2017 GLOBAL UPDATE

LIGHT-DUTY VEHICLE GREENHOUSE GAS AND FUEL ECONOMY STANDARDS

ZIFEI YANG AND ANUP BANDIVADEKAR

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1225 I Street NW, Suite 900, Washington DC 20005

communications@theicct.org | www.theicct.org | @TheICCT

T +1 202.534.1600

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1. INTRODUCTION

Global greenhouse gas (GHG) emission and fuel economy standards for light-duty vehicles (LDVs) have progressed significantly in a little more than a decade. Ten years ago, only four governments had introduced mandatory GHG emission/fuel economy[1] standards: China, Japan, South Korea, and the United States. The European Union and Canada had announced their intention to introduce GHG emission standards, but neither government had a legislative framework in place. Today, 10 governments—Brazil,[2] Canada, China, the European Union, India, Japan, Mexico, Saudi Arabia, South Korea, and the United States—have established fuel economy or GHG emission standards for LDVs. And all are among the top 15 vehicle markets worldwide: nearly 80% of new LDVs sold globally are currently subject to some kind of GHG emission or fuel economy standards. Other large markets, such as Australia, Thailand, and Vietnam, are in the process of developing standards as well.

The goal of GHG and fuel economy standards—to limit the amount of carbon dioxide emitted by vehicles and reduce their petroleum consumption—is crucial to any realistic plan to mitigate global warming.[3] Through implementation and strengthening of these standards, governments worldwide are demonstrating their commitment to: (a) improving global environmental health by reducing dependence on fossil fuels that are becoming ever harder to find, extract, and process, as well as keeping global agreements to limit climate change to less than 2°C (most notably the Paris Agreement in 2015); (b) ensuring energy security by reducing oil imports and reliance on politically unstable oil-producing nations; (c) protecting consumers' economic interests by shielding them from fluctuating oil prices; and (d) driving technological innovation, because manufacturers are able to meet the standards without sacrificing other aspects of vehicle performance.

Because the individual regulations that define GHG and fuel-efficiency standards differ in ways that affect how vehicle performance against standards is measured—for example, different test procedures require a vehicle to be tested in dissimilar conditions over a dissimilar operating range—the various standards are not directly comparable. In 2004, the Pew Center on Global Climate Change produced the first attempt to compare the vehicle standards in place at the time by applying conversion factors to account for differences in test procedures (An & Sauer, 2004). In 2007, ICCT researchers collaborated in an effort to improve on that methodology and reviewed worldwide standards in the publication Passenger Vehicle Greenhouse Gas and Fuel Economy Standards: A Global Update (ICCT, 2007).[4]

1 Because the values of greenhouse gas emission (in g/km or g/mi), fuel economy (l/km, mi/gallon), fuel consumption (l/100km), and energy consumption (MJ/km) can be converted to each other, these terms are interchangeable throughout this report.

2 The Brazil Inovar-auto program provides a strong tax incentive to manufacturers that have their vehicle fleet reach a certain fuel efficiency level. It is regarded as different from other tax incentive systems; therefore, this report compares its program in parallel with fuel efficiency standards in other regions.

3 The transport sector contributes 23% of global anthropogenic GHG emissions. Of that amount, 74% come from road transport (Miller & Façanha, 2014; Sims et al., 2014).

4 See also the regional policy updates and other materials collected at "Global passenger vehicle standards," http://www.theicct.org/info-tools/global-passenger-vehicle-standards

This report is an update to that 2007 publication. In it, we examine how the GHG and fuel economy standards have changed over time and how the auto industry in different regions has reacted, and we discuss how the standards may evolve in the future. We compare characteristics of vehicle fleets in major markets, and we estimate the policy impacts of fuel economy standards on transport GHG emission levels around the world.

To this update we have also added summaries of fuel economy standards for light trucks and commercial vehicles separate from those for passenger cars as more regions have set separate standards for light trucks and commercial vehicles. We have also revised the conversion factors across test cycles to reflect an improved methodology (Kühlwein, German, & Bandivadekar, 2014) and provide apples-to-apples comparisons among the passenger car fleet and light truck/commercial vehicle fleet. We also identify the principal regulatory trends in this policy area. We conclude with a summary of key findings.

2. OVERVIEW OF LDV FUEL ECONOMY TRENDS WORLDWIDE

2.1 CHARACTERISTICS OF VEHICLE FLEETS AROUND THE WORLD

2.1.1 DEFINITIONS OF PASSENGER CAR AND LIGHT TRUCK/COMMERCIAL VEHICLE

To clarify the scope of the GHG standards across regions, Table 1 lists the definitions of *passenger car* and *light truck/commercial vehicle* in each region. The definitions are different in maximum gross vehicle weight (GVW) and seat requirement, but generally fall into two groups. For passenger car, the maximum GVW is 3,856 kg in Brazil, Canada, Mexico, and the United States, whereas the maximum GVW is 3,500 kg in China, the European Union, India, Japan, Saudi Arabia, and South Korea. *Light truck* is the term commonly used in the United States, Canada, and Mexico, whereas *light commercial vehicle* (LCV) is used in other regions. The GVW cap for cargo/commercial vehicle is the same as for passenger car in each region. In addition to cargo vehicles, Canada and the United States categorize four-wheel drive SUVs and passenger vans up to 4,536 kg as light trucks, and China also regulates passenger vehicles with more than 9 seats in its LCV standards. The term light truck and LCV are interchangeable in this report. Note that the same vehicles maybe categorized differently in different regions. For example, four-wheel drive SUVs are registered as light trucks in the United States and would likely be registered as passenger cars in the European Union because they are used for private purposes. It is necessary to be mindful of these categorization differences, but we do not take them into account in the comparison of passenger cars and LCVs across regions.

Table 1. Definitions of passenger car and light truck/commercial vehicle

	Passenger car		Light truck/commercial vehicle	
	Max. GVW	Max. seats	Cargo vehicle max. GVW	Others
Brazil	3,856 kg	12	3,856 kg	/
Mexico	3,856 kg	12	3,856 kg	/
U.S. and Canada	3,856 kg	12	3,856 kg	Four-wheel drive SUVs and passenger vans ≤ 4,536 kg
China	3,500 kg	9	3,500 kg	Passenger vehicles with more than 9 seats and GVW ≤3,500 kg
EU	3,500 kg	9	3,500 kg	/
India	3,500 kg	9	3,500 kg	/
Japan	3,500 kg	10	3,500 kg	/
Saudi Arabia	3,500 kg	10	3,500 kg	/
South Korea	3,500 kg	10	3,500 kg (With 15 seats or fewer)	/

2.1.2 FLEET CHARACTERISTICS

The characteristics of passenger car and LCV fleets vary widely across regions. The vehicle specifications, including engine size, engine power, vehicle weight, and vehicle size, have an impact on the GHG emission level. For example, with similar energy-saving technologies, heavier and larger vehicles with larger engine and higher power tend to have higher fuel consumption and GHG emissions. For cars with similar characteristics, diesel cars are typically more efficient than gasoline cars because of the higher energy density of diesel fuel compared with gasoline, and because of the different combustion process.

Table 2 compares the passenger car fleet specification in some key automotive markets worldwide. Canada is excluded from the table because of a lack of data, but its fleet characteristics are similar to that of the United States. China, the European Union, and the United States are the top three passenger car markets based on new passenger car sales.

Table 2. Fleet specification of passenger car fleet

Passenger car fleet	Brazil (2013)	China (2014)	EU-28 (2015)	India (2015)	Japan (2011)	Mexico (2014)	Saudi Arabia (2012)	South Korea (2014*)	U.S. (2015)
Sales (million)	3.0	20.7	13.7	2.8	3.5	0.7	0.4	1.4	7.5
Engine displacement (L)	1.4	1.7	1.6	1.3	1.4	1.8	2.3	2.0	2.4
Engine power (kW)	76	98	93	59	78	95	120	120	149
Curb weight (metric tons)	1.1	1.4	1.4	1.1	1.2	1.2	1.4	1.5	1.6
Footprint (m²)	3.7	4.1	4.0	3.5	3.7	3.8	4.2	4.2	4.3
Fuel consumption - NEDC (l/100km)	6.8	7.3	5.1	5.3	5.8	6.3	6.8	6.4	6.8
CO_2 emission - NEDC (g/km)	154	171	120	123	136	147	158	148	158
Petrol	6%	98%	44%	47%	86%	99%	-	51%	94%
Diesel	0%	2%	52%	50%	0%	1%	-	39%	1%
Hybrid-electric	0%	0%	2%	0%	13%	0%	-	0%	5%
Others	94%	0%	2%	3%	1%	0%	-	10%	0%
Manual transmission	83%	49%	75%	92%	1%	56%	-	2%	6%
Automatic transmission	17%	51%	25%	8%	99%	44%	-	98%	95%

* South Korea footprint reflects 2011 fleet, engine power reflects 2013 fleet
Data sources: (Marklines, 2016; Mock, 2016), additional ICCT internal databases

In terms of engine size and power, the United States has the passenger car fleet with the largest average engine size of 2.5 L and highest average power of 150 kW, followed by Saudi Arabia (2.3 L, 120 kW), South Korea (1.9 L, 120 kW), and Mexico (1.8 L, 95 kW). The passenger car fleets in India, Brazil, Japan, the European Union, Mexico, and China have smaller engines with lower power. India has the smallest average engine size of 1.3 L and lowest average power of 59 kW, less than half of the U.S. fleet. Average engine sizes are expected to decrease somewhat as turbocharged gasoline engines will become more common.

In terms of vehicle weight and size, the United States, South Korea, and Saudi Arabia have fleets with heavier (avg. 1.4–1.6 metric tons) and larger (avg. 4.2–4.3 m²) passenger cars. The European Union also has an average fleet weight of 1.4 tons, but cars are smaller—4 m², on average. Passenger cars in China, Brazil, Japan, and India are lighter and smaller. India has the fleet with lightest (avg. 1.1 metric tons) and smallest (avg. 3.5 m²) passenger cars.

