BEIJING | BERLIN | BRUSSELS | SAN FRANCISCO | WASHINGTON

BRIEFING PAPER

IMPACTS OF WORLD-CLASS VEHICLE EFFICIENCY AND EMISSIONS REGULATIONS IN SELECT G20 COUNTRIES

Josh Miller, Li Du, Drew Kodjak

JANUARY 2017

icct
THE INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION

ACKNOWLEDGEMENTS

This paper has been drafted by the International Council on Clean Transportation at the request of the Transport Task Group of the G20 Energy Efficiency Action Plan. The authors thank staff at the ICCT for reviewing drafts of this paper, including Cristiano Façanha, Ray Minjares, and Jen Fela. Special thanks to Vance Wagner, U.S. State Department, who participated in a personal capacity in the review of this paper, as well as members of the Steering Committee of the Transport Task Group. The views and opinions expressed in this paper do not necessarily state or reflect those of the United States Government or any agency thereof, nor of the participating countries in the Transport Task Group.

The International Council on Clean Transportation
1225 I Street NW, Suite 900
Washington DC 20005
communications@theicct.org | www.theicct.org

TABLE OF CONTENTS

LIST OF ACRONYMS

BC	black carbon
CO	carbon monoxide
CO_2	carbon dioxide
CO_2eq	carbon dioxide-equivalent using 100-year global-warming potentials for non-CO_2 greenhouse gases unless otherwise specified
EELP	G20 Energy Efficiency Leading Programme
EU-28	28 member states of the European Union
G20	Group of 20; international forum for governments and central bank governors from 20 major economies
GHG	greenhouse gas
GTP	global temperature potential
GWP	global-warming potential
HC	hydrocarbon
HDV	heavy-duty vehicles include trucks and buses typically weighing more than 3,500 kg gross vehicle weight
INDC	Intended Nationally Determined Contribution; the primary mechanism for communicating internationally how each Party (country or region) to the UNFCCC climate negotiations intends to mitigate domestic GHG emissions (World Resources Institute, 2016)
LCV	light commercial vehicle
LDV	light-duty vehicles include passenger cars and light commercial vehicles. Although definitions vary by region, this category typically includes vehicles weighing less than 3,500 kg gross vehicle weight.
Mt	million metric tons
NO_x	nitrogen oxides
OC	organic carbon
PBEV	Programa Brasileiro de Etiquetagem Veicular (Brazil's Vehicle Labeling Scheme)
PM	particulate matter
$PM_{2.5}$	fine particles measuring less than 2.5 micrometers in diameter
PNLTES	Post New Long Term Emission Standards (Japan)
SLCP	short-lived climate pollutant
SO_2	sulfur dioxide
TTG	Transport Task Group established in the G20 Energy Efficiency Action Plan
ULSD	ultralow-sulfur diesel, with fewer than 15 ppm sulfur content
UNFCCC	United Nations Framework Convention on Climate Change
WLTP	World Harmonized Light Vehicle Test Procedures

EXECUTIVE SUMMARY

The economies of the G20 collectively account for two thirds of the world population, more than 80% of global energy demand, and over 90% of new light- and heavy-duty vehicle sales. In 2014, the G20 Energy Efficiency Action Plan prioritized the establishment of a Transport Task Group (TTG) to promote cooperation among participating G20 countries to develop domestic policies that improve the energy efficiency and environmental performance of motor vehicles, particularly heavy-duty vehicles (G20, 2014). Led by the United States, the TTG currently includes Australia, Brazil, Canada, China, the European Union (with Germany, Italy, and the United Kingdom also participating individually), India, Japan, Mexico, and Russia.

With global momentum for climate change action building, including through the entry into force of the Paris Agreement in November 2016 (United Nations Framework Convention on Climate Change, 2016b), there is now added motivation for TTG members to cooperate on the development and sharing of best-practice energy-efficiency policies for the transport sector. These policies can help countries meet their domestic climate targets and contribute to meeting the ultimate objectives of the Paris Agreement to limit the global temperature increase to below 2 degrees Celsius, and to pursue efforts to limit the temperature increase to 1.5 degrees.

In this paper, we assess the magnitude of carbon dioxide (CO_2) emission reductions that could be achieved by adopting world-class vehicle efficiency standards within TTG-participating countries. We evaluate the CO_2 emission reductions in 2040 that are expected under existing vehicle efficiency standards, as well as those achievable with continued improvements to new light-duty vehicle (LDV) and heavy-duty vehicle (HDV) efficiency. Additionally, we estimate the emissions and public health benefits of implementing world-class tailpipe emission standards to reduce fine particle ($PM_{2.5}$) emissions in those TTG member countries or regions that have not yet implemented such standards.

To support this analysis, we surveyed TTG members to gather up-to-date information on the status of policies for clean vehicles and fuels, including policies that are actively under development. These policies reflect the progress that TTG members have made over the past decade and establish a reference point for evaluating the potential to further improve the efficiency and environmental performance of on-road vehicles.

> THE MAGNITUDE OF EMISSION REDUCTIONS ACHIEVABLE WITH CONTINUED VEHICLE EFFICIENCY STANDARDS—ROUGHLY EVENLY SPLIT BETWEEN LIGHT- AND HEAVY-DUTY VEHICLES—INDICATES THE IMPORTANCE OF CONTINUED ACTIVITIES TO PROMOTE THESE POLICIES WITHIN THE G20 AND ESPECIALLY AMONG TTG-PARTICIPATING COUNTRIES.

We evaluate direct CO_2 emissions from light- and heavy-duty vehicles in TTG-participating countries under three scenarios for new vehicle efficiency and CO_2 standards: the "baseline" scenario assumes no further improvements in new vehicle efficiency after 2005, to enable the estimation of benefits from adopted policies. The "adopted policies" scenario includes all policies adopted as of September 2016, including those taking effect in the future. Finally, the "world-class" scenario models the impacts of all TTG participating countries developing new vehicle efficiency standards consistent with the objectives of the G20 Energy Efficiency Leading Program (EELP): these aspirational targets include a 50% reduction in LDV fuel consumption compared to a 2005 base year by 2030 and a 30% reduction in HDV fuel consumption compared to a 2010 base year by 2030 (G20, 2016). We estimate that currently adopted vehicle efficiency standards will avoid

2 billion tons of carbon dioxide ($GtCO_2$) in 2040, whereas new world-class LDV and HDV efficiency standards applied in all TTG member countries could mitigate direct emissions from fuel combustion by an additional 2.4 $GtCO_2$ in 2040 (Figure ES-1). The magnitude of emission reductions achievable with continued vehicle efficiency standards—roughly evenly split between light- and heavy-duty vehicles—indicates the importance of continued activities to promote these policies within the G20 and especially among TTG-participating countries.

Outdoor air pollution was associated with over 3.1 million early deaths worldwide in 2013, more than 75% of which occurred in G20 countries (Institute for Health Metrics and Evaluation, 2015). On-road vehicles, particularly HDVs, are a prime target for reducing air pollution because of the availability of cost-effective emission-control technologies and the proven capability of regulatory programs to ensure the adoption of cleaner vehicles and fuels (Miller & Façanha, 2014). Within the TTG, the United States, Canada, Japan, and member states of the EU-28 have already implemented "world-class" tailpipe emissions standards, defined as Euro 6, U.S. Tier 2/3, or equivalent standards for LDVs; and Euro VI, U.S. HD2010, or equivalent standards for HDVs (G20, 2016). Several other TTG members have already adopted, proposed, or are now developing plans to implement these standards in the 2018–2020 timeframe. In September 2016, India finalized Bharat VI standards for light- and heavy-duty vehicles, which will take effect in 2020 (Ministry of Road Transport and Highways, 2016). China has proposed to implement LDV standards equivalent to Euro 6 or better and is developing plans for HDV Euro VI-equivalent standards. Mexico has issued a proposal to implement Euro VI/U.S. 2010 standards for HDVs in 2018.

In this paper, we also evaluate the emissions and health benefits in 2030 of implementing world-class tailpipe emissions standards for LDVs and HDVs in six TTG participating countries that have not already done so—China, India, Mexico, Brazil, Russia, and Australia—compared to a baseline with current standards. If Euro 6/VI standards are implemented in the 2018–2020 timeframe, then Euro 6/VI vehicles will likely account for the majority of vehicles on the road in 2030. Ensuring that world-class standards for LDVs and HDVs are successfully implemented in these six countries will reduce tailpipe $PM_{2.5}$ emissions in these countries by 74% from 2015 levels by 2030 (Figure ES-2). Compared to a baseline with current standards, implementing world-class standards will avoid 60,000 premature deaths

