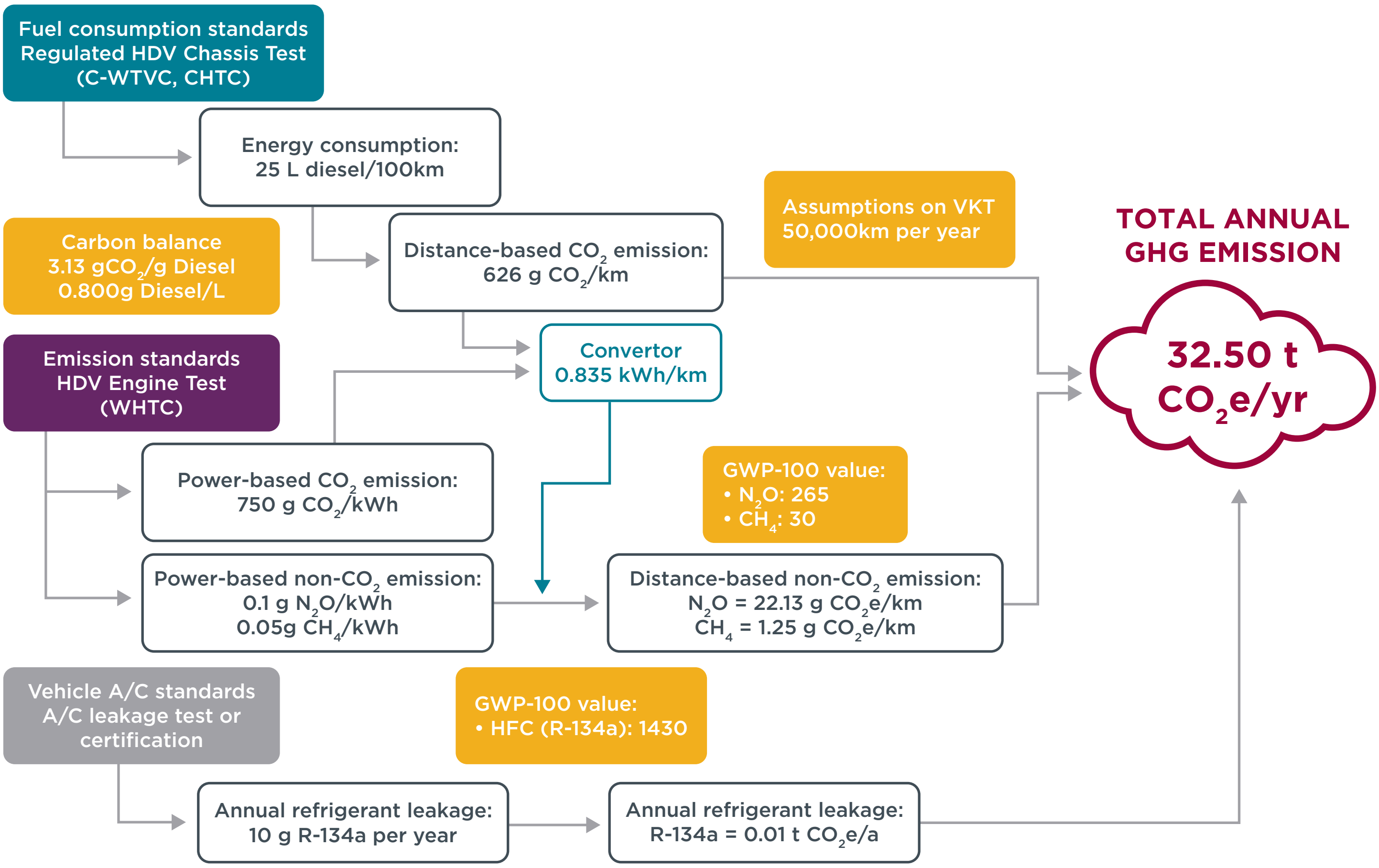


Figure 10. Methodology of total annual vehicle GHG emission for labeling

6. METHODOLOGY OF THE RATING SYSTEM FOR HDV LABELING

This section introduces the underlying method of the rating system along with the benchmark setting developed for China HDV GHG labeling.

6.1. EXISTING RATING SCHEMES

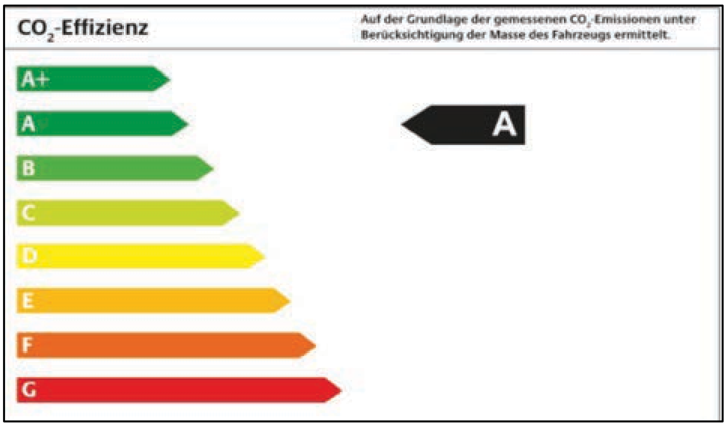
An emissions or energy efficiency rating clarifies for consumers how the vehicle performs compared to similar products. The rating on the label also reduces the burden on consumers of interpreting the merit of a given CO_2 or GHG emissions number, or of a fuel consumption number. For regulators, a well-designed rating scheme, along with a benchmark methodology, can also contribute greatly to regulatory standards, such as limit-setting.