Gasoline cars dominate the passenger car market in China, Japan, Mexico, and the United States, whereas diesel cars account for roughly half the market in the European Union, India, and South Korea. The Brazilian passenger car market is dominated by flex-fuel vehicles that are designed to run on gasoline (E22), ethanol (E100), or any combination of both fuels. Hybrid-electric car sales are relatively high in Japan and the United States, accounting for 19% and 5% of the passenger car market, respectively. In South Korea, 10% of new cars run on liquefied petroleum gas.

In Japan, the United States, and South Korea, nearly all new passenger cars are equipped with an automatic transmission system, whereas a manual transmission system is included in most new passenger cars in Brazil, the European Union, and India. In China and Mexico, roughly half of new passenger cars are equipped with a manual transmission and the other half with an automatic transmission.

Table 3 compares LCV fleet specification in some key automotive markets worldwide. Some regions are absent because of a lack of data. New LCV sales in the United States are the highest, because of the popularity of pickup trucks, but also because of the classification of four-wheel drive SUVs as light trucks. China and the European Union are the second and third highest LCV markets.

Table 3. LCV fleet specifications

Light commercial vehicle fleet	China (2012*)	EU-28 (2015)	India (2014)	Japan (2013)	Mexico (2014)	Saudi Arabia (2012)	South Korea (2014)	U.S. (2015)
Sales (million)	2.6	1.7	0.3	0.8	0.2	0.4	0.2	10.3
Engine displacement (L)	1.7	1.9	1.6	1.0	2.7	3.7	2.3	3.8
Engine power (kW)	46	86	33	-	135	173	-	211
Curb weight (metric tons)	1.4	1.8	1.3	1.1	1.7	2.0	1.9	2.2
Footprint (m²)	3.5	5.2	3.6	-	4.6	4.6	-	5.2
Fuel consumption - NEDC (l/100km)	8.7	7.2	6.8	6.5	9.6	10.7	8.9	9.7
CO_2 emission - NEDC (g/km)	202	168	158	151	224	251	209	226
Petrol	48%	3%	0%	94%	95%	-	0%	98%
Diesel	51%	97%	89%	6%	5%	-	96%	2%
Hybrid-electric	0%	0%	0%	0%	0%	-	0%	1%
Others	1%	1%	11%	0%	0%	-	4%	0%
Manual transmission	100%	96%	100%	-	65%	-	28%	1%
Automatic transmission	0%	4%	0%	-	35%	-	72%	99%

* China sales reflects 2014 fleet, footprint reflects 2010 fleet
Data sources: (CATARC, 2013; Mock, 2016), additional ICCT internal databases

Similar to comparison of the passenger vehicles fleet, the U.S. light truck fleet has the heaviest and largest vehicles with the largest engine displacement and highest power, on average, followed by Saudi Arabia, Mexico, and South Korea. The European Union's LCV fleet is heavier and larger than the fleet in Mexico, but the engine is smaller, on average, with lower power. The LCVs in China, India, and Japan are much smaller and lighter with less powerful engines.

Some markets have a far greater share of diesel vehicles in the LCV fleet than in their passenger car fleet. For example, the European Union, India, and South Korea are dominated by diesel LCVs. The split of gasoline and diesel LCVs in China is 50/50. Most light trucks in the United States and Mexico run on gasoline.

In the United States, nearly all new light trucks are equipped with an automatic transmission system, whereas a manual transmission system is common in most new LCVs in China, the European Union, and India. In Mexico, about half of new light trucks are equipped with a manual transmission, and the other half with an automatic transmission.

2.2 STATUS AND SPECIFICATIONS OF GLOBAL FUEL ECONOMY STANDARDS

2.2.1 OVERVIEW OF GLOBAL GHG EMISSION AND FUEL ECONOMY STANDARDS

Policymakers are faced with many choices when making GHG emission/fuel economy standards, including

- Which metric to regulate;
- Whether to set a single fleet-average standard or take a tiered approach;
- Which attribute to base the target on (e.g., vehicle footprint, weight, class, engine size, or interior size);
- Which test cycle to adopt; and
- Which year to target.

Tables 4 and 5 summarize the basic policy approaches adopted by various regions.

Table 4. Overview of regulation specifications for passenger cars

Country or Region	Target Year	Regulated metric	Unadjusted Fleet Target/Measure	Form of target curve	Test Cycle
Brazil	2017	Energy consumption	1.82 MJ/km	Weight-based corporate average	U.S. combined
Canada	2016 2025	GHG	217 gCO_2/mi[1] N/A[2]	Footprint-based corporate average	U.S. combined
China	2015 2020	Fuel consumption	6.9 L/100km 5 L/100km	Weight-class based corporate average	NEDC
EU	2015 2021	CO_2	130 gCO_2/km 95 gCO_2/km	Weight-based corporate average	NEDC[4]
India	2017 2022	CO_2	130 g/km 113 g/km	Weight-based corporate average	NEDC for low-powered vehicle
Japan	2015 2020	Fuel economy	16.8 km/L 20.3 km/L	Weight-class based corporate average	JC08[4]
Mexico	2016	Fuel economy/ GHG	39.3 mpg or 140 g/km	Footprint-based corporate average	U.S. combined
Saudi Arabia	2020	Fuel economy	17 km/L	Footprint-based corporate average	U.S. combined
South Korea	2015 2020	Fuel economy/ GHG	17 km/L or 140 gCO_2/km 24 km/L or 97 gCO_2/km	Weight-based corporate average	U.S. combined
U.S.	2016 2025	Fuel economy/ GHG	36.2 mpg[3] and 225 gCO_2/mi 55.2 mpg[3] and 147 gCO_2/mi	Footprint-based corporate average	U.S. combined

[1] In April 2010, Canada announced a target for its LDV fleet of 246 g/mi for model year 2016. The separated targets for car and light truck fleet are estimated by ICCT based on the overall target.
[2] Canada follows the U.S. standards in the proposal, but the final target value would be based on the projected fleet footprints.
[3] Assumes manufacturers fully use low-Global Warming Power (GWP) A/C refrigerants credits
[4] EU and Japan plan to switch to WLTP by 2018.

Table 5. Overview of regulation specifications for light-commercial vehicles

Country or Region	Target Year	Standard Type	Unadjusted Fleet Target/Measure	Structure	Test Cycle
Canada	2016 2025	GHG	293 gCO_2/mi[1] N/A[2]	Footprint-based corporate average	U.S. combined
China	2020	Fuel consumption	6.9 L/100km	Weight-class based	NEDC
EU	2017 2020	CO_2	175 gCO_2/km 147 gCO_2/km	Weight-based corporate average	NEDC[4]
Japan	2015 2022	Fuel economy	15.2 km/L 17.9 km/L	Transmission, vehicle structure, weight-class based corporate average	JC08[4]
Mexico	2016	Fuel economy/GHG	29.7 mpg or 185 g/km	Footprint-based corporate average	U.S. combined
Saudi Arabia	2020	Fuel economy	13.2 km/L	Footprint-based corporate average	U.S. combined
South Korea	2020	Fuel economy/GHG	15.6 km/L or 166 gCO_2/km	Weight-based corporate average	U.S. combined
U.S.	2016 2025	Fuel economy/ GHG	28.8 mpg[3] and 298 gCO_2/mi 40.6 mpg[3] and 202 gCO_2/mi	Footprint-based corporate average	U.S. combined

[1] In April 2010, Canada announced a target for its LDV fleet of 246 g/mi for model year 2016. The separated targets for car and light truck fleet are estimated by ICCT based on the overall target.
[2] Canada follows the U.S. standards in the proposal, but the final target value would be based on the projected fleet footprints.
[3] Assumes manufacturers fully use low-GWP A/C refrigerants credits
[4] EU and Japan plan to switch to WLTP by 2018.

Since we published our last overview in 2007 (ICCT, 2007), there have been major updates on fuel economy standards globally:

» Brazil introduced the Inovar-Auto program, providing strong tax incentives for manufacturers to meet the non-mandatory fuel economy standards, which are expected to achieve 12%–19% fuel consumption reduction from 2013–2017.

» California has been a pioneer in adopting GHG emission standards at the state level in the United States. California enacted the first state law requiring GHG emission limits from motor vehicles in 2002. The GHG emission standards issued by the California Air Resources Board took effect in 2009. The standards set fleet average caps to vehicles from model year 2009 to 2016. When the national GHG emission standards came into effect in 2012, California reached an agreement with the federal government that allows manufacturers to demonstrate compliance with California GHG standards by demonstrating compliance with national GHG standards (ARB, 2010).

» Canada has harmonized with the U.S. 2016 and 2025 requirements.

» China announced Phases III and IV standards for passenger cars and a Phase III standard for LCVs. The China State Council also announced a 2025 target for passenger cars of 4.0 L/100km (MIIT, 2015).

» The European Union released the 2015 and 2021 CO_2 emission standards for passenger cars and 2020 standards for LCVs. The European Commission is working on post-2020 CO_2 emission standards for cars and vans (European Commission, 2016).

» India released mandatory fuel consumption standards for passenger cars in early 2014 for 2017 and 2022.

- Japan released 2020 standards for passenger cars in 2011 following the 2015 standards. The fleet exceeded its 2015 fuel economy target in 2011 and exceeded its 2020 fuel economy target in 2013. Japan also set 2022 standards for LCVs in 2015 following the 2015 LCV standards.
- Mexico issued the 2016 standards for both passenger cars and LCVs following the U.S. and Canada standards as prototypes.
- Saudi Arabia issued the 2020 standard for both passenger cars and LCVs following the U.S. and Canada standards as prototypes.
- South Korea introduced 2015 and 2020 standards for passenger cars. The 2020 standards also set targets for LCVs.
- The U.S. Environmental Protection Agency (EPA) and National Highway Traffic Safety Administration (NHTSA) jointly established a national program and successively passed the 2012–2016 and 2017–2025 GHG emission and CAFE fuel economy regulations for passenger vehicles and light trucks.

