

# Cost-benefit analysis of early implementation of the China 6 light-duty vehicle emission standard in Guangdong Province

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## Introduction

Guangdong Province, ranked first in gross domestic product for the past 28 years in China, has consistently taken actions to improve local air quality. The region is well-known for the “Guangdong Blue (sky),” because its air quality is generally better than most regions in China. However, air quality in the region deteriorated in the first quarter of 2017; the monitored particulate matter (PM<sub>2.5</sub>), ozone (O<sub>3</sub>), and nitrogen dioxide (NO<sub>2</sub>) concentrations all increased compared with 2016 levels. More action is needed for Guangdong to maintain and improve the local air quality.

Mobile sources (e.g., vehicles) are recognized as a major contributor to air pollution in Guangdong. The newly announced China 6 light-duty vehicle (LDV) vehicle emission standard sets more stringent requirements for LDV emission control (He & Yang, 2017). The stringent China 6 standard presents an opportunity for Guangdong to address concerns about increasing emissions from the rapidly expanding LDV market.

This paper reviews the costs and benefits that would result from implementing the China 6 LDV emission standard

in Guangdong with a recommended timeline earlier than the national plan (2023). As an update to our previous work, this paper incorporates improved models and the latest emission standards, as well as our updated estimation of compliance costs. It provides modeled emission reductions of regulated ambient air pollutants; changes to PM<sub>2.5</sub> and ground-level O<sub>3</sub> concentrations; and avoided health impacts, including premature deaths and hospitalization. A cost-benefit analysis compares the social value of public health benefits with the costs associated with upgrading to cleaner vehicle technology.

## Background

Guangdong is one of the most advanced regions in China when it comes to managing local air quality. The annual average concentration of PM<sub>2.5</sub> was 32 µg/m<sup>3</sup> in Guangdong in 2016—already lower than the National Ambient Air Quality Standards requirement II of 35 µg/m<sup>3</sup> (Department of Environmental Protection of Guangdong Province, 2017a). Unlike most regions in China that are still struggling with severe air quality challenges, Guangdong has begun approaching healthier

air—that is, a limit of 10 µg/m<sup>3</sup> PM<sub>2.5</sub>, as recommended by the World Health Organization (WHO). Shenzhen, one of the Pearl River Delta (PRD) cities in Guangdong, proposed the target of 25 µg/m<sup>3</sup> by 2020 (Shenzhen Habitat Environment Committee, 2016). In early 2017, Guangdong’s top environmental regulators committed to eliminating heavy-pollution days by 2020 and maintaining the Guangdong Blue (Department of Environmental Protection of Guangdong Province, 2017b).

However, the challenge in Guangdong is unique. Located in southern China, long periods of high ambient temperature catalyzed the formation of ground-level O<sub>3</sub> emissions, another critical health-damaging pollutant. Monitored data from 2014 through the first quarter of 2017 suggest that O<sub>3</sub> and PM were the primary pollutants in Guangdong during the second and third quarters (summer) and during the first and last quarters (winter), respectively (Figures 1 and 2). In 2016, despite the decrease of other major air pollutant emissions, 8-hour O<sub>3</sub> and NO<sub>2</sub> increased compared with 2015 levels (Department of Environmental Protection of Guangdong Province, 2017c). Both pollutants are largely attributed to vehicular emissions. In

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addition, the PM<sub>2.5</sub> monitoring data for the first quarter of 2017 were higher compared with the same period in 2016 (Figure 1). Without more aggressive control measures, Guangdong will be at risk of losing the Guangdong Blue.

On-road transportation is one of the major contributors to the local air pollution in Guangdong. In its capital city, Guangzhou, mobile vehicles contributed about 21.7% of PM<sub>2.5</sub> based on the source apportionment analysis for 2013 and 2014 (Guangzhou Environmental Protection Bureau, 2015). In Shenzhen, vehicles contributed around 41% of local PM<sub>2.5</sub> in 2014 (Shenzhen Habitat Environment Committee, 2015). In addition, carbon monoxide (CO), nitrogen oxides (NO<sub>x</sub>), and volatile organic compounds (VOCs) emitted from motor vehicles are also important sources of O<sub>3</sub> precursors. A source apportionment study using U.S. EPA models (3 Community Multiscale Air Quality [CMAQ] and the Comprehensive Air-Quality Model with Extension [CAMx] modeling system) suggests that tailpipe emissions are the largest contributor to O<sub>3</sub> pollution in the PRD region—the economic center of Guangdong (Shen, Chen, & Zhong, 2015). To address the regional concerns about air pollution contributed by the tailpipe emissions, Guangdong should take aggressive actions on vehicle emissions control immediately.