Two methods are typically used to rate performance on emissions or efficiency. The first is to set different ranges for fuel consumption and tailpipe CO_2 emissions, then rate the vehicle according to its real fuel consumption or emissions. This is the method used in the U.S.'s PV labeling, shown in Figure 11a. The rates range from 1 (worst) to 10 (best) (U.S. EPA, 2021) according to the certified emission and efficiency. California adopted this rating scheme for their MDVs, the comparable rates from A+ to D are listed in the last column. The second is to set a benchmark for each vehicle segment and rate their energy consumption or emissions level according to their performance relative to the benchmark (e.g., percentage higher or lower than the benchmark value), similar to Germany's PV labeling, shown in Figure 11(b). The benchmark value for CO_2 emissions is calculated based on vehicle weight using a comprehensive formula prescribed by law. Depending on the deviation from the benchmark value, the vehicle is assigned to a CO_2 efficiency class. Classes A + to D are assigned to cars whose CO_2 emissions are lower than the benchmark value. Vehicles whose CO_2 emissions correspond to or exceed the benchmark value fall into efficiency classes E, F, or G (Alternativ Mobil, 2021).

a) US rating system

<table>
<tr><th>MY 2022, US LDV GHG Rating</th><th>CO_2 (g/mile)</th><th>MPG (gas)</th><th>Comparable, CA MDV GHG Rating</th></tr>
<tr><td>10</td><td>0</td><td rowspan="2">≥58</td><td>A+</td></tr>
<tr><td>10</td><td>1-155</td><td rowspan="6">A</td></tr>
<tr><td>9</td><td>156-200</td><td>45-57</td></tr>
<tr><td>8</td><td>201-243</td><td>37-44</td></tr>
<tr><td>7</td><td>244-291</td><td>31-36</td></tr>
<tr><td>6</td><td>292-335</td><td>27-30</td></tr>
<tr><td>5</td><td>336-338</td><td rowspan="3">22-26</td></tr>
<tr><td>5</td><td>339-394</td><td>A-</td></tr>
<tr><td>5</td><td>395-413</td><td rowspan="2">B+</td></tr>
<tr><td>4</td><td>414-450</td><td rowspan="2">19-21</td></tr>
<tr><td>4</td><td>451-480</td><td rowspan="2">B</td></tr>
<tr><td>3</td><td>481-507</td><td rowspan="3">16-18</td></tr>
<tr><td>3</td><td>508-563</td><td>B-</td></tr>
<tr><td>3</td><td>564-573</td><td rowspan="2">C+</td></tr>
<tr><td>2</td><td>574-619</td><td rowspan="2">14-15</td></tr>
<tr><td>2</td><td>620-658</td><td rowspan="2">C</td></tr>
<tr><td>1</td><td>659-676</td><td rowspan="3">≤13</td></tr>
<tr><td>1</td><td>677-732</td><td>C-</td></tr>
<tr><td>1</td><td>≥732</td><td>D</td></tr>
</table>

b) Germany rating system



Note: the reference value of car that weighs 1,500 kg is 171 gCO_2/km, weighs 1,000 kg is 126 gCO_2/km.

Figure 11. a) U.S. LDV rating system for fuel consumption and tailpipe emissions; b) German LDV rating system for CO_2 efficiency (U.S. EPA, 2021; Alternativ Mobil, 2021)

6.2. RATING SCHEME FOR CHINA HDV GHG LABELING

Rating HDVs with a benchmark value for each segment is a reasonable way to measure the various performances across different HDV types and weight segments. We further suggest considering labeling total GHG emissions (including N_2O, CH_4, and HFC as CO_2 equivalent) and energy efficiency, as well as MVAC systems; a summary of the rating scheme is found in Table 6.

For labeling total GHG emissions and energy efficiency together, the norm is that a ZEV, like a BEV, always have an 'A+' score for GHG emissions as it barely emits any pollutants. But it can be rated at 'C' or 'D' for energy efficiency if it consumes more in its BEV segment.

Further, MVAC systems can be rated separately as the system is independent of the vehicle's propulsion system but is indeed critical to HDV GHG emissions. The refrigerants' GWP value and the leakage rate in g/year are the two most critical metrics proposed for rating the MVAC system, as mentioned before. Because there are two metrics, the final rate for a MVAC is suggested to be determined by the worst one. As China doesn't have a mandatory standard covering the limit values of those two metrics, the EU and U.S. standards are used to set the rating scheme.