2.2.2 IMPACT OF TEST PROCEDURE ON FUEL ECONOMY OR GHG EMISSIONS

The relative standards level is strongly influenced by the test procedure used to measure fuel economy or GHG emissions. Over the last several decades, the European Union, Japan, and the United States have developed unique test procedures, which also have been adopted by other regions (see Tables 4 and 5), reflecting local driving conditions. Thus, the same vehicle may generate a markedly different fuel economy rating or GHG emissions when tested on the Japanese JC08, the U.S. combined cycle (CAFE), or the New European Driving Cycle (NEDC).

Many countries have been working to harmonize the test methodology and the test cycle. To mitigate manufacturers' costs to certify their vehicles under several procedures and standards, a world-harmonized light-duty vehicle test procedure (WLTP) designed to represent typical driving characteristics around the world was adopted by the United Nations Working Party on Pollution and Energy (GRPE) under the aegis of the World Forum for Harmonization of Vehicle Regulations (WP.29) of the United Nations Economic Commission for Europe (UNECE; Mock, 2013). The harmonized approach also makes it easier to compare fuel economy and emission standards across regions and countries. Japan and the European Union have committed to the WLTP for their fuel economy standards (Mock, Kühlwein, & Tietge, 2014).

For now, most governments that have promulgated or will promulgate fuel economy standards are using one of the above four test procedures for standards compliance. To compare them, an ICCT study (Kühlwein et al., 2014) established CO_2 emission conversion factors for these four test driving cycles. Figure 1 illustrates the relationship between the four test cycles using the new conversion factors, with the U.S. combined cycle as the baseline. The figure compares the level of GHG emissions when tested under the U.S. combined cycle (x-axis) to the level of emissions when tested under the other test cycles (y-axis), without considering difference of other elements (e.g., temperature, humidity) in test procedures. The conversion factors (i.e., the relationship of CO_2 emissions under different test cycles) change with the GHG emissions value, and gasoline and diesel vehicles behave very differently under the four test cycles (Yang, 2015b).

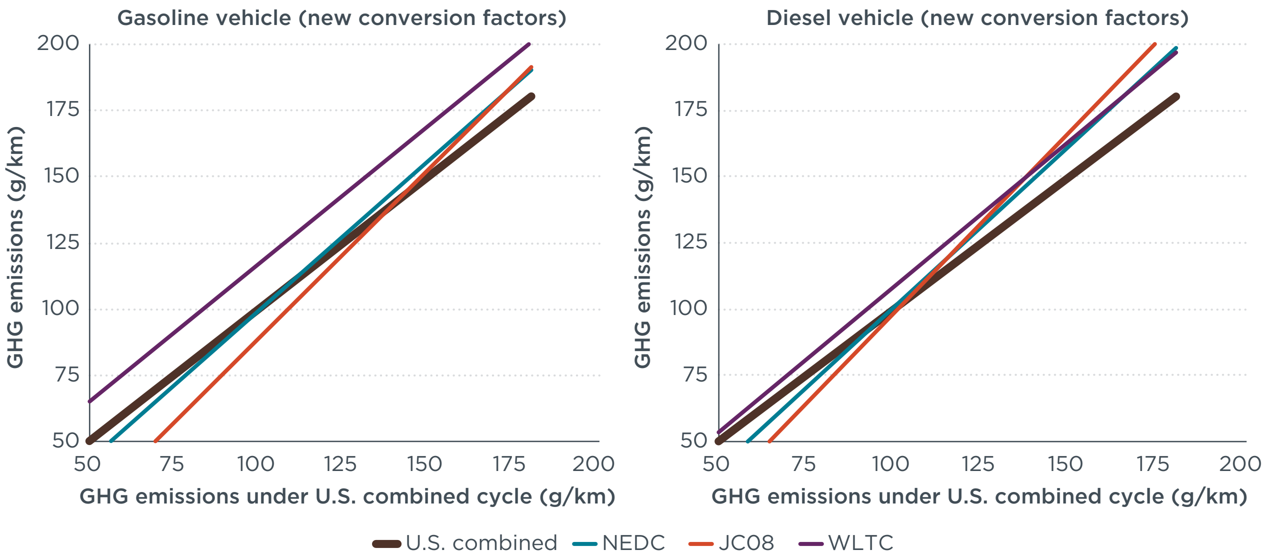

Figure 1. Relative stringency of the four test cycles (gasoline and diesel)

2.2.3 GLOBAL LDV STANDARDS COMPARISON

This section compares the passenger vehicle and light truck standards for both fuel economy and GHG emissions in Brazil, Canada, China, the European Union, India, Japan, Mexico, and Saudi Arabia, South Korea, and the United States. To compare the relative target levels of regulations accurately and fairly, each national standard has been adjusted to common reference standards by the methodology developed in the above-mentioned ICCT study (Kühlwein et al., 2014).

For this study, we adopted reference standards corresponding to two of the most common ways to measure and regulate fuel consumption and GHG emissions from passenger vehicles: a GHG emission standard measured in terms of grams of CO_2-equivalent per kilometer measured on the EU NEDC cycle, and a fuel economy–based standard measured in terms of U.S. CAFE-adjusted miles per gallon. The target values of each national standard are converted to values under these two reference standards.

Figures 2 and 3 compare country standards for passenger vehicles and LCVs in terms of grams of CO_2-equivalent per kilometer adjusted to the European NEDC test cycle.[5] The European Union has historically outpaced the world with the lowest fleet average target of 95 gCO_2/km by 2021. However, South Korea will match, if not exceed, the European Union with a fleet target of 97 gCO_2/km in 2020. With its high hybrid percentage, Japan already reached its 2015 target of 142 g/km in 2011 and 2020 target of 122 g/km in 2013. If Japan continues to reduce CO_2 emissions at the same rate as from 2010 to 2014, Japan's passenger vehicle fleet would achieve 82 g/km in 2020, far below the targets set by other countries. The United States and Canada, long laggard in regulating fuel economy, have evolved into leaders. As the first country with 2025 targets, the U.S. example has encouraged other countries (e.g., Canada) to consider enacting similarly long-term standards. The United States is expected to achieve 45% GHG emission reduction from 2010 to 2025.[6]

5 All comparisons are based on the new methodology developed by ICCT in Kühlwein et al. (2014).
6 China announced a fleet average fuel consumption of 4 L/100 km by 2025 (MIIT, 2015), which would be among the lowest target levels once it is supported by detailed standards.

For LCVs, Japan will be the lead with a fleet target of 133 g/km by 2022, followed by Canada, the United States, and the European Union. The light truck standards in Canada, Mexico, Saudi Arabia, and the United States are harmonized, following the same methodology and standards design. The standards in Mexico and Saudi Arabia are a couple of years behind Canada and the United States with regard to their stringency.

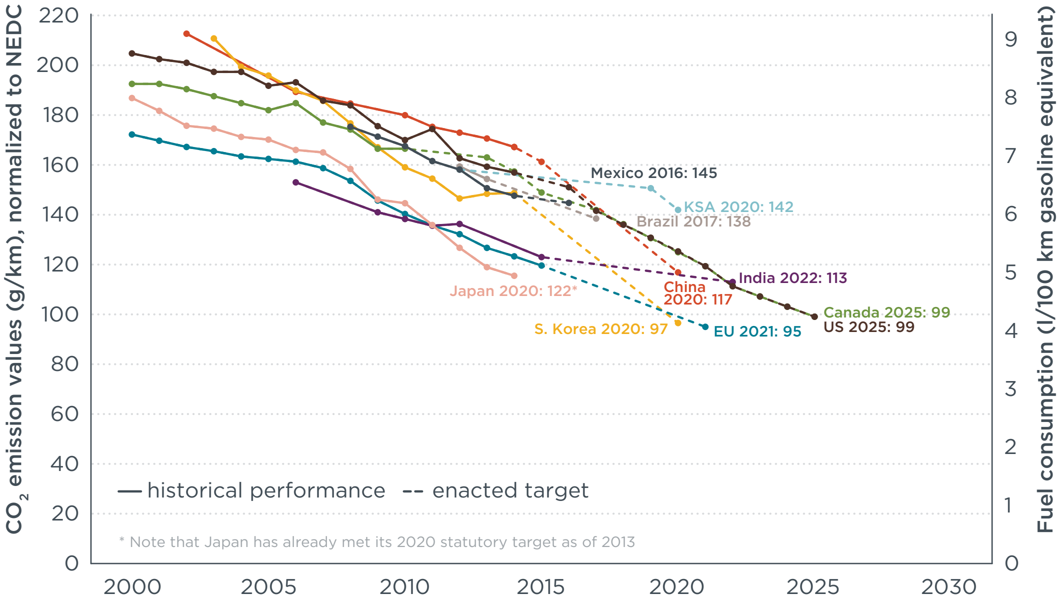

Figure 2. Historical fleet CO_2 emissions performance and current standards (gCO_2/km normalized to NEDC) for passenger cars

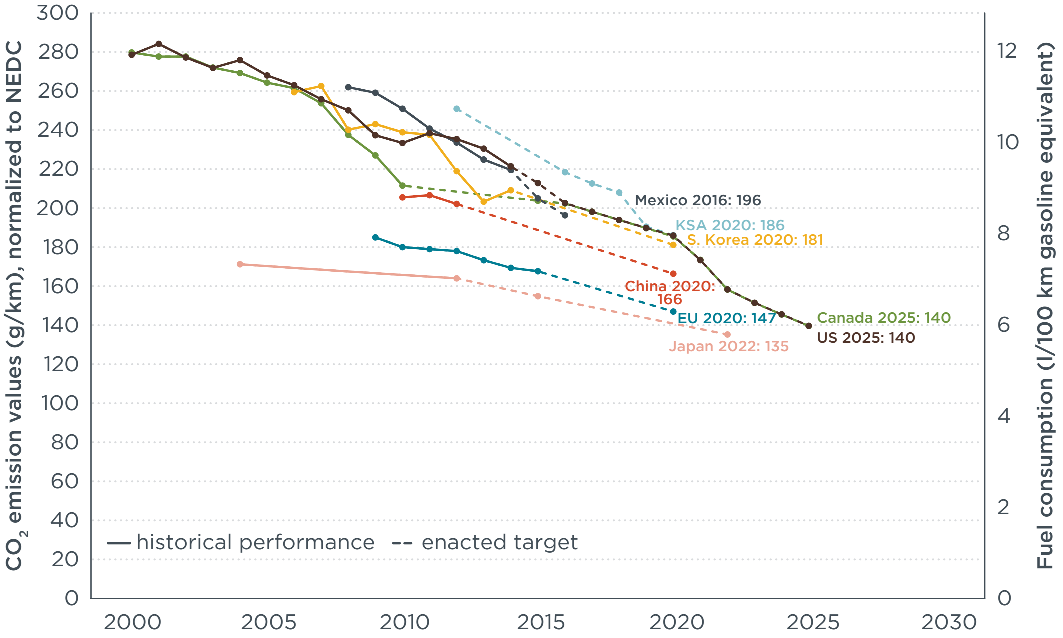

Figure 3. Historical fleet CO_2 emissions performance and current standards (gCO_2/km normalized to NEDC) for LCVs

Figures 4 and 5 show actual and projected fleet average fuel economy from 2000 to 2025 for new vehicles in U.S. combined-normalized miles per gallon for passenger vehicles and LCVs. All fuel economy values presented in gasoline equivalent units take into account varying carbon and energy contents of fuel mix by region (Alternative Fuel Data Center, 2014). The comparative ranking of regulations does not change, with the European Union and South Korea remaining the leaders in terms of fuel economy standards. The U.S. fuel economy target set by NHTSA is slightly different from the GHG target set by EPA, as we assume that manufacturers will take full advantage of the A/C off-cycle credit[7] (i.e., giving manufacturers credits for using A/C refrigerant with low global warming potential).