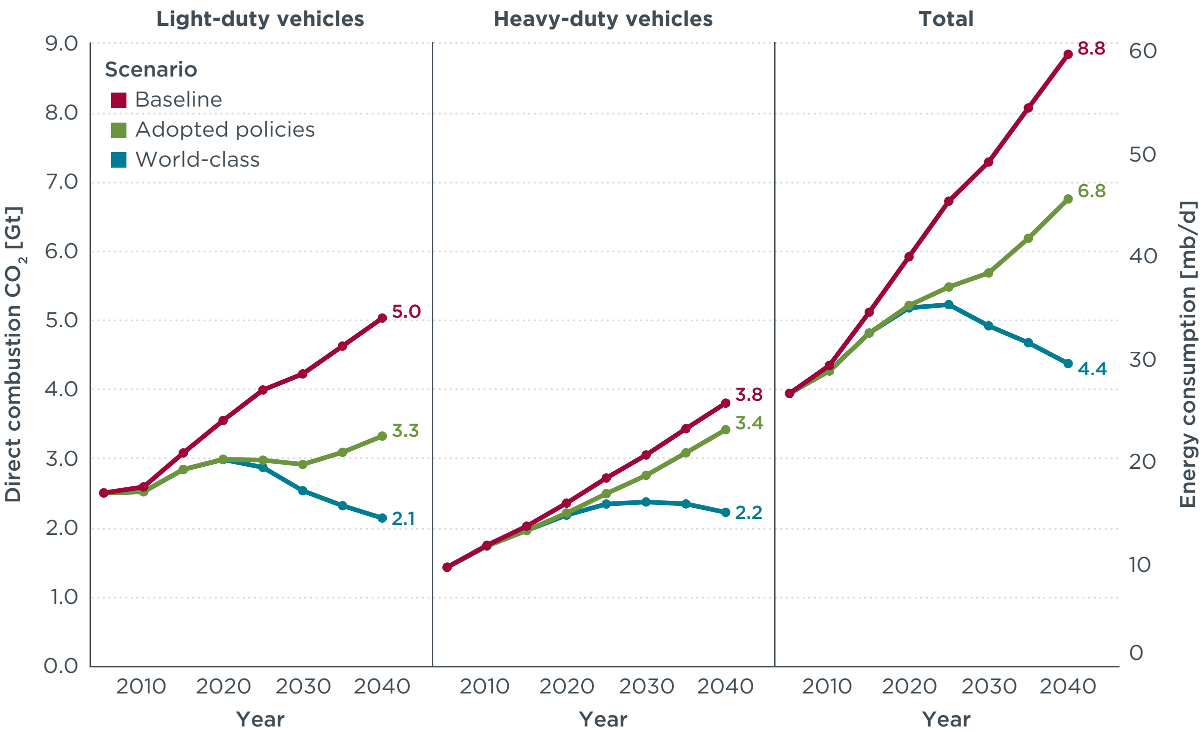

Figure ES-1. Direct combustion CO_2 emissions of light- and heavy-duty vehicles in TTG+EU member states under baseline, adopted policies, and world-class efficiency scenarios, 2005–2040. Figure shows historical and projected emissions for Australia, Brazil, Canada, China, the EU-28 (including TTG members Germany, Italy, and the United Kingdom), India, Japan, Mexico, the United States, and Russia.

associated with tailpipe $PM_{2.5}$ emissions in urban areas in these countries annually by 2030. Once implemented across the G-20, nearly 90% of new LDVs and HDVs sold worldwide will meet world-class emissions standards, compared to only half of new vehicles sold today.

HDVs account for approximately 70% of the potential tailpipe $PM_{2.5}$ reduction with world-class standards in 2030, making HDV emission standards an essential component to controlling air pollution from on-road vehicles. Such policies have been a focus of recent bilateral statements between the United States and China, India, and Mexico (U.S. Department of State, 2016; The White House, 2016a, 2016b).

A co-benefit of world-class standards, which force the use of particulate filters, is the reduction in black carbon (BC), a component of fine particulate matter that is also a potent short-lived climate pollutant. Implementing world-class emissions standards in China, India, Mexico, Brazil, Russia, and Australia could eliminate 66,000 tons of BC annually by 2030, with climate benefits offset by less than 2% due to concomitant reductions in climate-cooling organic carbon (OC) and sulfate emissions. The net climate benefits of reduced BC, OC, and sulfate emissions are equivalent to 58 million metric tons of CO_2 ($MtCO_2eq$) using a 100-year global-warming potential (GWP) and 208 $MtCO_2eq$ using a 20-year GWP.

ONCE IMPLEMENTED ACROSS THE G-20, NEARLY 90% OF NEW LDVS AND HDVS SOLD WORLDWIDE WILL MEET WORLD-CLASS EMISSIONS STANDARDS, COMPARED TO ONLY HALF OF NEW VEHICLES SOLD TODAY.

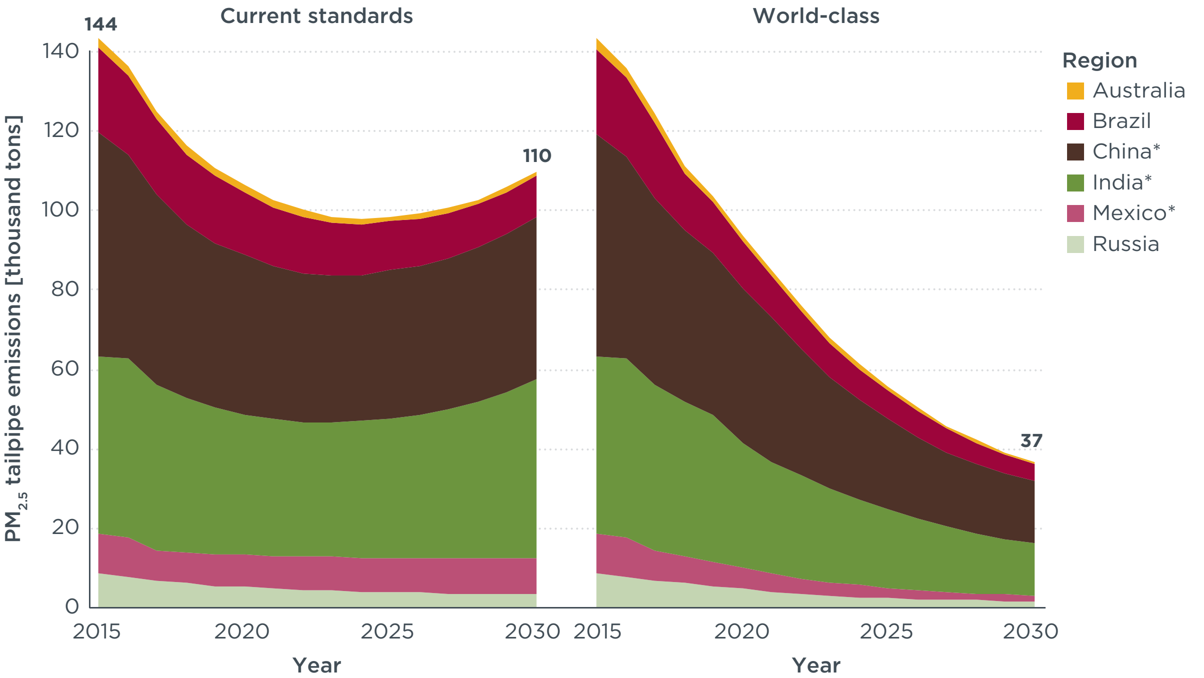

Figure ES-2. Impact of world-class standards on tailpipe $PM_{2.5}$ emissions from light- and heavy-duty vehicles in six G20 countries. *China, India, and Mexico have already adopted, proposed, or are developing plans to implement such standards.

INTRODUCTION

The transport sector currently consumes more than half of global oil demand and is responsible for about one quarter of anthropogenic CO_2 emissions. Within the transport sector, emissions from on-road motor vehicles account for approximately three quarters of direct CO_2 emissions (Kodjak, 2015). Motor vehicles also contribute to outdoor air pollution and a range of associated adverse health impacts. The economies of the G20 collectively account for two thirds of the world population, more than 80% of global energy demand, and over 90% of new vehicle sales (Figure 1). Therefore, the transport sector policies of G20 members largely dictate the impacts of the global transport sector on air quality, climate change, and energy consumption.

Although there is strong motivation among G20 members to mitigate the climate and health impacts of the transport sector, the level of environmental regulations for transport varies across these markets. In 2014, the G20 Energy Efficiency Action Plan prioritized the establishment of a Transport Task Group (TTG) to promote cooperation among participating countries to develop domestic policies that improve the energy efficiency and environmental performance of motor vehicles, particularly heavy-duty vehicles (HDVs; G20, 2014). Led by the United States, the TTG currently includes Australia, Brazil, Canada, China, the European Union (with Germany, Italy, and the United Kingdom also participating individually), India, Japan, Mexico, and Russia. With global momentum for climate change action building, including through the entry into force of the Paris Agreement in November 2016 (United Nations Framework Convention on Climate Change [UNFCCC], 2016b), there is now added motivation for TTG members to cooperate on the development and sharing of best-practice energy-efficiency policies. These policies can help countries meet their domestic climate targets and contribute to meeting the ultimate objectives of the Paris Agreement: to limit the global temperature increase to below 2 degrees Celsius and pursue efforts to limit the temperature increase to 1.5 degrees.