Table 6. Proposed HDV tailpipe rating scales

Rating	Explain	Criteria for GHGs	Criteria for energy efficiency	Criteria for A/C system
A+	**Extraordinary**	GHG emissions are at least 20% below the benchmark value	Energy consumption is at least 20% below the benchmark value	Refrigerant GWP ≤ 150 Leakage ≤ 5 g/year
A	**Excellent**	GHG emissions are 10%–20% below the benchmark value	Energy consumption is 10%–20% below the benchmark value	Refrigerant GWP ≤ 500 Leakage ≤ 10 g/year
B	**Good**	GHG emissions are 5%–10% below the benchmark value	Energy consumption is 5%–10% below the benchmark value	Refrigerant GWP ≤ 1000 Leakage ≤ 15 g/year
C	**Ordinary**	GHG emissions are less than 5% below or no more than 5% above the benchmark value	Energy consumption is less than 5% below or no more than 5% above the benchmark value	Refrigerant GWP ≤ 1500 Leakage ≤ 20 g/year
D	**Bad**	GHG emissions are 5% above the fleet average	Energy consumption is 5% above the fleet average	Refrigerant GWP > 1500 Leakage Rate > 20 g/year

6.3. SETTING THE BENCHMARK

For rating GHG emissions and energy efficiency, a benchmark value is the most critical element for making the methodology work. The EU is a good reference in setting the benchmark for HDVs. In 2019, the EU started monitoring CO_2 emissions from HDVs, as certified with VECTO, under the scope of the reporting and monitoring regulation, No. 2018/956. Europe's HDV CO_2 standards build on this by defining a baseline period—1st July 2019 to 30th June 2020, the first reporting period—and setting CO_2 emissions reduction targets compared to the fleet-average value collected during that period, which is the benchmark value. The EU benchmark value is also set by HDV type, weight segment, and application (Ragon & Rodriguez, 2021).

We propose to use a similar approach to set the benchmark value for GHG emission and energy consumption by HDV type, powertrain type and weight segment; the segmentation can be in line with the fuel efficiency standard, as shown in Table A2 in Annex II. The benchmark values will be updated on an annual or biennial basis.

The proposed annual basis workstream is shown in Figure 12 with the following assumptions:

1. Assume the program starts at the beginning of 2025
2. The first implementation period has an extra year for program evaluation and an extra half year for determining the benchmark value.
3. The following implementation and reporting period are 1 or 2 years, if necessary.
4. Generally, the benchmark values are determined at least half a year before being applied to the new period.
5. The benchmark value can alternatively be the limits set in the HDV GHG standards or a certain target, if available.
6. The rating system will use the fleet average annual GHG emissions (CO_2, N_2O, CH_4, and HFCs together as CO_2 equivalent) to rate each HDV's performance in its fleet, depending on the deviation from the benchmark value

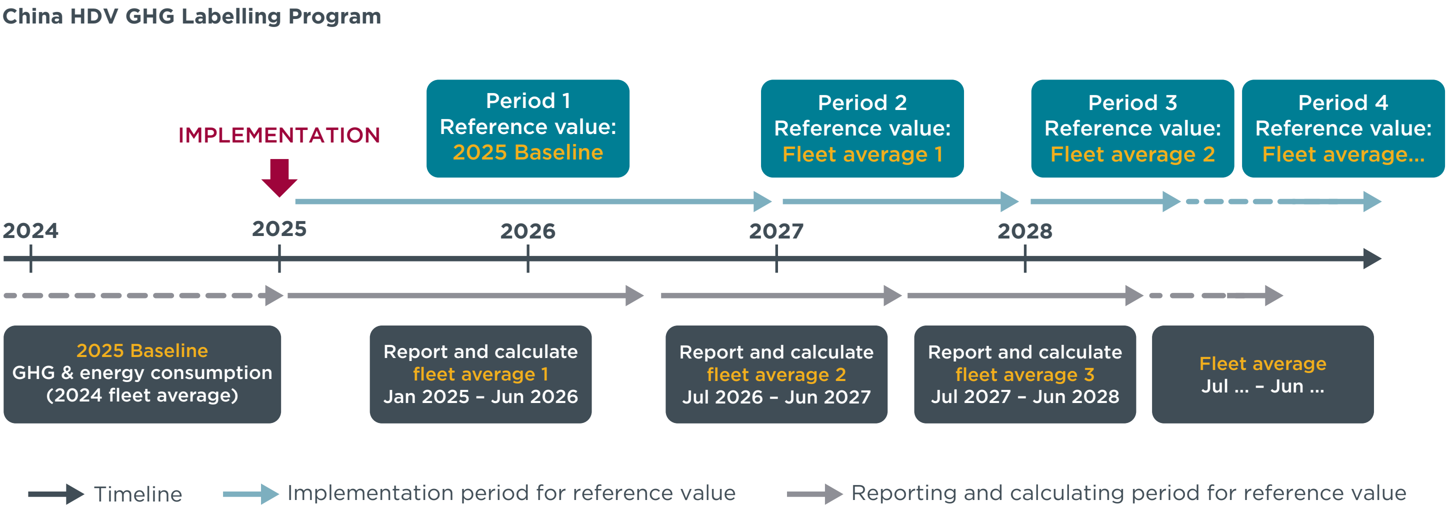


Figure 12. Proposed workstream to update benchmark value on one-year basis

6.4. ASSESSMENT OF THE RATING SCHEME

Our HDV database provides energy consumption data; we apply our rating scheme to that data to test whether our proposed method works effectively. We picked the diesel straight truck segment 8 (ST8, 16,000 kg < GVW ≤ 20,000 kg) and electric coach and bus segment 9 (CB9, 16,500 kg < GVW ≤ 18,000 kg), which have relatively high sales proportions of each fleet and are also common in vehicle fleets in the real world.