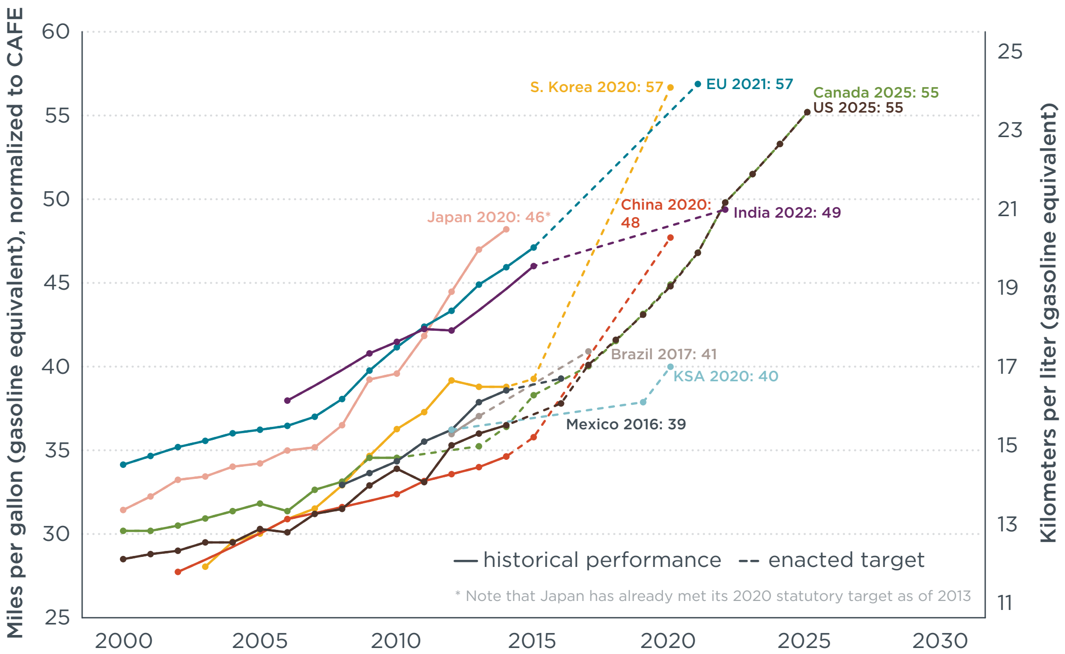

Figure 4. Historical fleet CO_2 emissions performance and current standards (mpg normalized to U.S. CAFE test cycles) for passenger cars

7 Off-cycle credits are used to award manufacturers for implementing technologies or designs that increase efficiency and reduce fuel consumption in the real world, but whose benefits are not captured via the standard testing procedure.

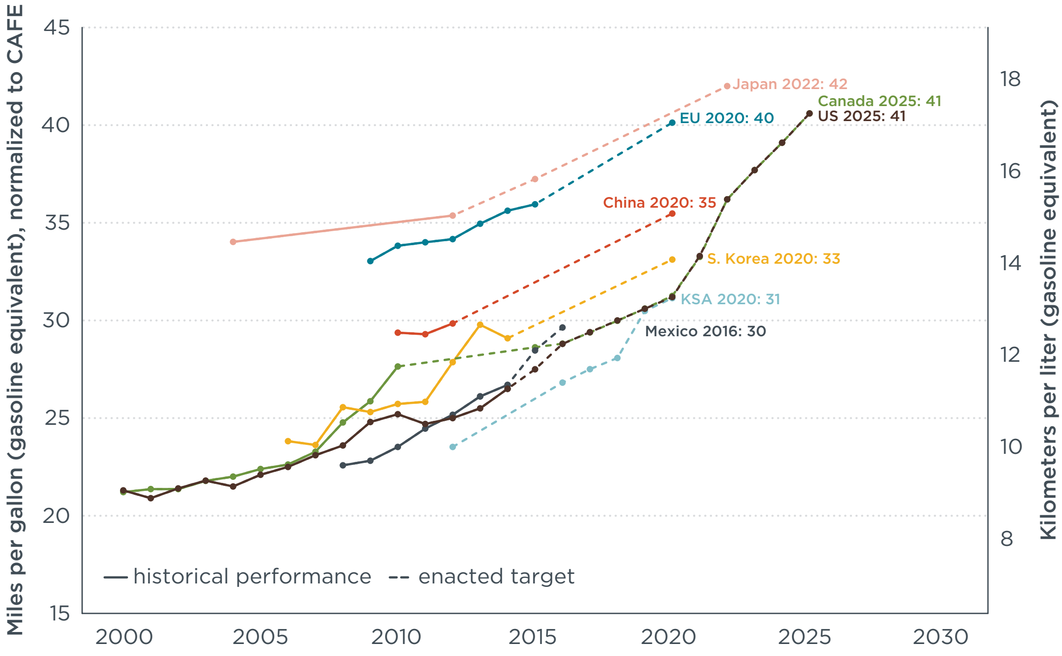

Figure 5. Historical fleet CO_2 emissions performance and current standards (mpg normalized to U.S. CAFE test cycles) for LCVs

Figures 2 to 5 provide an apples-to-apples comparison of passenger vehicle/light-commercial vehicle fuel economy and GHG emission standards in different regions. The figures show that despite the substantial improvements that proposed standards would require in many regions, a large gap remains between the fleet average fuel economy targets required by standards from different parts of the world.

Many factors play an important role in determining vehicle fleet performance for these metrics, such as technology deployment, vehicle size, curb weight, engine size, horsepower, and fuel type. In addition to adoption of efficiency technologies, any change in the fleet characteristics may impact the average performance of the fleet. For instance, the increasing popularity of larger, heavier vehicles in China (GFEI, 2016; Yang, 2015a) is eroding the benefits that would have been realized from the efficiency standards in the absence of the market shift. Although diesel vehicles typically emit less CO_2 per distance of the driving than similar sized gasoline vehicles, the popularity of diesel vehicles among larger, heavier, and more powerful vehicles has meant that the gap of fleet average CO_2 emission between diesel cars and gasoline cars in the European Union has decreased from 9% in 2001 to 3% in 2015 (ICCT, 2015).

2.2.4 IMPROVEMENT TRENDS IN DIFFERENT MARKETS

One way to partially control for the impact of variations in vehicle size, weight, technology penetration, and engine performance across countries is to compare standards in terms of the absolute improvement required over each regulatory implementation period. Figures 6 and 7[8] show the relative improvement required in passenger vehicle and light truck GHG emissions by country and/or region for each respective implementation period as measured under Europe's NEDC test cycle.