Building on a previous review of energy and environmental policies for light-duty vehicles (LDVs) and HDVs in G20 countries (Kodjak, 2015), we conducted a survey among the TTG members to validate and update this information on policies for clean vehicles and fuels, including: (a) tailpipe emission standards, (b) fuel economy and CO_2

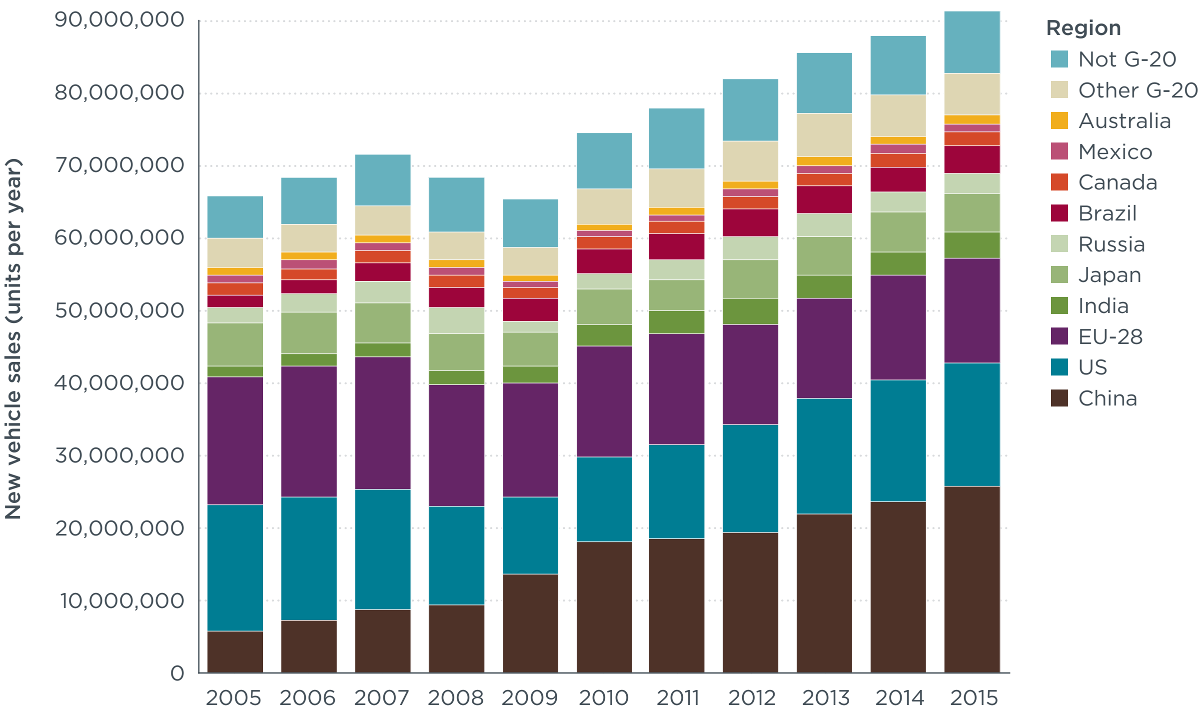

Figure 1. Sales of new light- and heavy-duty vehicles by region, 2005–2015 (ICCT, 2016b).

standards, (c) low-sulfur fuel standards, (d) alternative fuels, (e) green freight programs, and (f) regulatory compliance and enforcement. The survey, which was conducted as an official TTG activity with the full support of the TTG, was designed to capture policies that have been implemented, adopted but not implemented, and those under development. These policies reflect the progress that TTG members have made over the past decade and establish a reference point for evaluating the potential to further improve the efficiency and environmental performance of transport.

Taking into account the information obtained from the TTG survey, we evaluated the potential climate and health benefits of implementing world-class policies for fuel consumption and carbon dioxide (CO_2) and fine particle ($PM_{2.5}$) emissions from LDVs and HDVs in TTG countries. This paper covers the findings of that analysis and is divided into three parts:

1. The first section summarizes the status of vehicle efficiency and conventional pollutant emissions standards currently in force, adopted but not yet implemented, and under development in each TTG country based on the results of the TTG survey. The full results and methods of the TTG survey are reported in a separate publication (Du et al., 2017). This section also lists those transportation measures that were identified in the Intended Nationally Determined Contributions (INDCs) submitted by TTG countries (though not covered by the TTG survey).

2. The second section focuses on the climate and energy impacts of adopted and world-class vehicle efficiency and CO_2 standards.

3. Finally, the third section covers the health and emissions benefits of implementing world-class emissions standards to control tailpipe $PM_{2.5}$ in those TTG countries that have not already implemented these standards.

STATUS OF VEHICLE EFFICIENCY AND EMISSIONS STANDARDS

This section summarizes the status of vehicle efficiency and CO_2 regulations and conventional pollutant emissions standards that are currently in force, adopted but not yet implemented, or under development in TTG member countries. The category "under development" includes announced plans as well as official proposals. The policies in question cover on-road LDVs and HDVs. For ease of communication, standards that use fuel consumption, fuel economy, CO_2, or GHG emissions as a metric are collectively referred to as "vehicle efficiency" standards. In contrast, "vehicle emissions" standards limit conventional pollutant emissions, such as fine particles ($PM_{2.5}$), oxides of nitrogen (NO_x), and other pollutant species. Additional results of the TTG survey are provided in Du et al. (2017).

VEHICLE EFFICIENCY AND CO_2 STANDARDS

Table 1 summarizes the status of vehicle efficiency standards that are currently in force, adopted but not yet implemented, or under development by TTG members. All but two TTG members have adopted efficiency standards for LDVs. Australia has not yet adopted an LDV efficiency standard but is actively exploring this pathway. Compared to LDVs, HDVs are less regulated across TTG members. Canada, China, Japan, and the United States have already implemented HDV efficiency standards. In April 2016, China proposed a third phase of its HDV efficiency standards that will phase in starting in 2019 (Delgado, 2016). In August 2016, the United States finalized Phase 2 HDV standards that extend

Table 1. Status of light- and heavy-duty vehicle fuel efficiency regulations in G20 TTG members. (Countries/regions are ordered alphabetically.) Adapted from Du et al. (2017).

Region	Light-duty			Heavy-duty		
	Current	Adopted but not yet implemented	Under development	Current	Adopted but not yet implemented	Under development
Australia			Standards under discussion			
Brazil	Inovar-Auto; Vehicle labeling (PBEV)					
Canada	Phase 1 [2012-2016]	Phase 2 [2017-2025]		Phase 1 [2014-2018]		Phase 2 [2019+]
China	Phase IV			Phase 2		Phase 3
EU	PV - Regulation 443/2009; LCV – Regulation 510/2011		Regulations relating to cars and vans beyond 2020			Legislation on CO_2-emission certification, monitoring, & reporting and standards
India		113 gCO_2/km in 2021				
Japan	Top runner	Top runner		Top runner		
Mexico	NOM-163-SEMARANT-ENER-SCFI-2013		Aligned with U.S. LDV 2017-2025			Aligned with U.S. HDV 2018-2027
Russia						
United States	Phase 1 [2012-2016]	Phase 2 [2017-2025]		Phase 1 [2014-2018]	Phase 2 [2019+]	

to 2027 (U.S. EPA, 2016). In addition to those policies that have been adopted or proposed, several TTG members have expressed their intent to develop new HDV efficiency standards. Canada is expected to continue its alignment with the United States by adopting Phase 2 HDV standards. In July 2016, the European Commission announced that it will speed up preparatory work for a legislative proposal on HDV efficiency standards (European Commission, 2016).

VEHICLE EMISSIONS STANDARDS

Table 2 covers conventional pollutant emission standards for LDVs and HDVs. "Current" policies indicate the most recent policy that is in force: for example, Tier 2 emission standards apply to all LDVs sold in the United States as of September 2016. Similarly, "adopted but not yet implemented" indicates any policy that has been adopted as of September 2016, but that is not yet in force: for example, U.S. Tier 3 emission standards will phase in for new LDVs (and some medium-duty vehicles) starting in 2017. Finally, "under development" applies to policies that have been formally proposed or are under development by regulatory agencies: for example, as of September 2016, Mexico has proposed Euro VI/U.S. 2010-equivalent emission standards for HDVs, but these have not been finalized. Currently implemented world-class standards such as Euro 6/U.S. Tier 2 and Euro VI/U.S. 2010 are color-coded dark green, and more stringent standards (e.g., U.S. Tier 3) are color-coded light blue.

A large fraction of TTG members have already implemented world-class tailpipe emissions standards for both LDVs and HDVs, including Canada, the European Union and its member states, Japan, and the United States. Six TTG members have not yet implemented such standards, including Australia, Brazil, China, India, Mexico, and Russia. Australia and Brazil have implemented tailpipe emission standards roughly equivalent to Euro 5/V. The Australian government has been exploring pathways to Euro 6/VI equivalent standards and released a discussion paper on the impact of these standards for public consultation (The Department of Infrastructure and Regional Development, 2016). In February 2016, India issued a draft notification of Bharat VI standards that will go into effect for LDVs, HDVs, and two- and three-wheeled vehicles in 2020 (Dallmann & Bandivadekar, 2016). In June

Table 2. Policy status of light- and heavy-duty tailpipe emissions standards in G20 TTG members. (Countries/regions are ordered alphabetically.) Adapted from Du et al. (2017).