To fully follow our methodology, we calculated the fleet average energy consumption for diesel ST8 and electric CB9 for year 2019—31 L/100km and 55 kWh/100km respectively—and set them as references for model year 2020. Figure 13 shows the energy consumption density distribution for new sales in model year 2020 of each fleet, the benchmark value (the dash line), and each rating level area according to Table 6. It shows that a well-designed rating system split the vehicle into different performance levels with a healthy proportional distribution: a few A+ level vehicles, 60%-70% A- and B-level vehicles (with space to improve), over 30% C-level vehicles (requiring more effort), and a few D-level vehicles (not recommended).

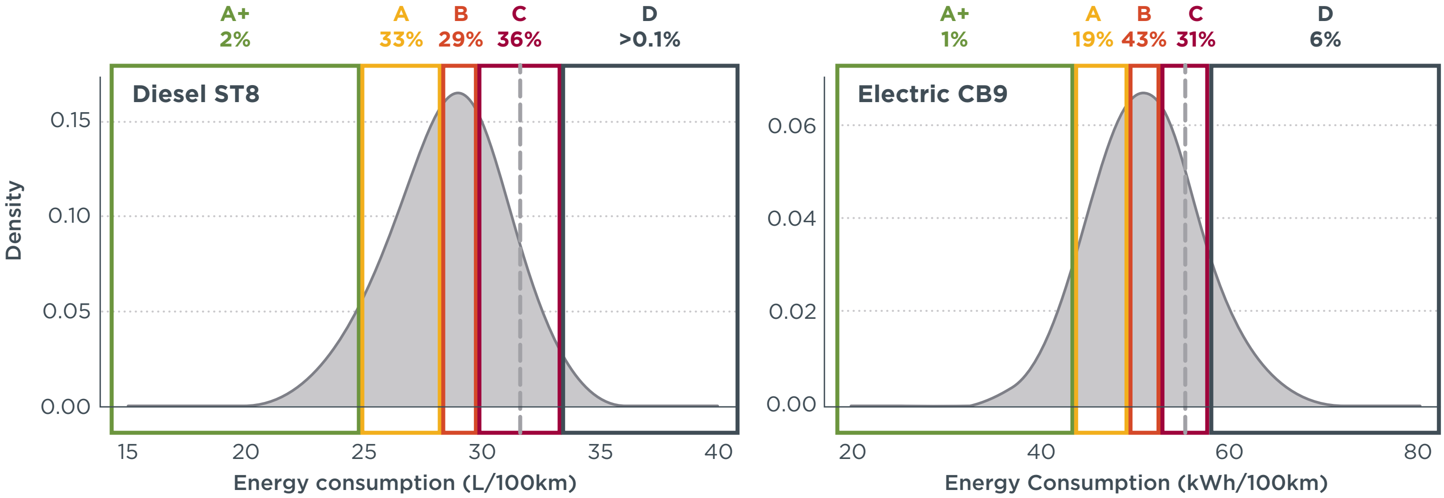


Figure 13. Evaluation of rating system for energy efficiency

7. METHODOLOGY OF ESTIMATING ECONOMIC PERFORMANCE AND LABEL NOTE

Information on economic performance is critical for consumers contemplating a purchase decision. This section provides detailed analysis and discussion of the key dimensions of economic performance required for China HDV GHG labeling, and the estimation methodology for developing it.

7.1. ENERGY COST AND SAVING

As previously noted, high monetary savings from low energy costs can be very effective in motivating consumers to choose a low-carbon vehicle, especially for BEVs (Fries et al., 2017; Wolfram & Lutsey, 2016). ICCT studies also proved that ZE-HDVs can be beneficial from an economic point of view in China and Europe (Mao et al., 2021; Basama et al., 2021). However, these savings are usually not immediate and are outweighed by the immediate high purchase price.

The U.S. LDV label provides a good methodology for estimating energy costs and savings. First, to compare all vehicles fairly, several assumptions are applied including annual average vehicle kilometers traveled (VKT) and the retail price of energy (e.g., gasoline, diesel and electricity). The assumptions are described in the label notes, along with a reminder to consumers that real fuel economy and emissions vary because of a variety of factors. Then, the label shows the vehicle's estimated annual fuel cost and the fuel cost saving or spending over a five-year period compared to the average new vehicle. For example, if a vehicle would result in savings to the consumer compared to the average vehicle, the label would state, "You save $x,xxx in fuel costs over 5 years compared to the average new vehicle." (U.S. EPA, 2021)

We propose a similar methodology to estimate energy costs and savings by HDV type and GVW segment for China HDV GHG labeling; the methodologies or assumptions for key elements are listed in Table 7. To highlight the economic benefits of ZEVs, we propose to compare all vehicles' cost savings with the segment benchmark fuel consumption value of the diesel vehicle, as determined in the rating system. Figure 14 shows the average 5-year energy cost saving/spending for CB9 fleet estimated by powertrain and rating level; it is clear that electric coaches have significantly higher economic benefits than diesel vehicles, even if the energy efficiency is not high. Assumptions on annual VKT for each segment are proposed in Table A2 in ANNEX II.