Led by the PRD area, Guangdong has already taken a few measures to control vehicular emissions, from both new and in-use vehicle fleets. The China V gasoline fuel standard and diesel fuel standard were in place starting from October 2014 and July 2015, respectively—more than 2.5 years earlier than national timeline. The China 5/V light-duty and heavy-duty vehicle emission standards were phased in beginning in 2016—about 1 year ahead of the national timeline. The early retirement of “yellow-labeled

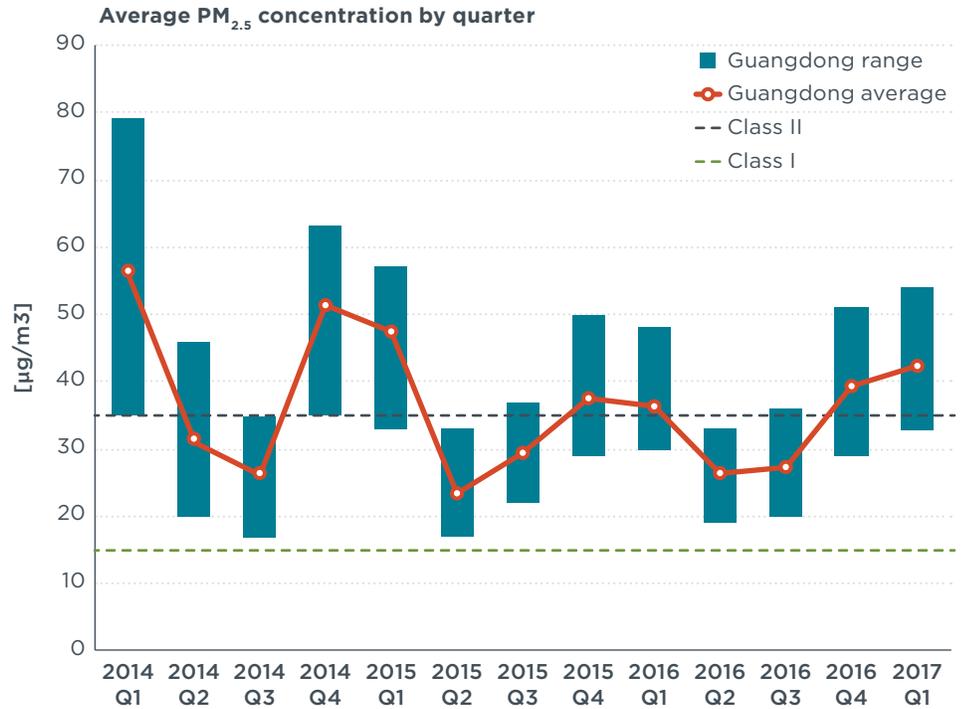


Figure 1: Annual average PM<sub>2.5</sub> concentration in Guangdong, 2014–2017 (Department of Environmental Protection of Guangdong Province, 2017a)