Region	Light-duty			Heavy-duty		
	Current	Adopted but not yet implemented	Under development	Current	Adopted but not yet implemented	Under development
Australia	ADR 79/04 [2016.11]		Euro 6	ADR 80/03		Euro VI
Brazil	L-6			P-7		
Canada	Tier 2	Tier 3 [2017]		US 2010		
China	China 4	China 5 [2017.01]	China 6	China IV	China V [2017. 01]	China VI
EU	Euro 6b	Euro 6c [2017.09]	WLTP RDE Phase 3-4	Euro VI	Implementing package	
India	Bharat III	Bharat IV	Bharat VI	Bharat III	Bharat IV	Bharat VI
Japan	Post New Long Term Emission Standards (PNLTES)			PNLTES	PNLTES [2016.10]	
Mexico	NOM-042-SEMARNAT-2003		US Tier 3	US 2004/ Euro IV		Euro VI/US 2010
Russia	Euro 5			Euro V		
United States	Tier 2	Tier 3 [2017]		US 2010		

Euro-equivalent emission level

None reported	Euro 3/III	Euro 4/IV	Euro 5/V	Euro 6/VI	Post Euro 6/VI

2016, China announced its intention to implement China 6/VI standards nationwide by 2020 (He, 2016). In 2014, Mexico proposed U.S. 2010/Euro VI standards for HDVs with an implementation year of 2018. At the North American Leaders' Summit in June 2016, Mexico's president affirmed the HDV timeline and committed to similarly harmonize emission standards for LDVs (Blumberg, 2016).

Although Brazil has not yet adopted a pathway to Euro 6/VI equivalent standards, the country has been increasing the required percentage of biodiesel in the diesel fuel mix, which is set to increase to 10% (B10) by 2019; the Ministry of Science and Technology has reported reductions in emissions of carbon monoxide (CO), hydrocarbon (HC), and particulate matter (PM) for LDVs and HDVs tested with B10 compared to conventional diesel.

MEASURES IDENTIFIED IN INDCS

All of the TTG-participating countries submitted INDCs in advance of the Paris Agreement. Each of these INDCs includes a quantitative, economy-wide greenhouse gas (GHG) emission control target for the year 2025 or 2030. In addition to GHG targets, some parties identified transportation or energy-efficiency measures to support achieving their GHG reduction target (Table 3). These identified measures include improving fuel efficiency and fuel quality, phase-down of high-GWP refrigerants, and promoting public transportation, advanced vehicle technologies, and alternative fuels.

Table 3. Transport measures identified in INDCs submitted by TTG participants. Regions are listed in alphabetical order. Blanks indicate that specific measures were not identified.

Country/ Region	Fuel efficiency	Fuel quality	High-GWP refrigerants	Public transportation	New-energy vehicles	Alternative fuels
Australia	✓					
Brazil				✓		✓
Canada	✓		✓			
China		✓		✓	✓	✓
EU[1]						
India	✓			✓	✓	✓
Japan	✓		✓	✓	✓	
Mexico						
Russia						
United States	✓		✓			

1 Transport as a whole is indicated as one of the sectors meant to contribute to the economy-wide reduction target.

CLIMATE AND ENERGY IMPACTS OF VEHICLE EFFICIENCY STANDARDS

VEHICLE EFFICIENCY SCENARIOS

We constructed three scenarios of current and projected LDV and HDV CO_2 emissions and energy use to evaluate the climate and energy impacts of vehicle efficiency standards in TTG member countries.[2] For each scenario, direct CO_2 emissions (from the combustion of transportation fuels) and energy use are estimated using the ICCT's Global Transportation Roadmap Model (ICCT, 2016a). First, we evaluate the expected climate and energy impacts of adopted LDV and HDV efficiency regulations compared to a baseline without these policies. Next, we examine the potential additional impact of finalizing policies under development as well as continuing new vehicle efficiency improvements with future regulations. The three vehicle efficiency scenarios are defined as follows:

» **Baseline:** Assumes no further improvements in new vehicle efficiency after 2005. This "business-as-usual" scenario allows us to estimate the marginal benefit of adopted policies that have improved, or will improve, LDV and HDV efficiency since 2005 (in the "adopted" scenario) by comparing against this "baseline" (without those policies).

» **Adopted policies:** Includes new vehicle efficiency policies implemented since 2005 as well as those adopted as of September 2016. This scenario includes policies that are "current" and "adopted but not yet implemented," but excludes policies that are "under development."

» **World-class:** Includes all policies in the "adopted" scenario, as well as policies "under development" (including draft notifications and proposals). Beyond the timeframe of specific policies that have been adopted or are under development, this scenario models the impacts of all TTG participating countries developing new vehicle efficiency standards that meet or exceed the objectives of the Energy Efficiency Leading Program by 2030: these aspirational targets include a 50% reduction in LDV fuel consumption compared to a 2005 base year by 2030 and a 30% reduction in HDV fuel consumption

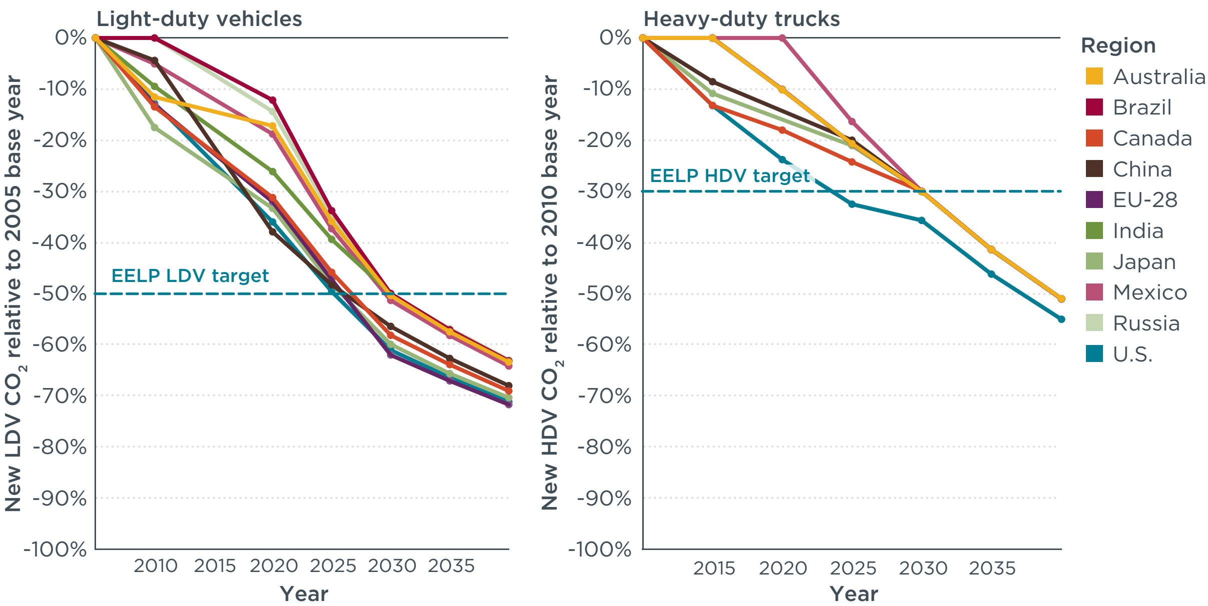

Figure 2. Change in CO_2 rate of new light-duty vehicles and heavy-duty trucks with world-class standards.

2 Australia, Brazil, Canada, China, EU-28 (including Germany, Italy, and the United Kingdom), India, Japan, Mexico, United States, and Russia.

compared to a 2010 base year by 2030 (G20, 2016). These improvements are assumed to continue after 2030 at a rate of 3.0% per year for LDVs (National Research Council, 2013) and until reaching a reduction of 50% for HDVs compared to a 2010 base year according to the level of technology potential previously estimated for these modes.[3] Regions are assumed to reach a 50% reduction for HDVs between 2035 and 2045 depending on the presence/stringency of existing regulations. Figure 2 illustrates these "world-class" assumptions for LDVs and heavy-duty trucks in each region.

Based on these scenario definitions, we can estimate the emission reduction associated with adopted policies by subtracting CO_2 emissions in the adopted scenario from the baseline scenario. Similarly, we can estimate the potential emission benefit of new policies by subtracting CO_2 emissions in the world-class scenario from the adopted scenario.

CLIMATE AND ENERGY IMPACTS

Figure 3 illustrates historical and projected vehicle stock (population) in TTG-participating countries. These fleet projections are applied for all three vehicle efficiency scenarios. Although HDVs typically account for less than 10% of the vehicle fleet, they tend to have much higher annual vehicle travel, longer vehicle lifetimes, and higher energy consumption (as a result of their operational demands for passenger/freight transport) compared to LDVs. For this reason, HDVs account for a disproportionate share of CO_2 from on-road vehicles.

Figure 4 shows direct CO_2 emissions and energy use from LDVs and HDVs in TTG members from 2005 to 2040 under each vehicle efficiency scenario. Compared to a baseline scenario without these policies, adopted vehicle efficiency standards are expected to slow the rate of growth in LDV and HDV CO_2 emissions and energy use.