Table 7. Methodologies and assumptions of key elements for estimating energy cost and saving for China HDV GHG labeling

ELEMENT	Methodology or assumption
Benchmark energy efficiency (*EE,* in L/100km or kWh/100km)	Benchmark energy consumption value by vehicle segment determined in rating system, or potential HDV GHG standard
Annual average VKT (in km)	An estimated annual VKT by vehicle segment, details in Annex
Energy price (in CNY/L, CNY/kWh)	Annual average energy retail price. Including gasoline, diesel, electricity, CNG, LPG, hydrogen.
Vehicle energy efficiency (*EE,* L/100km or kWh/100km)	Energy consumption for the specific labelled vehicle
Annual energy consumption (*EC,* in L/year, kWh/year)	$EE \times 0.01 \times Annual\ VKT$
Energy Cost Rate (CNY/km)	$EC \times Energy\ Price$
5-year fuel cost saving (CNY)	$5 \times \frac{EE - Fleet\ Ave.EE}{100} \times Annual\ VKT \times Fuel\ Price$

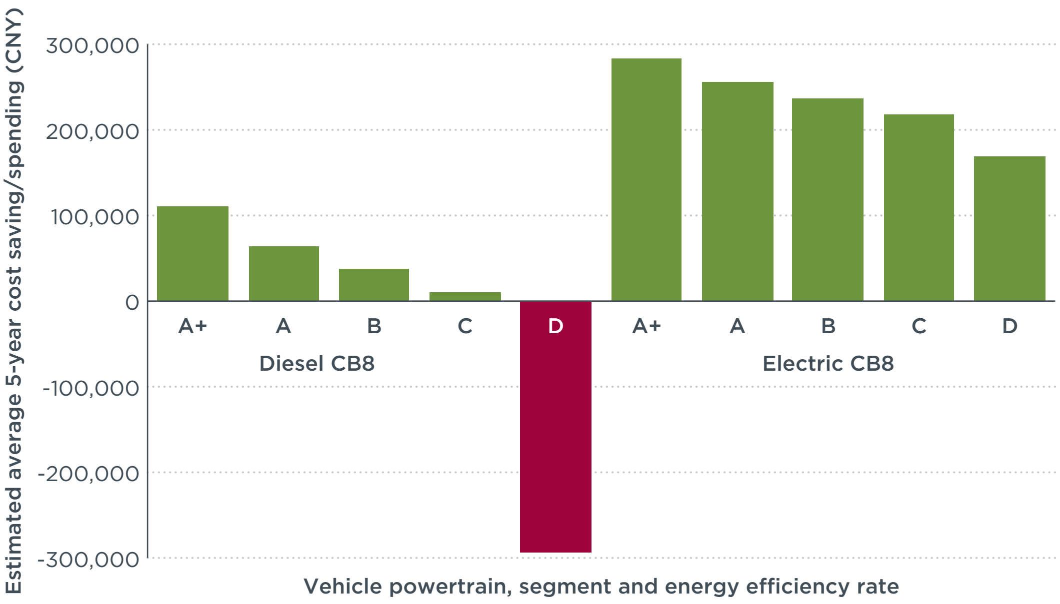


Figure 14. The average 5-year energy cost saving/spending for CB9 fleet estimated by powertrain and rating level

7.2. INCENTIVE POLICY AND FURTHER INFORMATION

In China, various incentive policies promote low- and zero-emission HDVs including purchase subsidies, tax reduction and exemption, and access rights to specific zones or on specific dates, among others. (Xie & Rodriguez, 2021). However, these benefits are easily ignored or missed by consumers, despite being critical to control of TCO. The proposed information on incentive policies includes but is not limited to:

» **Purchase subsidies**, which can be directly labeled.

» **Tax policies**, which are comprehensive and depend on the type of vehicle and tax. A simple yes/no regarding whether the vehicle can benefit from tax policies can be labeled, and the detailed policies and benefits can be posted online.

» **Others, such as toll fees and accessibility**, which are also comprehensive and city-specific. These may only be able to be posted online.

Because incentive policies change quickly and may be different every year in China, a clear disclaimer would be necessary on the label note to inform consumers that all costs and benefits are current as of creation of the HDV label, and that they might change in the future.

7.3. ACCESS TO EXTENSIVE INFORMATION IN LABEL NOTE

As mentioned, we suggest that an official website or manufacturers' platform provide extensive information such as detailed vehicle technical information and consumer incentives; for China, the existing data disclosure system is a great start. It can take the form of a customized information platform on smartphones—an app—since people today frequently conduct research using their phone, often well ahead of going to a showroom. Access to extensive information can be provided via a website address or a QR-code.

8. CONCLUSIONS AND POLICY RECOMMENDATIONS

This section provides the conclusions and policy recommendations for China HDV GHG labeling.