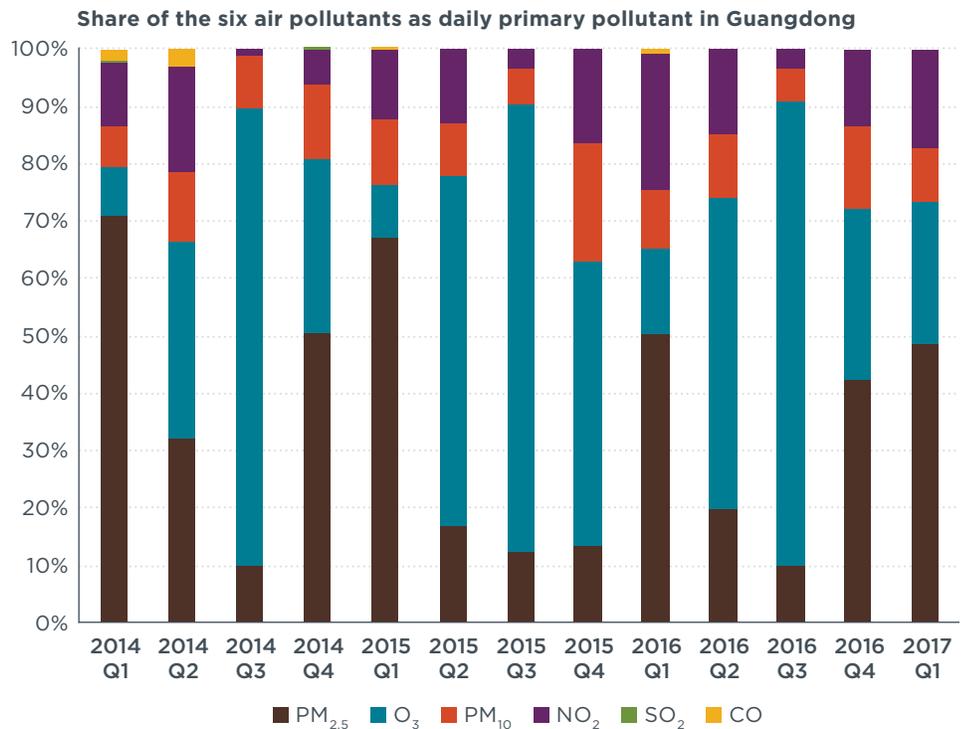
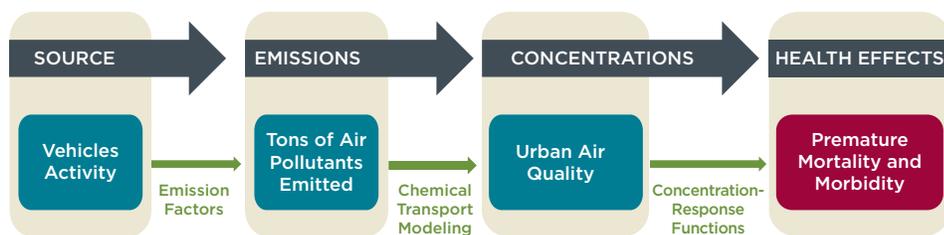


Figure 2: Share of daily primary pollutants in Guangdong, 2014–2017 (Department of Environmental Protection of Guangdong Province, 2017a)

vehicles” (YLVs)<sup>1</sup> significantly reduced emissions from on-road vehicles between 2013 and 2015 (Department of Environmental Protection of Guangdong Province, 2015).

But this is not enough. With the expectation of a continuously expanding vehicle market, emissions from vehicles will further increase, resulting in worsened impacts on the local air quality. Only with more ambitious control strategies will Guangdong be able to achieve its air quality commitment (Shao, Wagner, & Yang, 2014). We highly recommend that Guangdong move forward to adopt more stringent emission standards more quickly to achieve better air quality earlier and with more certainty.

On December 23, 2016, the Chinese Ministry of Environmental Protection (MEP) released the final rule of the China 6 LDV emission standard (He & Yang, 2017). The standard sets more stringent requirements on LDVs, by integrating best practices from the latest emission regulations in the European Union, the state of California, and the United States. In addition, the new Clean Air Law, adopted in 2016, gives governments of qualified regions the opportunity to apply national vehicle emission standards earlier than the national timeline and implement various measures for effective emission control of the in-use fleet. The standard offers a great opportunity for Guangdong to further reduce emissions, especially O<sub>3</sub>- and PM-formulating pollutants, from motor vehicles and to protect public health.



**Figure 3:** Conceptual framework for evaluating the health impacts of transportation emissions.

## Scope and methodology

In 2014, we estimated the costs and benefits of implementing China 5/V and 6/VI vehicle emission standards in Guangdong on an accelerated timeline (Shao, Wagner, & Yang, 2014). The results indicated that the China 6/VI standards, which were treated as the Euro 6/VI equivalent in that analysis, would lead to long-term emissions reduction and public health benefits from reduced exposure to air pollution.