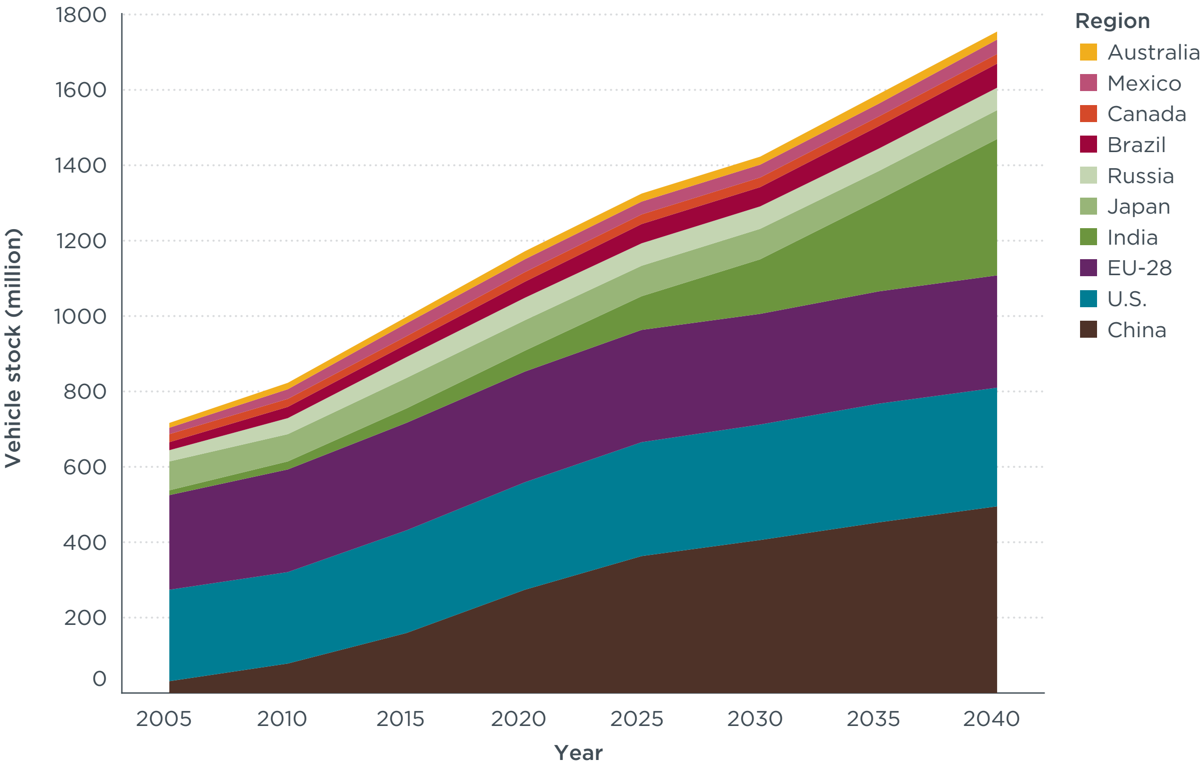

Figure 3. Historical and projected light- and heavy-duty vehicle stock, 2005–2040.

3 ICCT (Meszler et al., 2015), National Research Council (2010, 2014), and TIAX LLC (2009) for the U.S. market; TIAX (Law et al, 2011) for the European market.

ADDITIONAL EFFICIENCY IMPROVEMENTS ASSOCIATED WITH THE WORLD-CLASS SCENARIO COULD STABILIZE DIRECT CO_2 FROM LDVS AND HDVS IN THE 2020–2030 TIMEFRAME AND REDUCE ABSOLUTE EMISSIONS THROUGH 2040.

For LDVs, adopted policies are projected to reduce absolute CO_2 emissions from 2025–2030; however, additional policies are needed to sustain this decrease after 2030. Additional efficiency improvements associated with the world-class scenario could stabilize direct CO_2 from LDVs and HDVs in the 2020–2030 timeframe and reduce absolute emissions through 2040.

Figure 5 summarizes the CO_2 emissions and energy consumption pathways for light- and heavy-duty vehicles, aggregated across TTG participating countries. Whereas LDVs account for approximately 80% of the benefits of adopted vehicle efficiency policies among TTG participating countries (plus other member states of the EU-28), the additional mitigation potential associated with world-class policies is evenly split between LDVs and HDVs. In total, policies already adopted by TTG members are expected to reduce CO_2 emissions by 2 Gt per year in 2040, with fuel savings equivalent to 15 million barrels of oil per day (mb/d), compared to a baseline without these policies. Moreover, CO_2 emissions could be reduced by another 2.4 Gt in

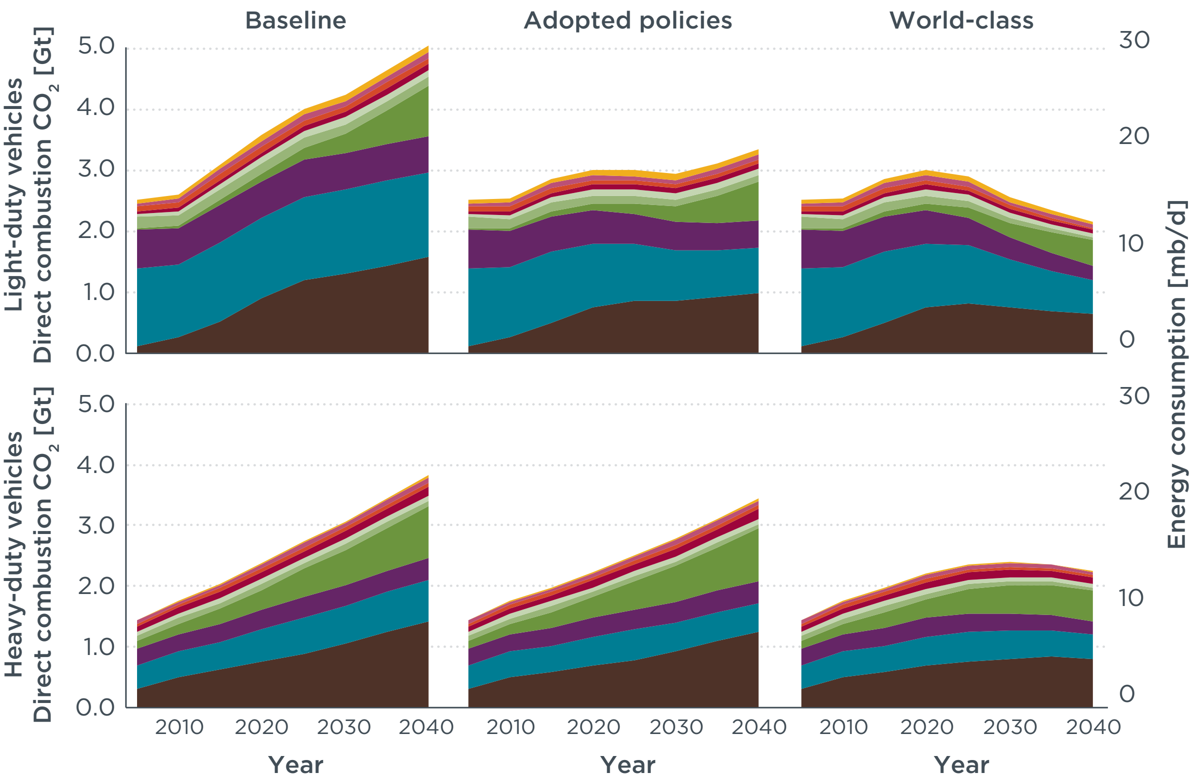

Figure 4. Direct CO_2 emissions and energy use of light- and heavy-duty vehicles, 2005–2040.

WHEREAS LDVS ACCOUNT FOR APPROXIMATELY 80% OF THE BENEFITS OF ADOPTED VEHICLE EFFICIENCY POLICIES AMONG TTG PARTICIPATING COUNTRIES (PLUS OTHER MEMBER STATES OF THE EU-28), THE ADDITIONAL MITIGATION POTENTIAL ASSOCIATED WITH WORLD-CLASS POLICIES IS EVENLY SPLIT BETWEEN LDVS AND HDVS.

2040 (16 mb/d) with new policies (world-class scenario) compared to projected emissions under adopted policies. Even at a low oil price of 50 USD/barrel, the direct annual savings to consumers and freight operators with these new policies could be on the order of $290 billion in 2040.[4] Combined, adopted and world-class vehicle efficiency policies could result in CO_2 emissions that are 4.4 Gt lower in 2040 (31 mb/d) compared to a baseline without these policies.