8.1. CONCLUSIONS

The key findings for labeling programs are:

1. **Vehicle GHG emissions or efficiency labeling or information disclosure programs are key complements to regulations and fiscal policies in curbing vehicular GHG emissions and improving their energy efficiency.** Thirty markets (EU 27 member states count as a single market) that have adopted vehicle GHG emission control programs have included some form of vehicle labeling. Nevertheless, experience with HDV labeling programs has been sparse.
2. **A global review of labeling programs shows that a typical vehicle GHG or efficiency label contains four types of information: vehicle information, GHG and efficiency, economic performance, and label notes.** Sixty-six percent of labeling programs show vehicle information like manufacture, model, and powertrain type. Ten will include vehicle segments for more accurate information on efficiency and CO_2 emissions. Ninety percent of the programs labeled energy efficiency performance or included a rating, and 66% gave CO_2 performance or rating for in-use performance or consumer awareness. Twenty percent of the total further includes economic performance with more consideration from the consumer side. Finally, more than 80% of labels have reminders on assumptions or disclaimers, and more than 50% have access to extensive information.
3. **From the literature review of surveys of consumer-focused information, vehicle technical information including battery, driving range, and charging time, and economic performance such as purchase price, energy consumption and cost savings are critical in the purchase decisions of private car owners.** Among these variables, driving range, purchase price, energy consumption, and cost savings are also concerns of HDV buyers. In particular, accurate information on energy consumption and economic data could be a deciding factor to buyers to control their total cost of ownership of their HDVs.
4. **Further investigation is needed on fundamental methodologies for labeling key information, including GHG emissions and efficiency, the rating system, and economic performance:** Most markets adopted vehicle testing or simulations to determine CO_2 and energy efficiency for labeling programs or regulatory standards, while the broad GHG emissions are lacking. Further, rating HDV performance by segment using benchmark value is a more reasonable solution for HDV labeling. Then, economic attractiveness can be estimated by both measured energy efficiency and the benchmarks.

8.2. POLICY RECOMMENDATIONS FOR CHINA HDV GHG LABELING

Based on our findings, we recommend the following actions to establish a robust HDV GHG emission labeling program for China:

1. **China needs to establish an HDV GHG labeling for all GHGs emissions, to include CO_2, N_2O, CH_4, and HFC emissions, with total annual GHGs expressed in terms of CO_2 equivalents.** With the inclusion of non-CO_2 emissions, reporting total GHG emissions (rather than individual emissions for each GHG) will be an important common metric for comparing different vehicles.
2. **China HDV GHG labeling should classify HDVs by vehicle type, powertrain type, and GVW segment.** Vehicle types should include straight trucks,

dump trucks, tractor trailers, coaches and buses, and utility vehicles, and the segmentation can follow the method in China Fuel Consumption Standard. At the same time, the labeling should cover all powertrain types, especially for electric or fuel-cell HDVs, which are critical for emissions reduction.

3. **The elements on the HDV GHG label shall reflect the regulatory goals and address consumers' concerns.** Therefore, we recommend that China HDV GHG label include 1) basic technical vehicle information; 2) GHG emissions and energy efficiency performance and rating; 3) economic performance such as energy cost and savings, and incentive policies; 4) label notes for necessary reminders and access to extensive information. Figure 7 and Figure 8 illustrate the proposed label designs for a diesel straight truck in segment ST8 (GVW 16,000 kg–20,000 kg), and an electric coach in CB9 (GVW 16,500 kg–18,000 kg).

The following recommendations focus on the methodologies of key elements of the China HDV GHG labeling program:

4. **Measures of CO_2 emissions and energy efficiency values should be based on vehicle testing or simulation; measures of N_2O and CH_4 emissions on vehicle testing, measures of HFC emissions on the refrigerant GWP and on the leakage rate of the MVAC. Calculating total annual GHG emissions should be based on measured emissions of CO_2, N_2O, CH_4 and HFC, expressed in CO_2 equivalent, and on assumptions of annual vehicle kilometers traveled (VKT).** HDV CO_2 standards in the EU and U.S. provide examples of measuring HDV CO_2 emissions and energy efficiency by vehicle testing or simulation, and of measuring HFC emissions. The U.S. further provides references for measuring non-CO_2 HDV GHG emissions.

5. **We propose rating the performance of GHG emissions and energy efficiency based on the deviation of the benchmark value by vehicle type, GVW segment, and powertrain type, and rating the MVAC system based on a combination of refrigerant GWP value and its leakage rate.** The EU's HDV CO_2 standard provides a good example of setting benchmark values using a fleet-average method. EU and U.S. standards on MVAC provide reference regulatory limits on refrigerant's GWP and leakage rate.

6. **The estimated cost savings are relative to a benchmark (diesel) vehicle of the same vehicle segment. The cost of a vehicle model is calculated by multiplying its certified energy consumption, the energy retail price, and a presumed VKT for the vehicle category.** Energy cost savings are critical to make consumers aware of the benefits of clean and low-carbon HDVs. To highlight the economic benefits of ZEVs, all vehicles' cost savings are proposed to be compared with the diesel HDVs' benchmark value for each segment.

7. **The label shall denote key assumptions to the environmental and economic ratings** (such as VKT, energy retail price etc.) and provide disclaimers on the potential discrepancies between labeled value and real-world performance, to avoid misunderstandings regarding the reported results.

8. **The label may provide a QR code that links to external resources with extensive information about the vehicle models' environmental performance, if such details do not fit on the label.** The place where consumers can get more detailed vehicle technical information and incentive policies could be an official website, a manufactures' platform, or even a smart phone application**.**

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ANNEX I. OVERVIEW OF SIMULATION TOOLS DEVELOPMENT

Table A1 summarizes reviewed regulatory documents and stakeholder interviews for the simulation tool development in China, EU, US, Korea, and Japan. Further details for China, EU, and U.S. are discussed.