8 Figure 7 does not show the full history of standards in some countries because of a lack of data.

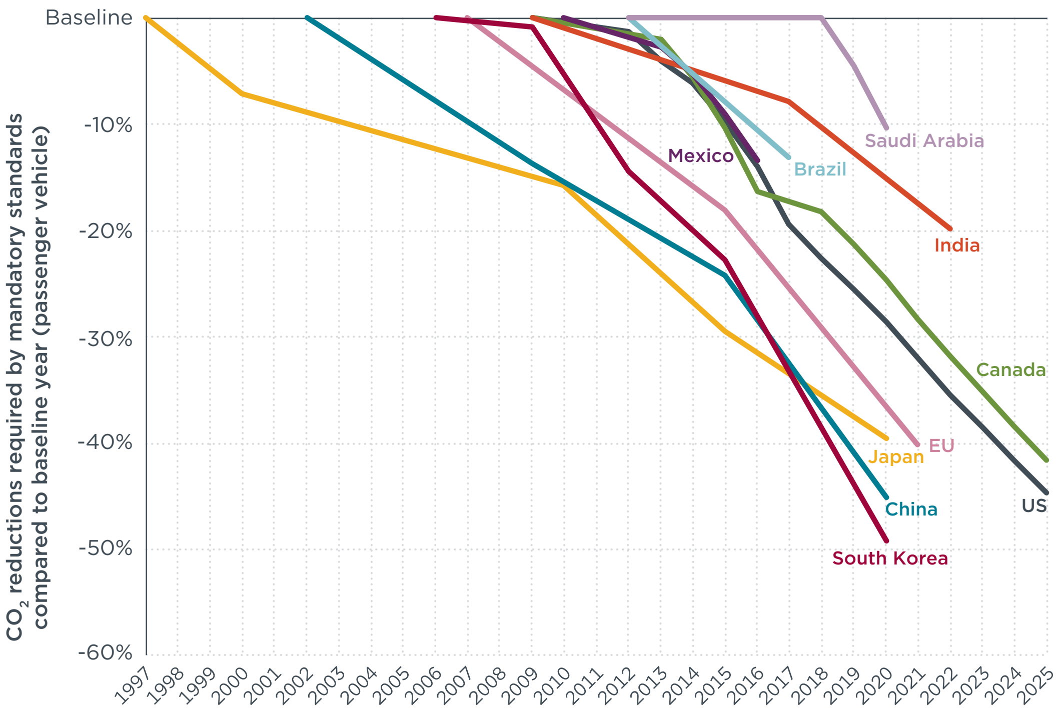

Figure 6. Overall CO_2 reduction required by passenger car standards

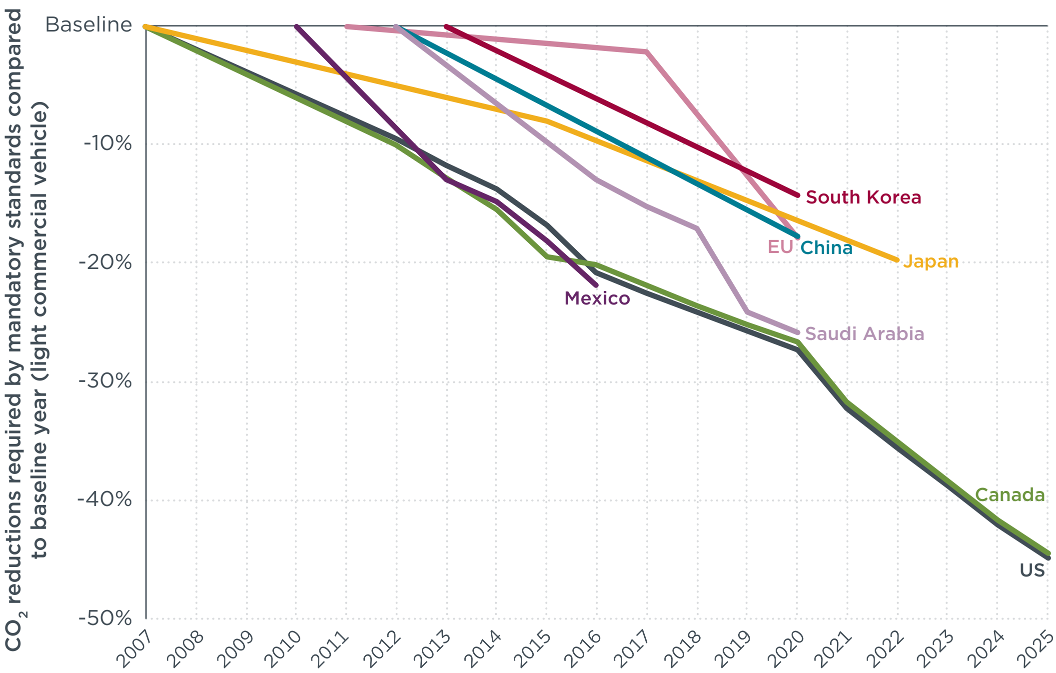

Figure 7. Overall CO_2 reduction required by LCV standards (only showing the most recent standards)

This benchmarking exercise suggests that there is substantial room for improvement for many regions. As Figures 6 and 7 demonstrate, the largest absolute reductions are expected in countries and regions with relatively high baseline values but that have recently adopted aggressive policies to reduce GHG emissions from passenger vehicles and LCVs.

For passenger cars, when fully implemented, the standards in South Korea, China, the United States, and Canada will cut average GHG emissions values from new passenger vehicles by 40%—50% of GHG-equivalent per kilometer compared to the fleet average level when the regulations are introduced. Japan and the European Union would cut GHG emissions by 40% compared to the year when the regulations are introduced. For light trucks and commercial vehicles, the U.S. standards require the largest absolute reduction of 45%.

The slope of the reduction lines in Figures 6 and 7 present the annual reduction required by the standards. In many regions, the reduction line becomes steeper as the regions establish the next phase of their standards. The annual reduction required by the U.S. passenger car standards increases from 1%–2% by 2016 to 4%–5% by 2025, and the annual reduction required by the South Korea passenger car standards increases from 3% by 2015 to 8% by 2020. A similar trend occurs with the passenger vehicle standards in Mexico, India, and the European Union, and with the LCV standards in the European Union, Canada, the United States, Japan, and Mexico.

2.3 IMPACT OF DIFFERENT POLICIES ON LDV GHG EMISSION LEVEL

With current standards in place, global LDV GHG emissions are expected to be lower in the future than when we first compared the global fuel efficiency standards in 2007 (ICCT, 2007).

Figure 8 provides a GHG emission projection considering worldwide growth in vehicles and mileage driven, the existing regulations, and potential policies to improve vehicle efficiency beyond the current timeline and for the other regions.[9] The "Business as usual" line reflects what would happen if standards were frozen today and did not change in the future. The "Adopted" line reflects future standards that have already been adopted, but assumes no GHG reductions beyond the currently adopted standards. The "Technology potential" line reflects continued reduction in GHG emissions that could be achieved based on our understanding of what potential technology can deliver in the time frame. This potential may not be reached unless policies encourage technology deployment with the goal of reducing fuel consumption. The figure shows that despite the growth of the vehicle fleet, the potential vehicle efficiency improvements could stabilize GHG emissions from the global passenger vehicle fleet around 2025 and drive reductions in GHG emissions through 2050.

9 For detailed policy scenarios, please see Global Transportation Energy and Climate Roadmap, Chapter 6. http://www.theicct.org/sites/default/files/publications/ICCT%20Roadmap%20Energy%20Report.pdf

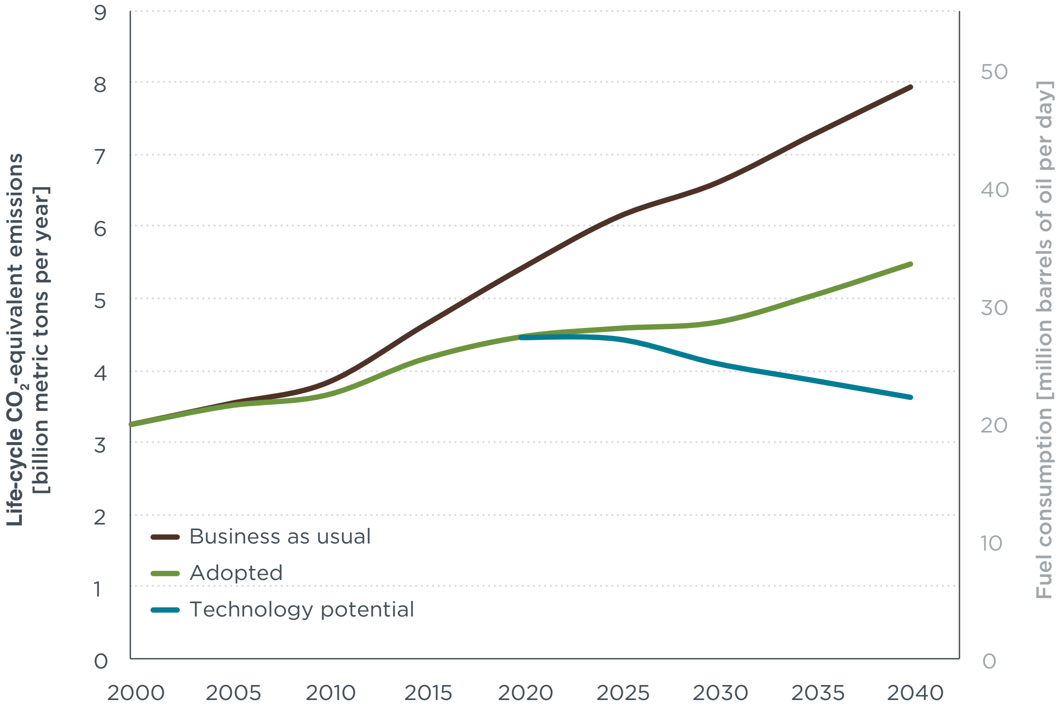

Figure 8. Impact of light-duty efficiency standards on global life-cycle GHG emissions (estimated using ICCT's Global Transportation Roadmap model; ICCT, 2014). Business as usual = vehicle efficiency remains at 2015 levels.

3. SPOTLIGHT ON FUEL ECONOMY REGULATION DEVELOPMENT

This section discusses the general trend of LDV fuel economy regulation development, focusing on five key aspects of fuel economy regulation: (a) development trend of passenger vehicle fuel economy standards, (b) flexibility systems of compliance with passenger vehicle fuel economy standards, (c) development trend of light truck/commercial vehicle fuel economy standards, (d) real-world fuel economy/CO_2 performance compared to standard-certified values, and (e) complementary vehicle fuel economy policies.

3.1 DEVELOPMENT TREND OF PASSENGER VEHICLE FUEL ECONOMY STANDARDS

The landscape of fuel economy standards globally has been transformed in many ways since we published our last overview in 2007 (ICCT, 2007):

First, the number of countries/regions that have fuel economy standards for passenger vehicles has expanded from 4 to 10 out of the top 15 vehicle markets.[10] Brazil, India, Mexico, and Saudi Arabia have introduced standards/programs[11] for the first time to improve passenger car fuel economy. By the end of 2015, about 80% of new passenger car sales were subject to GHG emission and fuel economy standards.

Second, the regulation time frame has been expanded by 10 years from 2015 to 2025, as the United States issued its final rule to extend LDV GHG emissions and fuel economy standards for model year (MY) 2017 through MY 2025. Long-term standards provide a clear policy signal to industry and give manufacturers enough time to adjust their strategies to maintain compliance. Following the steps taken by the United States, Canada has already harmonized with the U.S. 2025 standards. Other countries are on their way to make longer term standards; for example, China set a 2025 target of fleet average fuel economy of 4 L/100 km in a national plan released by the China State Council in 2015 (MIIT, 2015), and the European Commission is working on post-2020 standards for car passenger vehicles and LCVs and is expected to bring out a proposal for 2025 and 2030 standards in 2017 (European Commission, 2016). Nevertheless, the establishment of long-term standards should be based on a thorough study to accurately predict the fleet and technology development. Otherwise, the standards may lag behind on actual technology development in times of changing markets. For example, Japan published its 2020 standards in 2011 but achieved the 2020 targets in 2013 as a result of a fast-growing market of hybrid vehicles.