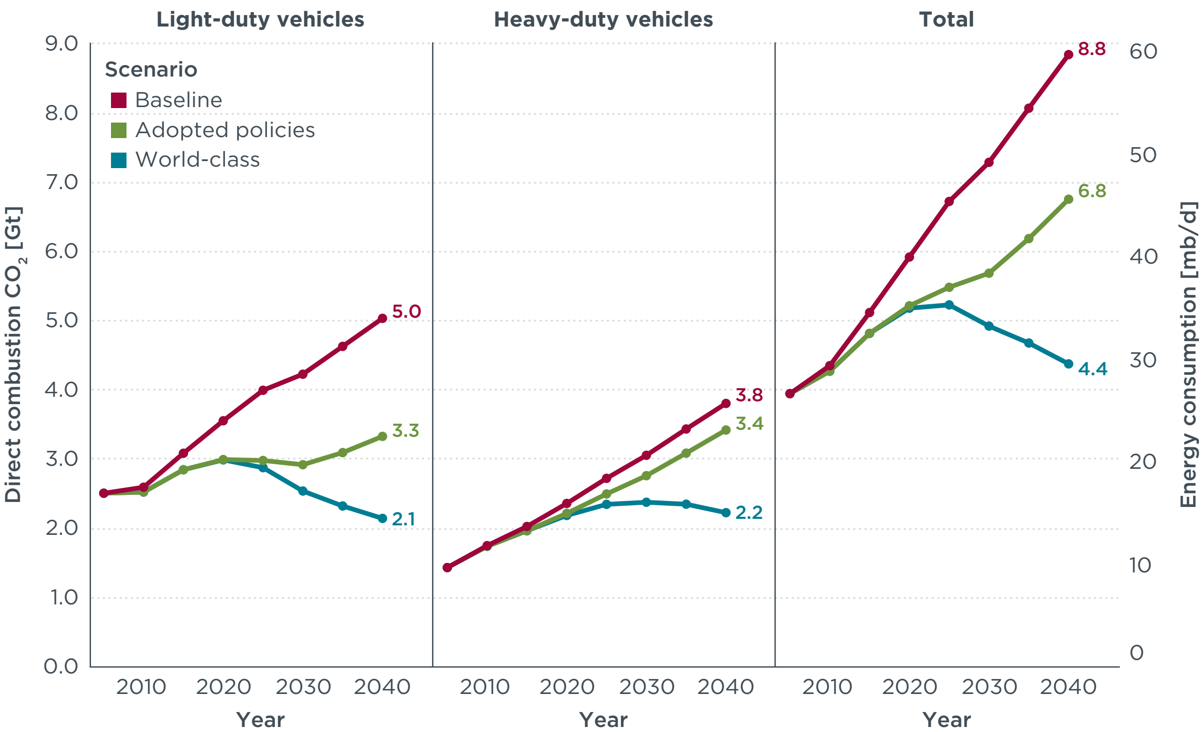

Figure 5. Direct combustion CO_2 emissions of light- and heavy-duty vehicles in TTG+EU member states under baseline, adopted policies, and world-class efficiency scenarios, 2005–2040. Figure shows historical and projected emissions for Australia, Brazil, Canada, China, the EU-28 (including TTG members Germany, Italy, and the United Kingdom), India, Japan, Mexico, the United States, and Russia.

4 Simplified estimate of fuel savings reflects only the price of oil in terms of energy equivalent and does not intend to capture differences in fuel prices among regions or the value added from refined products: 16 mb/d * 365 days/year * $50/bbl * 1 billion/1000 million = $292 billion/year.

EMISSIONS AND HEALTH IMPACTS OF VEHICLE EMISSIONS STANDARDS

CONVENTIONAL POLLUTANT EMISSION SCENARIOS

We constructed two scenarios for the analysis of vehicle emissions standards. These scenarios cover the six TTG members that have not yet implemented world-class standards to reduce fine particle ($PM_{2.5}$) exhaust from LDVs and HDVs: Australia, Brazil, China, India, Mexico, and Russia. As discussed earlier, China, India, and Mexico have already established plans to implement world-class standards by 2020 (and 2018 for Mexico).

» **Current standards:** Assumes that the six countries that have not yet implemented world-class standards for LDVs and HDVs remain at current (in force) standards. These current standards range from the equivalent of Euro 3 to Euro 5 for LDVs and from Euro III to Euro V for HDVs.

» **World-class:** Assumes that all six countries implement Euro 6/VI equivalent standards for LDVs and HDVs in the 2018–2020 timeframe. This scenario includes the timelines for China 6/VI, Bharat Stage VI, and NOM 044 established by China, India, and Mexico, respectively. Standards considered world-class for control of other pollutants such as nitrogen oxides (NO_X) are beyond the scope of this analysis.

As with CO_2 emissions, tailpipe $PM_{2.5}$ emissions were estimated for LDVs and HDVs using the ICCT's Global Transportation Roadmap Model (ICCT, 2016a). Emissions are projected to 2030, corresponding to the expected timeframe when Euro 6/VI vehicles will account for the majority of vehicles on the road, assuming the implementation of these standards in the 2018–2020 timeframe. This analysis conservatively considers only the impacts on primary (tailpipe) $PM_{2.5}$ emissions; other pollutants such as NO_X, CO, and sulfur dioxide (SO_2) would also be substantially reduced with Euro 6/VI equivalent standards but are outside the scope of this analysis.

IMPACT OF WORLD-CLASS STANDARDS ON FINE PARTICLE EMISSIONS

Implementation of world-class standards will substantially reduce emissions of fine particles ($PM_{2.5}$) in all six TTG members that have not yet implemented these standards (Figure 6). By 2030, $PM_{2.5}$ emissions

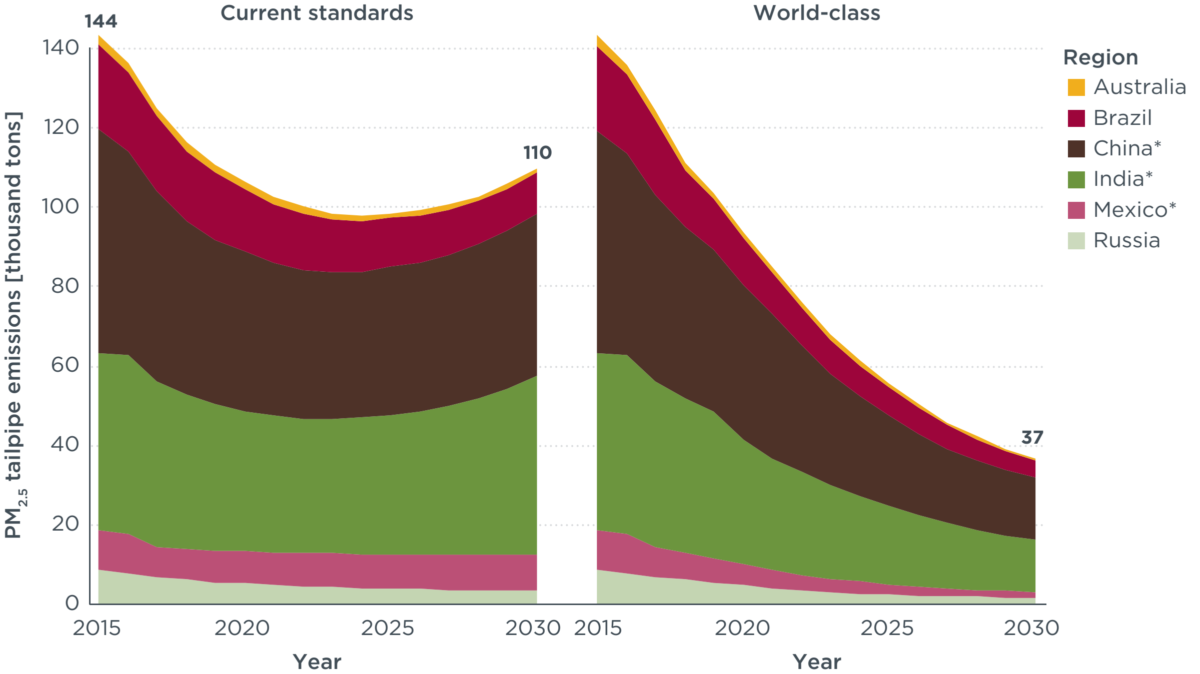

Figure 6. Impact of world-class standards on tailpipe $PM_{2.5}$ emissions from light- and heavy-duty vehicles in six G20 countries. *China, India, and Mexico have adopted, proposed, or are developing plans to implement such standards.

COMPARED TO CURRENT POLICIES, IMPLEMENTING WORLD-CLASS EMISSIONS STANDARDS IN THE SIX TTG MEMBERS THAT HAVE YET TO IMPLEMENT THESE REGULATIONS WILL REDUCE TAILPIPE PM2.5-RELATED HEALTH IMPACTS BY TWO THIRDS AND AVOID 60,000 EARLY DEATHS IN URBAN AREAS ANNUALLY BY 2030.

from LDV and HDV tailpipes will be 74% lower than in 2015 assuming Euro 6/VI-equivalent standards are implemented between 2018 and 2020 (consistent with the planned timelines in China, India, and Mexico).

HEALTH BENEFITS OF WORLD-CLASS EMISSIONS STANDARDS

Compared to current policies, implementing world-class emissions standards in the six TTG members that have yet to implement these regulations will reduce tailpipe $PM_{2.5}$-related health impacts by two thirds and avoid 60,000 early deaths in urban areas annually by 2030. These benefits will continue to grow after 2030 as vehicles meeting world-class emissions standards account for a larger share of fleet-wide vehicle activity. In absolute terms, these benefits are largest in India and China, followed by Mexico, Brazil, Russia, and Australia.