Table A1. Advanced and Chinese local HDV simulation tools for the determination of fuel consumption and GHG emissions

	China	VECTO (EU)	GEM (US)	HES (Korea)	MLIT Tool (JAPAN)
Developer (Leader)	CATARC	Graz University of Technology on behalf of EC	US. EPA, (NHTSA)	MOE & NIER	MLIT, Japan
Adopted date	Internal testing stage	December 2017	January 2011	3rd distribution in 2019	Set in 2005
Supporting regulation and methodology	HDV FE standard (MIIT): *GB 30510-2018*; Measurements (MIIT): *GB/T 27840-2021* *GB/T 19745-2021*	HDV CO_2 standard Fuel consumption certification regulation	HDV GHG emissions standard (EPA); HDV Fuel efficiency standards (NHTSA)	CO_2 emission monitoring regulation (MOE, expected in 2024)	HDV fuel economy standard (MLIT)
Covered vehicle types	Tractor trailers, straight trucks, dump trucks, coaches, city buses	Class N2 vehicles with a gross vehicle weight (GVW) above 7.5 tonnes and class N3 vehicles Extension to trucks with GVW < 7.5 tonnes, buses and coaches in 2022.	Class 7 and 8 combination tractors and Class 2b-8 vocational vehicles	Rigid trucks: tractors and buses	Diesel trucks (>3/5t), Tractor trucks, buses
Covered powertrain types	Diesel, hybrid, BEV, CNG	Diesel, petrol, ethanol, liquid petroleum gas, natural gas. Extension to dual fuel*, hybrid, and BEVs in 2022. Extension to FCEVs and H_2-ICE vehicles is under study	Diesel, gasoline, CNG, LNG	Diesel, CNG	Diesel
Test cycles	Specific China cycles for each HDV category: CHTC-C CHTC-LT CHTC-HT CHTC-D CHTC-TT C-WTVC Custom cycles available.	5 VECTO cycles: urban delivery (UD) regional delivery (RD) long-haul (LH) municipal utility (MU) construction I. Custom cycles available (time-based or distance-based)	5 GEMs cycles: CARB HHDDT cycles[2] 2 cruise cycles 2 idle cycles for vocational vehicles only	WHVC[3] Korean-WHVC	For light HDTs: WLTC[4] Urban for HDVs: JE05[5] Interurban HDVs: HDV Interurban Testing Cycle
Related outputs	Fuel consumption (in L/100km, kWh/100km, etc.)	CO_2 emissions (in g/km, g/t-km, etc.) Fuel consumption (in L/100km, g/t-km, MJ/km, etc., Extension to electric energy consumption in 2022.) Extension to the impact of trailers and semi-trailers on the vehicle's CO_2 emissions and energy consumption in 2022.	CO_2 emissions (in g/t-mile) Fuel consumption (in gal/1000t-mile)	CO_2 emissions (in g/km) Fuel consumption (in km/L)	Fuel consumption (in km/L)

* Type 2A dual-fuel engine only, which means a dual-fuel engine that operates over the hot part of the WHTC test-cycle with an average gas ratio between 10 per cent and 90 per cent (10 % < GERWHTC < 90 %) and that has no diesel mode or that operates over the hot part of the WHTC test-cycle with an average gas ratio that is not lower than 90 per cent (GERWHTC ≥ 90 %), but that idles using exclusively diesel fuel, and that has no diesel mode

2 CARB HHDDT is for California Air Resources Board's heavy heavy-duty diesel truck
3 WHVC is for World Harmonized Vehicle Cycle
4 WLTC is for Worldwide Harmonized Light Vehicles Test Cycles
5 JE05 is for Japanese Heavy-duty Urban Test Cycle

CHINA

China has actively studied energy efficiency and vehicle simulation methods for decades; one of the sources used is the Commercial Vehicle Energy Consumption Simulation Tool developed by CATARC. This tool is a very comprehensive version with the capacity to model different HDV types, powertrain types, testing cycles, and even driver styles. This tool is developed under the proposed simulation methodology in GB/T 27840 (National Standard for Fuel Consumption Test Methods for Heavy-duty Commercial Vehicles) for conventional HDVs, and is upgraded with hybrids and electric vehicles for its internal version.

The latest version of this tool can simulate fuel consumption for different types of HDVs under 5 specific China heavy-duty commercial vehicle test cycles (CHTC test cycles, including CHTC for bus and coach (CHTC-C), light HDTs (GVW ≤ 5,500 kg, CHTC-LT), heavy HDTs (GVW > 5,500 kg, CHTC-HT), dump trucks (CHTC-D) and tractor trailers (CHTC-TT)), China World Transient Vehicle Cycle (C-WTVC) or any other custom cycle. Further, their validation results show that the gap between the simulation and testing results is only 4.37% for semi-tractor trailer and 3.36% for straight truck under the under C-WTVC. (Liu, 2021)

EU

VECTO is the simulation tool that has been developed by the European Commission and shall be used for determining CO_2 emissions and fuel consumption from heavy-duty vehicles. The requirement to use VECTO currently only applies to trucks with a gross vehicle weight (GVW) above 7,500 kg powered by internal combustion engines, running on either diesel, natural gas, petrol, ethanol, or liquefied petroleum gas (LPG). However, the tool is constantly updated to match amendments to the certification regulation. The upcoming amendment, which will likely be implemented in July 2022, will extend the requirement to use VECTO to all trucks with a GVW above 3,500 kg, as well as buses and coaches. In addition, manufacturers of trailers and semi-trailers will have to determine the contribution of their bodies to the complete vehicle's fuel consumption and CO_2 emissions. Finally, simulation of the fuel and energy consumption of alternative powertrains will progressively be integrated into VECTO. Dual fuel, hybrid and fully electric vehicles will be covered as soon as 2022, while fuel cell electric and hydrogen combustion engine vehicles will be covered at a later stage.