10 The top 15 vehicle markets in 2014 were China, the European Union, the United States, Japan, Brazil, India, Russia, Canada, South Korea, Indonesia, Australia, Thailand, Mexico, Turkey, and Saudi Arabia (in descending order).

11 Brazil introduced an incentive program that is strong enough to have a similar effect as standards.

Third, countries that were laggards in target levels are catching up as they renew their standards. In the past decade, the United States has dramatically reduced the gap between its passenger car standards and the leading market standards. With an aggressive overall reduction rate from 2011 to 2025, the United States has set a course to closely follow the European Union's 2021 target. Considering that the existing U.S. fleet is 50% more powerful, 14% heavier, and 5% larger than the EU fleet, meeting a similar target is more challenging for the United States. Note that many light trucks in the United States are categorized as passenger cars in the European Union. Those vehicles are heavier and larger than their European counterparts but are currently subjected to the lower fuel economy standards for light trucks. Hence, the average LDV fuel economy is higher in the European Union than in the United States. In its standard for 2020, South Korea aggressively set a target at the same level as the European Union and the United States, but 5 years ahead of the U.S. timeline.

Fourth, there is more harmonization of standards around the world. Currently, Canada, Mexico, Saudi Arabia, and the United States are following the methodology and standard design originally adopted by the United States, while Brazil and India are following the European Union methodology for setting GHG emission standards. Regions with harmonized standards typically choose a similar standards structure (e.g., per-vehicle or fleet-average standard), standard coverage (e.g., passenger vehicle, LCV), index parameter (e.g., weight-based or footprint-based standard), or test procedure (e.g., U.S. CAFE, NEDC). Some regions (e.g., Canada and the United States) even choose a similar off-credit strategy or credit banking and trading system. Japan, after having a special regulation structure and test procedure since 2000, also decided to adopt the WLTP test procedure along with the European Union in 2017–2018, which is another big step in standard harmonization. Therefore, different regions' work on fuel efficiency regulations is inevitably related. Decisions on how to set and enforce GHG standards in released policies will not only affect regional fleets, but set examples for worldwide GHG standards for generations to come.

3.2 FLEXIBILITY SYSTEMS OF COMPLIANCE WITH PASSENGER VEHICLE FUEL ECONOMY STANDARDS

Most fuel economy standards allow manufacturers flexibilities to meet their targets. The flexibility can reduce manufacturers' cost of compliance in the short run, encourage technology innovation and early adoption, and create cost-effective pathways for greater fuel economy improvement in the long run. The approaches to create flexibilities include setting corporate average fuel economy targets; providing off-cycle credits; establishing super credits for electric-drive vehicles; and allowing credit banking and trading across years, fleets, or manufacturers. Additional flexibilities that are not elaborated on in this report include alternative standards and treatment for small-volume manufacturers, such as in the United States and European Union.

3.2.1 CORPORATE AVERAGE TARGET

Setting a corporate average fuel economy target instead of targets for individual models is a common practice across regions. Because efficient models can offset the negative impact of less efficient models from the same manufacturer, regulators can set stricter standards for the fleet rather than for individual models to motivate technology innovations that are still feasible for manufacturers to meet. To determine the compliance with corporate average targets, manufacturers are required to report the sales, specifications, and fuel economy of the vehicles sold by the end of each required reporting period. The sales-weighted fuel economy or average CO_2 emissions value will be compared with the corresponding targets to determine the compliance to standards of each manufacturer. Most standards for passenger cars and LCVs are corporate average standards, except the LCV standards in China, which set targets for individual models. China started to include a corporate-average fuel consumption standard in addition to vehicle-maximum fuel consumption limits in its 2012–2015 standards for passenger vehicles (AQSIQ & SAC, 2014). Japan's 2015 standards are corporate average within each weight class, whereas the 2020 standards are corporate average across all weight classes (NRE & CTP, 2011).

3.2.2 CREDIT BANKING AND TRADING

Credit banking and trading include accumulation of excess credits with respect to compliance targets that can be used in future years and trading between cars and trucks or between manufacturers. This mechanism incentivizes manufacturers to adopt technologies early while allowing them to have a temporary shortfall without paying the penalty by carrying forward/backward, transferring, or trading credits.

Table 6 lists the credit banking and trading in different regions. The banking and trading rule includes how the manufacturers get the credits, what manufacturers can do with the credits, and whether there is an adjustment factor applied to traded or transferred credits to ensure equal lifetime fuel saving of the vehicles.[12] The table indicates the years that a manufacturer can carry forward and backward (to payback the deficit) its annual credits in each system.

Table 6. Credit banking and trading systems

	Rule	Carry forward	Carry backward
China (proposal)	Accumulate the exceedance as credit Trade between manufacturers 80% rollover to following year	3 years	/
Japan	Accumulate the exceedance as credit Trade among weight categories	Not clear	Not clear
Mexico	Accumulate the exceedance as credit Transfer between passenger cars and light trucks Trade between manufacturers Adjustment factors apply	4 years	/
Saudi Arabia	Accumulate the exceedance as credit Transfer between passenger cars and light trucks Trade between manufacturers	5 years	1 or 3 years
South Korea	Accumulate the exceedance as credit Trade between manufacturers No participation from small-volume manufacturers	3 years	3 years
United States Canada	Accumulate the exceedance as credit Transfer between passenger cars and light trucks Trade between manufacturers Adjustment factors apply	5 years	3 years

If a manufacturer fails to meet the target of the year after credit transferring or trading, or a manufacturer fails to submit a valid plan to pay off credit in regions that allow carrying backward credit, the manufacturer must pay the penalty, if any.

12 For example, the vehicle-kilometers traveled (VKT) of passenger cars is typically lower than that of light trucks in the United States; therefore, the credits are discounted when transferred from passenger cars to light trucks.

3.2.3 OFF-CYCLE CREDITS

Setting off-cycle credits aims to reward the use of technologies or designs that increase efficiency in the real world but whose benefits are not captured via the standard testing procedure. Off-cycle credits can incentivize new and innovative technologies. Regulators usually pre-define a list of technologies that are eligible for off-cycle credits and allow manufacturers to apply for additional off-cycle credits with sufficient demonstration of improved efficiency in the real world. Table 7 lists the menu of off-cycle credits offered in each fuel economy regulation and the maximum credit each technology can receive. In some countries, off-cycle credits are pre-granted technologies. In some cases, manufacturers may generate off-cycle credits with technologies not covered in the regulation, but a demonstration is needed to prove the real-world benefits.

Table 7. Overview of off-cycle credit system in passenger car fuel economy standards

	Reduction in latest target	Technology	Max. credit (% of reduction)	Note
Brazil	14 g/km (2013–2017)	Start–stop	1.7 g/km	Additional technologies upon manufacturer's application
		Active grill shutter	0.4 g/km	
		Gear shift indicator	1 g/km	
		Tire-pressure monitoring system	1 g/km	
		(Total)	4 g/km (29%)	
China	44 g/km (2016–2020)	Start–stop Gear shift indicator High-efficiency A/C	11.7 g/km (27%)	Additional technologies may be considered
EU	35 g/km (2016–2021)	Technology not be covered by the NEDC (possible change after transitioning to WLTP)	7 g/km (20%)	High-efficiency A/C, gear-shift indicator, tire-pressure management system, low rolling resistance tire, and biofuels up to 10 g/km already included in the target
Mexico	16 g/km (2013–2016)	Low GWP/leakage refrigerant High-efficiency A/C	0.9 g/km	Technology penetration should be above 80% to receive credits
		6-speed/CVT/dual-clutch transmission Gasoline direct injection Variable valve timing Start–stop Regenerative braking Thermal management	0.9 g/km	
		(Total)	1.8 g/km (11%)	
Saudi Arabia	28 g/km (2016–2020)	High-efficiency A/C	6.1 g/km	Advanced technologies consistent with the U.S. regulation, additional technologies upon OEM's application
		Advanced technologies	6.2 g/km*	
		(Total)	12.3 g/km (44%)	
South Korea	43 g/km (2016–2020)	Tire-pressure management system Low rolling resistance tire Gear-shift indicator High-efficiency A/C	10 g/km	Credit may change from 2015 to 2020. Maximum credit is the same for 2020, but the list of technologies has not been specified yet
		Eco-innovation (e.g., energy-efficient lights)	4 g/km	
		(Total)	14 g/km (33%)	
U.S. and Canada	43 g/km (2017–2025)	High-efficiency A/C	3.1 g/km	Tire-pressure monitoring system is mandatory for safety; additional technologies upon OEM's application. Credits are different for cars and light trucks
		Low GWP/leakage refrigerant	8.6 g/km	
		Start–stop Thermal management Solar/thermal control Additional technologies	6.2 g/km	
		(Total)	17.9 g/km (42%)	

* The cap is on a combined passenger car and light truck fleet average; assumes all credits are generated by passenger car fleet.

An effective off-cycle credit system can reduce manufacturers' compliance costs while spurring technology innovation, but improper design can undermine the effectiveness and credibility of fuel economy standards. Thus, regulators must ensure that the granted technologies are not required by other laws and that their benefits are not duplicated on the regulatory test cycles (Façanha, 2015). Moreover, regulators should grant credits to technologies that actually improve the in-use fuel economy over the vehicle life-cycle and that are independent from driver behavior and where and how the products are used (ICCT, 2013).

3.2.4 SUPER CREDITS

Some fuel economy standards provide additional flexibility in compliance accounting to promote efficient vehicles, such as electric and alternative fuel vehicles. The regulators commonly (a) count fuel cell vehicles and electricity consumption of electric vehicles as 0 g CO_2/km; (b) increase the weighting of each low-emission vehicle in the calculation of average fleet emissions by using "super credits" or "multipliers"; and (c) provide direct credit based on the sales share of qualified vehicles. Table 8 lists the super credits provided in each market for the target year and describes how the rule changes over years.