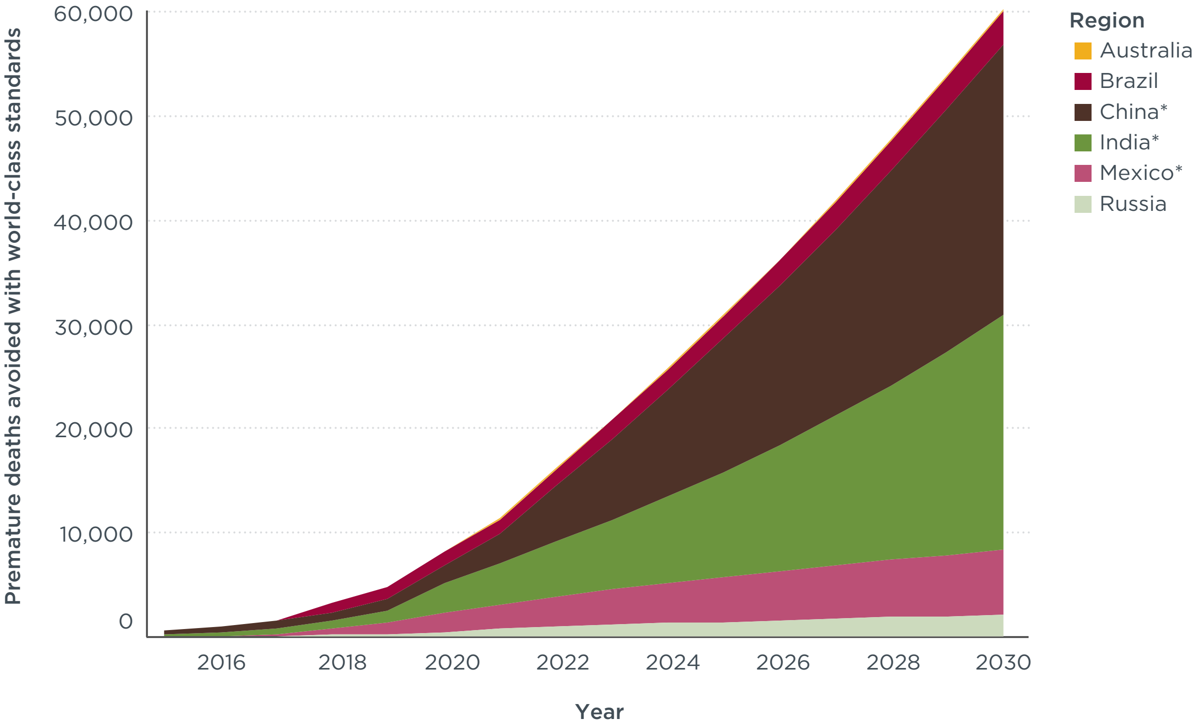

Figure 7. Premature deaths avoided with world-class standards for tailpipe $PM_{2.5}$ emissions in six G20 countries. *China, India, and Mexico have adopted, proposed, or are developing plans to implement such standards.

COST-EFFECTIVENESS OF WORLD-CLASS EMISSIONS STANDARDS

Previous nationwide analyses of the costs and benefits of these standards have found that the benefits to society consistently outweigh the costs, with benefit-to-cost ratios averaging 11:1 for HDV emission standards equivalent to Euro VI in Mexico and Brazil, and about 3:1 for programs covering all vehicle types (Table 4).

CLIMATE BENEFITS OF SHORT-LIVED CLIMATE POLLUTANT REDUCTION

Black carbon (BC) is a component of fine particulate matter that is also a potent short-lived climate pollutant (SLCP). Organic carbon (OC) and sulfates, also components of fine particulate matter, have climate-cooling effects. BC emissions can constitute up to 75% of tailpipe PM from diesels with Euro V-equivalent emission controls and ultralow-sulfur diesel (ULSD; U.S. EPA, 2012). This analysis quantifies the potential climate benefits of world-class emissions standards in terms of GWP and global temperature potential (GTP) over a 20-year and 100-year time horizon, drawing on the latest climate science reviewed in the IPCC Fifth Assessment Report (Myhre et al., 2013). Table 5 gives the GWP and GTP values applied for emissions of BC, OC, and sulfates. In each year, emissions of these pollutants were multiplied by their respective values to estimate climate impacts in terms of carbon dioxide equivalent (CO_2eq).

In 2030, implementing world-class emissions standards in China, India, Mexico, Brazil, Russia, and Australia could eliminate 66,000 tons of BC, with climate benefits offset by less than 2% due to concomitant reductions in climate-cooling OC and sulfate emissions. The net climate benefits of reduced BC, OC, and sulfate emissions are equivalent to 58 million metric tons of CO_2 (MtCO_2eq) using a 100-year GWP, and 208 MtCO_2eq using a 20-year GWP (Table 6). These impacts could also be incorporated in INDCs; for example, Mexico's inclusion of BC emissions in its INDC will allow the climate co-benefits of U.S. 2010/Euro VI-equivalent HDV emissions standards to be recognized for their climate benefits as well as their health benefits.

Table 4. Summary of cost-effectiveness analyses of Euro 6/VI-equivalent emissions standards in Mexico, Brazil, China, and India.

Regulation	Vehicle type	Time period	2015 US dollars (billions)			Source
			Total benefits[5]	Total costs[6]	Net benefits	
Mexico NOM 044	HDV	2018–2037	146	13	133	Miller et al. (2014)
Brazil P-8	HDV	2018–2048	74	7	67	Miller & Façanha (2016)
China 6/VI	LDV/HDV/MC	2018–2045	220	100	121	Shao & Wagner (2015)
India Bharat VI	LDV/HDV/MC	2010–2035	1,090	303	787	Bansal & Bandivadekar (2013)

Table 5. Global warming and temperature impacts of short-lived climate pollutants (Miller & Façanha, 2016).

Pollutant	GWP-20	GWP-100	GTP-20	GTP-100	Source / Notes
CO_2	1	1	1	1	By definition, the GWP and GTP of CO_2 are equal to 1
BC	3200	900	920	120	IPCC AR5 (Myhre et al., 2013)
OC	-240	-65	-71	-9	IPCC AR5 (Myhre et al., 2013)
Sulfate	-360	-100	-41	-6.3	Derived from Bond et al. (2013)

IPCC AR5: Fifth Assessment Report, Working Group 1.

Table 6. Reduction in climate pollutant emissions with world-class emissions standards in 2030 (MtCO_2eq).

Climate benefit	Global warming potential		Global temperature potential	
	GWP-20	GWP-100	GTP-20	GTP-100
BC	210	59	60	8
OC and Sulfate	–3	–1	–1	0
Net CO_2eq	208	58	60	8

5 Total benefits include valuation of avoided premature mortalities from exposure to exhaust $PM_{2.5}$; some analyses also include monetized climate benefits and fuel savings.

6 Total costs include vehicle technology costs; some analyses also include incremental cost of lower sulfur fuels and additional operating and maintenance costs.

CONCLUSION

This analysis characterizes the climate and health benefits of adopting world-class standards for new vehicle efficiency/CO_2 and conventional pollutant emissions in all members of the G20 TTG. We find that new world-class LDV and HDV efficiency standards applied in all TTG members could mitigate direct emissions from fuel combustion by an additional 2.4 $GtCO_2$ beyond the 2.0 $GtCO_2$ estimated to be avoided in 2040 under existing adopted vehicle efficiency standards (10 years earlier—in 2030—adopted and world-class standards could avoid 1.6 and 0.8 $GtCO_2$ per year, respectively). This additional mitigation potential, associated with all TTG members meeting or exceeding the aspirational targets of the EELP, is evenly split between light- and heavy-duty vehicles. For reference, the UNFCCC estimates that the aggregate effect of the INDCs submitted as part of the Paris Agreement will be to reduce global economy-wide emissions by a median estimate of 3.3 (ranging from 0.3 to 8.2) $GtCO_2eq$ in 2030 compared to a pre-INDC emission trajectory (UNFCCC, 2016a). The rate of growth in vehicle populations worldwide—coupled with their cost-effective CO_2 mitigation potential (achievable with fuel savings)—indicates that policies to improve vehicle efficiency should be a core component of meeting countries' climate targets, including INDCs. That four TTG participating countries (Canada, India, Japan, and the United States,) specifically mention fuel efficiency in their INDCs indicates that world-class vehicle efficiency standards could play an even greater role in future INDCs.

THE RATE OF GROWTH IN VEHICLE POPULATIONS WORLDWIDE—COUPLED WITH THEIR COST-EFFECTIVE CO_2 MITIGATION POTENTIAL (ACHIEVABLE WITH FUEL SAVINGS)—INDICATES THAT POLICIES TO IMPROVE VEHICLE EFFICIENCY SHOULD BE A CORE COMPONENT OF MEETING COUNTRIES' CLIMATE TARGETS, INCLUDING INDCS.

For conventional pollutants, we find that implementing world-class emissions standards for LDVs and HDVs in the six TTG members that have not yet implemented these standards could reduce $PM_{2.5}$-related health impacts in these countries by two thirds and avoid 60,000 premature deaths in urban areas alone annually by 2030. Once world-class emissions standards are implemented across all G-20 members, we estimate that nearly 90% of new LDVs and HDVs sold worldwide will meet the standards, compared to about only half of new vehicles sold today. These standards will result in additional climate co-benefits by reducing emissions of black carbon, a component of fine particle emissions. Mexico's inclusion of black carbon emissions in its INDC implies a core component for transport, potentially including the climate co-benefits of U.S. 2010/Euro VI-equivalent HDV emissions standards. Yet, even without these co-benefits, such standards have been found to be worthwhile many times over based on the health benefits of reduced $PM_{2.5}$ exposure.

The significant climate and health benefits demonstrated by this analysis bolster the rationale for G20 countries to continue improvements in new vehicle efficiency and lower conventional pollutant emissions from LDVs and HDVs. In particular, given that G20 members account for 90% of new vehicles sold in the world today (and more than 80% for TTG members), TTG members have considerable capacity to transform the global vehicle market and, ultimately, most of the vehicles on the road. The analysis also reinforces the importance of both light- and heavy-duty vehicles in securing future CO_2 reductions from on-road vehicles.