VECTO offers a large number of inputs to account for the performance of a specific truck's components and subsystems. These include engine characteristics and fuel consumption maps, aerodynamic features, tire rolling resistance, and transmission efficiencies, among others. Five duty cycles are used in VECTO, to account for the different operating conditions encountered by vehicles. These include the Urban Delivery, Regional Delivery, Long-Haul, Municipal Utility, and Construction cycles. Depending on the vehicle segment a truck belongs to, its CO_2 emissions and fuel consumption are determined by running VECTO simulations over specific combinations of these duty cycles and regulatory payloads. Simulation results are then communicated individually for each combination of payload and cycle.

US

The Greenhouse Gas Emission Model (GEM) was developed by U.S. Environmental Protection Agency (EPA) as a means of determining compliance with EPA's GHG emissions standard and National Highway Traffic Safety Administration (NHTSA)'s fuel efficiency standards (US EPA, 2011a), for Class 7 and 8 combination tractors and Class 2b-8 vocational vehicles. The latest version is GEM P2v3.5.1. The tool is used both by the agency to develop greenhouse gas emission standards and by manufacturers to demonstrate compliance. It covers regulatory HDV subcategories fueled by diesel, gasoline, and nature gas (U.S. EPA, 2016).

Similar to the VECTO model, various physical characteristics of each vehicle are measured by manufactures and then used as inputs to the GEM model, including engine characteristics and maps, aerodynamic features, tire rolling resistance, and transmission efficiencies, among others. Then, HDV's energy efficiency is calculated under a weighted average over 3 specific drive cycles; for vocational vehicles 5 testing cycles are used, including 2 extra idling cycles. Some generic values for input will usually be taken from a built-in database to reduce the pre-testing work for each vehicle. Compared to VECTO, important differences can be found in the driver model and gearshift strategies (Rodriguez, 2018; Sharpe et al., 2016).

ANNEX II. VEHICLE SEGMENTATION FOR LABELING

Table A2 gives the proposed vehicle segmentation compliance levels under the China Fuel Efficiency standard. Note that for straight trucks, dump trucks, utility vehicles, city buses and coaches it refers to the gross vehicle weight (GVW); for tractor trailers it refers to gross combination weight (GCW).

Table A2. Vehicle segmentation according to China's Fuel Efficiency Standard, along with annual VKT assumptions

Vehicle type	Fleet name	Weight segment*	Annual VKT assumption
Straight truck Dump truck Utility vehicle	ST1 / DT1 / UV1	3,500 kg–4,500 kg	ST1 – ST5: 30,000 km DT1 – DT5: 25,000 km UV1 – UV5: 30,000 km
	ST2 / DT2 / UV2	4,500 kg–5,500 kg	
	ST3 / DT3 / UV3	5,500 kg–7,000 kg	
	ST4 / DT4 / UV4	7,000 kg–8,500 kg	
	ST5 / DT5 / UV5	8,500 kg–10,500 kg	
	ST6 / DT6 / UV6	10,500 kg–12,500 kg	ST6 – ST9: 50,000 km DT6 – DT9: 30,000 km UV6 – UV9: 30,000 km
	ST7 / DT7 / UV7	12,500 kg–16,000 kg	
	ST8 / DT8 / UV8	16,000 kg–20,000 kg	
	ST9 / DT9 / UV9	20,000 kg–25,000 kg	
	ST10 / DT10 / UV10	25,000 kg–31,000 kg	ST10 – ST11: 60,000 km Other: 35,000 km
	ST11 / DT11 / UV11	31,000 kg above	
Coach and bus	CB1	3,500 kg–4,500 kg	CB1 – CB5: 55,000 km
	CB2	4,500 kg–5,500 kg	
	CB3	5,500 kg–7,000 kg	
	CB4	7,000 kg–8,500 kg	
	CB5	8,500 kg–10,500 kg	
	CB6	10,500 kg–12,500 kg	CB6 – CB9: 60,000 km
	CB7	12,500 kg–14,500 kg	
	CB9	14,500 kg–16,500 kg	
	CB9	16,500 kg–18,000 kg	
	CB10	18,000 kg–22,000 kg	
	CB11	22,000 kg–25,000 kg	CB10 – CB11: 65,000 km
	CB12	25,000 kg above	
Tractor trailer	TT1	3,500 kg–18,000 kg	TT1 – TT3: 60,000 km
	TT2	18,000 kg–27,000 kg	
	TT3	27,000 kg–35,000 kg	
	TT4	35,000 kg–40,000 kg	TT4 – TT6: 65,000 km
	TT5	40,000 kg–43,000 kg	
	TT6	43,000 kg–46,000 kg	
	TT7	46,000 kg–49,000 kg	TT7 – TT8: 70,000 km
	TT8	49,000 kg above	