Table 8. Overview of efficient vehicle super credit system in vehicle fuel economy standards

	Target year	Qualified vehicles	Credit rule	Note
Brazil	2017	Ethanol and flex-fuel engines	0.0041 MJ/km	Fixed value
China	2015	Electric vehicle (EV) with electric range ≥50 km	Electricity consumption account as 0 g/km Multiplier = 5	Fixed value
		Vehicle with fuel consumption ≤2.8 L/100 km	Multiplier = 3	
	2020	EV with electric range ≥50 km	Multiplier = 2	Decrease from 5 in 2016 to 2 in 2020
		Vehicle with fuel consumption ≤2.8 L/100 km	Multiplier = 1.5	Decrease from 3.5 in 2016 to 1.5 in 2020
EU	2015	Vehicle with CO_2 ≤50 g/km	Electricity consumption account as 0 g/km Multiplier = 1.5	Decrease from 3.5 in 2012 to 1.5 in 2015
	2021	Vehicle with CO_2 ≤50 g/km	Multiplier = 1.67	Decrease from 2 in 2020 to 1 in 2023, cap of 7.5 g/km/OEM over 2020–2022
Mexico	2016	Hybrid, EV, vehicle with CO_2 below 80% of CO_2 target	Penetration x 1.8 g/km	Decrease from 2.7 in 2013 to 1.8 in 2016
South Korea	2015	Vehicle with CO_2 <50 g/km	Multiplier = 3	Fixed from 2012 to 2015
		Vehicle with CO_2 <100 g/km	Multiplier = 2	
	2020	Zero-emission vehicle	Multiplier = 3	Fixed from 2016 to 2020
		Vehicle with CO_2 <50 g/km	Multiplier = 2	
U.S.	2016	EV	Electricity consumption account as 0 g/km	For the first 200,000 vehicles of each OEM
	2025	EV and fuel cell vehicle (electricity consumption converted into GHG emissions)	No multiplier	Decrease from up to 2 in 2017 to 1.5 in 2021 and 1 (no multiplier) from 2022 to 2025

The off-cycle credits and super credits for efficient vehicles make the deployment of efficiency technologies more compelling from a manufacturer's perspective. However, they reduce the stringency of the CO_2 targets for conventional vehicles because manufacturers benefit from maximum off-cycle credits and increasing penetration of efficient vehicles for standard compliance. In the United States, for example, the fuel efficiency value in 2014 would be reduced by 8% if the off-cycle and super credits were excluded (EPA, 2015). Figure 9 shows the actual fleet average CO_2 emission targets under the NEDC test cycle after taking into account off-cycle and super credits in each region.

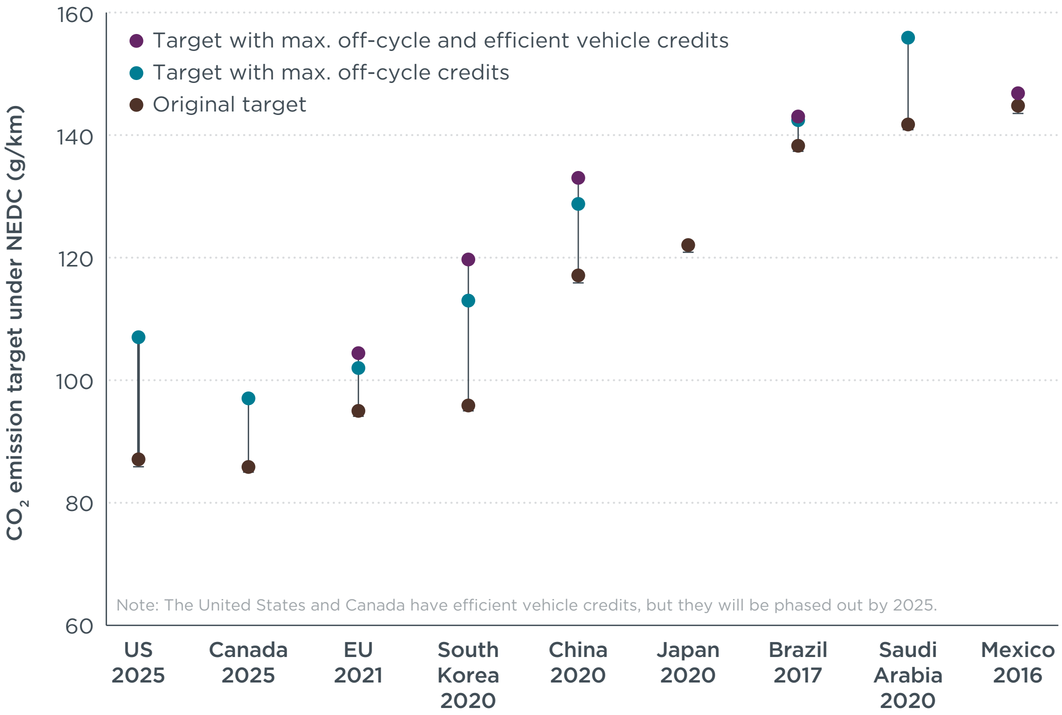

Figure 9. Effects of off-cycle credits and efficient vehicle credits on CO_2 targets

As shown in Figure 9, if manufacturers generate the maximum off-cycle credits and take advantage of super credits[13] for compliance, the actual fleet average CO_2 emission level under the regulatory test procedure can be very different from the target value for compliance. The impact of super credits may be higher if the future growth of the electric vehicle fleet is taken into account; however, if electric vehicle penetration remains at the current level, the impact of off-cycle credits is larger than super credits for efficient vehicles. The real-world CO_2 emissions reduction can be realized only if the off-cycle credits are properly designed to incentivize technologies that reduce in-use vehicle emissions.

13 The impact of super credits is based on the assumption of electric vehicle penetration according to the electric vehicle development trend or target of each region.

3.3 DEVELOPMENT TREND OF LIGHT TRUCK/ COMMERCIAL VEHICLES FUEL ECONOMY STANDARDS

Since 2007, many regions have started to regulate the fuel economy of LCVs. This report is the first attempt to summarize fuel economy standards for LCVs separately from those for passenger cars. By the end of 2015, approximately 82% of new light truck/commercial vehicles sales worldwide were subject to GHG emission and fuel economy standards. Light truck sales in the United States are significantly higher than in other countries, because they include not only the popular pick-up trucks but also four-wheel drive SUVs, which together account for 50% of the regulated light trucks.

Although the fuel economy regulations for these vehicles are still under development in many regions, some trends and patterns are emerging.

Because the specifications and technologies of LCVs are similar to those of passenger cars, regulators generally design the fuel economy regulations for both types of vehicles in a similar way (e.g., using a similar attributed parameter, test procedure, or compliance and flexibility mechanism). However, the characteristics of LCVs vary widely across regions. For example, in the United States, Canada, and Saudi Arabia, the average engine displacement, size, and weight of light trucks are much higher than passenger cars, whereas in China and India, LCVs have similar, or even lower, engine displacement, vehicle size, and weight as average passenger cars. On one hand, this is influenced by the different definition of LCVs; on the other hand, functions of the LCVs vary across regions. For example, LCVs in China are used for urban light logistic transportation or for carrying agricultural goods by small business owners, farmers, and lower income suburban residents (Tu, Zou, & He, 2014), whereas light trucks in the United States are designed with a higher payload capacity and better performance and are used as passenger cars in most cases.

The fuel economy standards for LCVs are evolving along with standards for passenger cars. The United States, Canada, Mexico, Saudi Arabia, and South Korea have the CO_2 regulation for LCVs in the same regulatory document as for passenger cars. The United States and Canada already set the 2017–2025 standards after the first period of 2012–2016 standards for light trucks. South Korea added standards for LCVs in its 2020 LDV fuel-efficiency regulations. The European Union and Japan have designed the standards for LCVs in the same way as for passenger cars. China's latest LCV standards (Phase III) follow the design of the country's Phase II passenger car standards, meaning that the fuel economy targets for LCVs are still for individual models rather than being more stringent corporate average fuel economy targets as in the Phases III and IV passenger car standards.

The average fuel economy for the LCV fleet is lower than that of the average of passenger car fleet; this is because LCVs are heavier and larger than passenger cars,[14] and LCV standards are generally more lenient than passenger car standards because of less penetration of advanced technologies. In markets like China, although some LCVs adopt more advanced efficiency technologies, technologies used for LCVs tend to be less advanced than those used for its passenger cars (Tu et al., 2014). In some regions, the differential requirements for the two categories may incentivize manufacturers to game the system for easier compliance. For example, in the U.S. regulation, light trucks, some of which are categorized as passenger cars in other regions, are subject to a lower

14 Except in India and Japan, where the LCV fleet is lighter and smaller than the passenger car fleet. Note that for the same footprint, a pickup truck could be lighter than a corresponding sedan car or SUV.

fuel economy standard than cars with the same footprint; thus, the lower requirement for light trucks increases the incentive for manufacturers to reclassify cars as light trucks (German, 2011).

3.4 REAL-WORLD FUEL ECONOMY/CO_2 PERFORMANCE

Although the standards have been successful in reducing declared fuel economy and CO_2 emission values measured in laboratories, the reductions also must be realized in the real world. Concern has been growing in recent years, as the divergence between real-world and official CO_2 emissions in the European Union increased from approximately 8% in 2001 to 40% in 2014 (Tietge et al., 2015). The growing trend is found in other major markets, such as in Japan, China, and the United States (Greene et al., 2015; iCET, 2015; Tietge, Diaz, Yang, & Mock, 2017). The average divergence between real-world and official CO_2 emission values in China increased from 12% in 2007 to 27% in 2015. The gap in Japan increased dramatically since 2009; the real-world CO_2 emissions are 40% higher than the certified value (Tietge et al., 2017). U.S. real-world CO_2 emission values were 31% higher than the certified value in 2014 and had increased by 17 percentage points compared to 2001.

The growing gap between real-world and official CO_2 emission value is worrisome because it dilutes the fuel economy standards. The achievements by policies on official CO_2 values do not translate into full real-world benefits in fuel savings. Regarding policy implications, there is an increasing need to improve representation of type-approval value and strengthen production and in-use compliance.