The focus of this paper on tailpipe emissions and vehicle efficiency standards in TTG member countries leaves an opportunity for subsequent analysis. In particular, future analysis could specifically address the impacts of vehicle efficiency standards along with other low-carbon transport policies in the context of possible global 2-degree and 1.5-degree emissions scenarios—although it is apparent from the scale of necessary GHG mitigation that all cost-effective solutions will be needed to attain a 2- or 1.5-degree pathway. Additionally, future analysis could be extended to other G20 countries currently not within the TTG membership.

THE SIGNIFICANT CLIMATE AND HEALTH BENEFITS DEMONSTRATED BY THIS ANALYSIS BOLSTER THE RATIONALE FOR G20 COUNTRIES TO CONTINUE IMPROVEMENTS IN NEW VEHICLE EFFICIENCY AND LOWER CONVENTIONAL POLLUTANT EMISSIONS FROM LDVS AND HDVS. IN PARTICULAR, GIVEN THAT G20 MEMBERS ACCOUNT FOR 90% OF NEW VEHICLES SOLD IN THE WORLD TODAY (AND MORE THAN 80% FOR TTG MEMBERS), TTG MEMBERS HAVE CONSIDERABLE CAPACITY TO TRANSFORM THE GLOBAL VEHICLE MARKET AND, ULTIMATELY, MOST OF THE VEHICLES ON THE ROAD.

REFERENCES

Bansal, G., & Bandivadekar, A. (2013). Overview of India's vehicle emissions control program. Washington, D.C.: International Council on Clean Transportation. Retrieved from http://www.theicct.org/indias-vehicle-emissions-control-program

Blumberg, K. (2016, July). Common ground on clean transportation. Washington, D.C.: International on Clean Transportation. Retrieved from http://www.theicct.org/blogs/staff/common-ground-on-clean-transportation

Dallmann, T., & Bandivadekar, A. (2016, April). India Bharat Stage VI emission standards. Washington, D.C.: International Council on Clean Transportation. Retrieved from http://www.theicct.org/india-bharat-stage-vi-emission-standards

Delgado, O. (2016, July). Stage 3 China fuel consumption standard for commercial heavy-duty vehicles. Washington, D.C.: International Council on Clean Transportation. Retrieved from http://www.theicct.org/china-stage-3-fuel-consumption-standard-commercial-HDVs

The Department of Infrastructure and Regional Development [Australia]. (2016). *Vehicle emissions discussion paper.* Retrieved from https://infrastructure.gov.au/roads/environment/forum/files/Vehicle_Emissions_Discussion_Paper.pdf

Du, L., Miller, J., & Kodjak, D. (2017). Status of clean vehicle and fuel regulations in select G20 countries. Washington, D.C.: International Council on Clean Transportation.

European Commission. (2016, July). Consultation on the preparation of legislation on monitoring/reporting of heavy-duty vehicle fuel consumption and CO_2 emissions. Directorate-General Climate Action–Unit C4. Retrieved from http://ec.europa.eu/clima/consultations/articles/0031_en.htm

G20. (2014). G20 energy efficiency action plan: Australia 2014. Retrieved from http://www.ipeec.org/upload/publication_related_language/pdf/11.pdf

G20. (2016). G20 energy efficiency leading programme: 2016 China. Retrieved from https://ec.europa.eu/energy/sites/ener/files/documents/G20%20Energy%20Efficiency%20Leading%20Programme.pdf

He, H. (2016, July). China's latest step forward on vehicle emissions regulation. Washington, D.C.: International Council on Clean Transportation. Retrieved from http://www.theicct.org/blogs/staff/latest-step-forward-on-china-vehicle-emissions-regulation

Institute for Health Metrics and Evaluation. (2015). GBD compare. Retrieved from https://vizhub.healthdata.org/gbd-compare/

International Council on Clean Transportation. (2016a). Global Transportation Roadmap Model (internal version). Documentation available from http://www.theicct.org/global-transportation-roadmap-model

International Council on Clean Transportation. (2016b). Global Vehicle Sales Database (internal version). Documentation available from http://www.theicct.org/methodological-notes-global-vehicle-sales-database

Kodjak, D. (2015). Policies to reduce fuel consumption, air pollution, and carbon emissions from vehicles in G20 nations. Washington, D.C.: International Council on Clean Transportation. Retrieved from http://www.theicct.org/policies-reduce-fuel-consumption-air-pollution-and-carbon-emissions-vehicles-g20-nations

Law, K., Jackson, M., & Chan, M. (2011). European Union greenhouse gas reduction potential for heavy-duty vehicles. Prepared by TIAX for the International Council on Clean Transportation. Retrieved from http://www.theicct.org/ghg-reduction-potential-heavy-duty-vehicles-eu

Meszler, D., Lutsey, N., & Delgado, O. (2015). Cost effectiveness of advanced efficiency technologies for long-haul tractor-trailers in the 2020–2030 timeframe. Washington, D.C.: International Council on Clean Transportation. Retrieved from http://www.theicct.org/us-tractor-trailer-tech-cost-effectiveness

Miller, J., Blumberg, K., & Sharpe, B. (2014) Cost-benefit analysis of Mexico's heavy-duty emission standards (NOM 044). Washington, D.C.: International Council on Clean Transportation. Retrieved from http://www.theicct.org/cost-benefit-analysis-mexicos-heavy-duty-emission-standards-nom-044

Miller, J., & Façanha, C. (2014, December). The state of clean transport policy: A 2014 synthesis of vehicle and fuel policy developments. Washington, D.C.: International Council on Clean Transportation. Retrieved from http://www.theicct.org/state-of-clean-transport-policy-2014

Miller, J., & Façanha, C. (2016). Cost-benefit analysis of Brazil's heavy-duty emission standards (P-8). Washington, D.C.: International Council on Clean Transportation. Retrieved from http://www.theicct.org/cost-benefit-analysis-brazil-HDV-emission-standards-p-8

Ministry of Road Transport and Highways. (2016, September). Notification [Bharat VI]. Gazette of India. Retrieved from http://morth.nic.in/showfile.asp?lid=2391

Myhre, G., Shindell, D., Bréon, F.-M., Collins, W., Fuglestvedt, J., Huang, J., ... Zhang, H. (2013). Anthropogenic and natural radiative forcing supplementary material. In Stocker, T. F., Qin, D., Plattner, G.-K., Tignor, M., Allen, S.K., Boschung, J., ... Midgley, P.M. (Eds.) *Climate change 2013: The physical science basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, United Kingdom: Cambridge University Press.

National Research Council. (2010). Technologies and approaches to reducing the fuel consumption of medium- and heavy-duty vehicles. Available from https://www.nap.edu/catalog/12845/technologies-and-approaches-to-reducing-the-fuel-consumption-of-medium-and-heavy-duty-vehicles

National Research Council. (2013). Transitions to alternative vehicles and fuels. Washington, D.C.: National Academies Press. Available from http://www.nap.edu/catalog.php?record_id=18264

National Research Council. (2014). Reducing the fuel consumption and greenhouse gas emissions of medium- and heavy-duty vehicles, Phase Two: First report. Washington, D.C.: The National Academies Press.

Shao, Z., & Wagner, D. V. (2015). Costs and benefits of motor vehicle emission control programs in China. Washington, D.C.: International Council on Clean Transportation. Retrieved from http://www.theicct.org/costs-and-benefits-motor-vehicle-emission-control-programs-china

TIAX LLC. (2009, September). Assessment of fuel economy technologies for medium- and heavy-duty vehicles. Final Report for the National Academy of Sciences.

United Nations Framework Convention on Climate Change. (2016a, May). Aggregate effect of the intended nationally determined contributions: An update. Synthesis report by the secretariat (advance version). Retrieved from http://unfccc.int/focus/indc_portal/items/9240.php

United Nations Framework Convention on Climate Change. (2016b). The Paris Agreement. Retrieved from http://unfccc.int/paris_agreement/items/9485.php

U.S. Department of State, Office of the Spokesperson. (2016, June). U.S.-China strategic & economic dialogue outcomes of the strategic track [Media Note]. Retrieved from http://www.state.gov/r/pa/prs/ps/2016/06/258146.htm

U.S. Environmental Protection Agency. (2012). *Report to Congress on black carbon*. Retrieved from https://www3.epa.gov/airquality/blackcarbon/2012report/fullreport.pdf

U.S. Environmental Protection Agency. (2016, August). EPA and DOT finalize greenhouse gas and fuel efficiency standards for medium- and heavy-duty engines and vehicles. Retrieved from https://www3.epa.gov/otaq/climate/regs-heavy-duty.htm

The White House, Office of the Press Secretary. (2016a, June). JOINT STATEMENT: The United States and India: Enduring global partners in the 21st century [Press release]. Retrieved from https://www.whitehouse.gov/the-press-office/2016/06/07/joint-statement-united-states-and-india-enduring-global-partners-21st

The White House, Office of the Press Secretary. (2016b, June). Leaders' statement on a North American climate, clean energy, and environment partnership [Press release]. Retrieved from https://www.whitehouse.gov/the-press-office/2016/06/29/leaders-statement-north-american-climate-clean-energy-and-environment

World Resources Institute. (2016). What is an INDC? Retrieved from http://www.wri.org/indc-definition

THE INTERNATIONAL COUNCIL
ON CLEAN TRANSPORTATION

www.theicct.org

communications@theicct.org