On one hand, governments around world should work to establish test procedures or adopt correction factors to better represent in-use CO_2 emissions. For example, since the mid-1980s, the United States has been adjusting the city test result downward by 10% and the highway test result downward by 22% as the fuel economy value presented to consumers on the label. In 2008, the adjustment factor was replaced by the five-cycle test, which uses supplementary test cycles to capture additional driving conditions. The United States also conducted the standards cost–benefit analysis assuming a 23% gap between the real-world and laboratory fuel economy (EPA, CARB, & NHTSA, 2016). The WLTP that the European Union and Japan are planning to adopt by 2018 is also expected to reduce the gap between the test and real-world CO_2 emission levels, although the gap will remain, and those regions may not use a correction factor (Stewart, Hope-Morley, Mock, & Tietge, 2015).

On the other hand, each region needs to build a mechanism to ensure compliance of production vehicles and in-use vehicles with the standards. Clear policies need to be in place to penalize manufacturers that fail to meet fuel economy/CO_2 emission standards. For example, in the European Union, if a manufacturer fails to comply with its CO_2 target, an excess emissions premium must be paid. The amount of premium exceeds the cost of compliance and could easily amount to multimillion-euro penalties. Moreover, some recent cases and scandals regarding fuel economy standards violations highlight the importance of government surveillance. In the United States, EPA found that Hyundai had been overstating the fuel efficiency for 1.2 million vehicles from 2011 to 2013. This was discovered because EPA found, through auditing in 2012, that the vehicle had a higher road load force than was described in the application (EPA, 2014). In Japan in 2016, Mitsubishi Motors was found to have been cheating on fuel economy tests for 25 years, which pushed the regulatory agency to reinforce its compliance program. Both cases are related to the calculation of road load, a parameter that has a strong impact on vehicle

CO_2 emissions. The road load information, which was derived from the coastdown test, is rarely released by regulatory agencies and is difficult for the general public to obtain (Kühlwein, 2016). A comprehensive compliance mechanism is needed to ensure that manufacturers test the vehicles as required by the regulation and that regulators can identify noncompliant vehicles and take actions against any violation.

3.5 COMPLEMENTARY VEHICLE FUEL ECONOMY POLICIES

The fuel economy standard is one of the most effective measures to improve the fuel economy of vehicle fleets, but there are complementary policies that are widely adopted by regions around the world. Fiscal incentives and vehicle fuel economy labeling are two important ones.

Fiscal incentives are targeted toward consumers to influence purchase decisions. Vehicle taxation based on vehicle CO_2 emission or fuel economy encourages consumers to choose fuel-efficient vehicles to reduce the purchase cost. Vehicle taxation based on parameters that are linked to CO_2 emissions (e.g., engine displacement, vehicle size and weight) also indirectly influence consumer purchase choice, although such taxes are not as effective as direct taxation based on CO_2. High fuel taxation drives up the operating cost because of the higher fuel cost, therefore incentivizing consumers to buy vehicles that burn less fuel per mile of driving and reduce the annual driving distance. In addition, many regions provide a direct subsidy or tax reduction for purchasing electric vehicles, which generally create less CO_2 than conventional vehicles (depending on how the electricity is generated).

Table 9 lists the fiscal policies adopted by some major markets around the world (GIZ, 2015; Mock & Yang, 2014).

Table 9. Fiscal policies on fuel economy/CO_2 emission in major markets

	Direct CO_2 tax	Indirect CO_2 tax	Fuel tax*	Electric vehicle incentive
Australia	Yes (L)	Displacement, weight	**+**	
Brazil		Displacement	**+**	
Canada	Partly		**+**	
China		Displacement	**+**	Subsidy and tax reduction
France	Yes	Engine power	**++**	Subsidy and tax reduction
Germany	Yes	Displacement	**++**	Tax reduction
India		Displacement, engine power (L)	**+ (G)** **– (D)**	Subsidy
Indonesia		Displacement	**+ (G)** **– (D)**	
Italy		Engine power	**++**	Subsidy and tax reduction
Japan		Displacement, weight	**++**	Tax reduction
Russia		Engine power	**+**	
South Africa	Yes		**+**	
South Korea		Displacement	**++ (G)** **+ (D)**	Subsidy and tax reduction
Turkey		Displacement	**++**	
UK	Yes		**++**	Subsidy
U.S.	Partly	Weight (some states)	**+**	Subsidy

* **+** fuel taxation, **++** high fuel taxation, **–** fuel subsidies, **(G)** gasoline, **(D)** diesel, **(L)** local policy

Vehicle fuel economy labeling aims to provide vehicle fuel economy information to consumers to increase demand for more fuel-efficient vehicles. A well-designed labeling program not only presents the fuel economy–related information, but also highlights the benefit of purchasing a fuel-efficient vehicle (for more information, see Yang, Zhu, & Bandivadekar, 2015).

As shown in Figure 10, vehicle fuel economy labeling programs have been adopted widely across the world. The labeling program collects fuel economy information of the fleet, which will pave the way to create other fuel economy–related policies, and reinforces the effectiveness of fuel economy standards and fiscal policies if they are already in place.

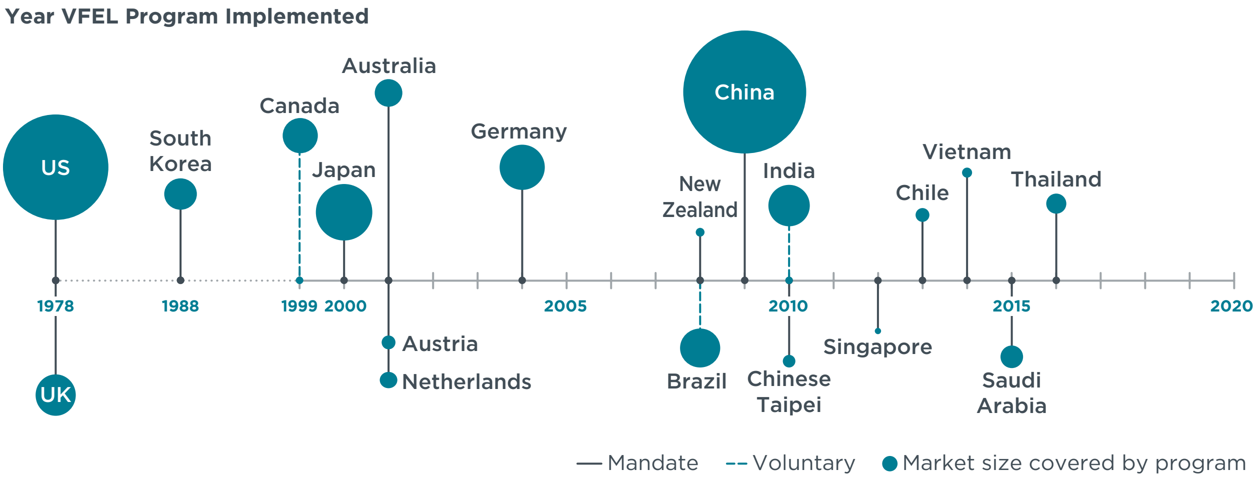

Figure 10. Year of implementation of vehicle fuel economy labeling programs

4. CONCLUSION

Over the past decade, GHG emission and fuel economy standards have dramatically improved worldwide in two ways. First, the number of regions that have fuel economy standards for passenger vehicles increased from 4 to 10. Standards now cover two thirds of the world's largest vehicle markets and 80% of new vehicles sold. Worldwide, there is greater harmonization of regulations with regard to how the standards are structured, types of vehicles covered, index parameters, and test procedures. Second, not only have standards become more ambitious over time, but also the time frame of regulation in some regions has been extended by 10 years, from 2015 to 2025. Countries that were laggards with respect to targets, such as China, South Korea, and the United States, are catching up as they renew their standards.

To summarize the state of GHG/fuel economy standards worldwide in 2017:

- Fuel economy regulations in most regions give manufacturers substantial flexibility in meeting their targets. Examples include setting corporate average fuel economy targets; indexing targets to vehicle attributes; providing off-cycle credits; establishing super credits for electric vehicles; and allowing credit banking and trading across years, fleets, or manufacturers. Such features of fuel economy regulation can reduce manufacturers' compliance costs while spurring technology innovation.
- Fuel economy standards for LCVs are evolving along with standards for passenger cars. Although the characteristics of LCVs vary widely across regions, LCV standards are generally more lenient than those for passenger cars everywhere. More development of LCV standards is expected in the future.
- The increasing gap between real-world and official fuel economy/CO_2 emission value is a growing concern because it compromises the actual benefit of standards and undermines their legitimacy. Improving test protocol and establishing effective compliance-and-enforcement mechanisms will be the key to addressing this problem.
- A number of regions are adopting complementary policies to improve vehicle fleet fuel economy. Fiscal policies related to vehicle CO_2 emissions/fuel economy or fuel can effectively promote efficient vehicles by influencing consumers' purchase decisions. Fuel economy labeling also reinforces the effectiveness of fuel economy standards and fiscal policies while increasing the demand for efficient vehicles.
- Compared to business as usual, the standards that have already been adopted will significantly reduce GHG emissions. However, to offset the impact of a growing number of vehicles and increases in total vehicle kilometers traveled over the long term, regulation must spread beyond the 10 regions discussed in this report. Governments around the world must work together to continue progress toward a more efficient global LDV fleet.

The increasing willingness of governments to adopt and strengthen vehicle GHG emission and fuel economy standards reflects their growing understanding that reducing GHG emissions and fuel consumption is crucial to improving environmental health (including meeting global climate change commitments), ensuring energy security, shielding consumers from fluctuating oil prices, and driving technological innovation. Because the auto industry plans, develops, and markets globally, the standards have accelerated the development and deployment of fuel-efficiency technologies.

Proposals to extend GHG emission standards beyond 2025 highlight policy makers' awareness of the effectiveness of such a policy approach. The European Union is currently discussing regulation that would cover the 2025–2030 time frame, and China has conducted a technology roadmap study of feasible passenger vehicle fuel consumption targets for 2025–2030. Our analysis of trends over the past decade indicates that stronger GHG/fuel economy standards drive innovation, and there is no end in sight for efficiency technology advances.

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