Like that previous study, this paper reviews the impacts of adopting the most stringent vehicle emission standards in Guangdong. The release of the China 6 LDV emission standard and suggested timeline helps us better capture the impacts from the next phase of the emission standards, rather than referring to the equivalent European standards. In addition to the emission and health impacts, we estimate the air quality impacts from LDVs, as LDVs are mostly driven in urban areas, where the population density is high.

We updated the China model (Shao & Wagner, 2015) to better capture the real-world emission impacts from the transportation sector. This analysis includes three major improvements: (a) updated emission factors from the National Emission Inventory guidebook, released by the MEP (2014); (b) a function of capturing real-world compliance; and (c) a

three-step approach<sup>2</sup> to evaluating the health impacts (as described conceptually in Figure 3). Using the emission factors suggested by the MEP can better estimate the real-world emissions, because those rates are tested from typical vehicles used in China. The added compliance function further captures the emission of in-use vehicles, especially those not fully complying with the standards. The improved approach to evaluating the health effects better translates the emission impacts on ambient PM<sub>2.5</sub> and O<sub>3</sub> concentrations, as those are the top two concerns in Guangdong. In addition, we evaluated evaporative emissions from LDVs using an external model developed by Ingevity Corporation with inputs from the Motor Vehicle Emission Simulator (MOVES) 2014 (U.S. EPA, 2014). Those improvements ensure that the model can better reflect the emission inventory contributed by on-road vehicles, as well as capture the potential air quality and health impacts from the stringent emission standards.

## Scenarios

The China 6 standard introduces two phases of fuel-neutral emission limits (i.e., limits that are the same for both gasoline and diesel vehicles), 6a and 6b, for air and climate pollutants, which will

<sup>1</sup> *Yellow-label vehicles* are defined as gasoline vehicles not meeting the China 1 LDV standard (in other words, they have uncontrolled emissions) and diesel vehicles not meeting the China 3 LDV standard (uncontrolled, China 1, and China 2).

<sup>2</sup> Refer to *Cost-benefit assessment of proposed China 6 emission standard for new light-duty vehicles* (Cui et al., 2017) for detailed information on the methodology and underlying assumptions.

be implemented nationwide in 2020 and 2023, respectively. Compared with the Euro 6 light-duty standard, China 6a tightens the CO limit for gasoline vehicles by 50%–67% depending on vehicle class; tightens the NO<sub>x</sub> limit for diesel vehicles by 25%–33% depending on vehicle class; and tightens the evaporative and refueling emission-control requirements, reducing the evaporative emissions by 90%. China 6b further tightens CO, NO<sub>x</sub>, and PM limits by 50%, 40%, and 33%, respectively, compared with China 6a. In addition, China 6 adopts a World Harmonized Light-Duty Test Cycle and Procedure, a Real-Driving Emissions (RDE) testing requirement, stringent evaporative and refueling emission-control requirements, and a stronger on-board diagnosis (OBD) provision that will improve vehicles' in-use emission compliance.

This analysis reflects impacts from the improved China 6 standard, including the reduced emission limits and the more stringent compliance requirements for the in-use fleet.

To better capture the full benefits of the China 6 LDV emission standard and its measure of in-use fleet emission control, this analysis generates four scenarios for Guangdong to capture the emission impacts and further evaluates the impacts on air quality, health, and cost-benefit ratio for adopting China 6b in advance (Early Adoption scenario; Table 1).

- **Business as usual (BAU):** The BAU scenario maintains the China 5/V light-duty and heavy-duty vehicle emission standards in Guangdong throughout the study period. It also includes the scrappage program of YLVs as requested by the national government (i.e., scrap most YLVs in Guangdong by 2017).
- **China 6 national timeline (National Timeline):** This scenario

**Table 1:** Assumptions for the four scenarios.

	China 6 adoption		Scrappage	Modeling			
				Emission	Air quality	Health	CBA
<b>BAU</b>	N/A	N/A	YLVs	√	√	√	√
<b>National Timeline</b>	China 6a	2020.1.1	YLVs	√			
	China 6b	2023.1.1					
<b>Early Adoption</b>	China 6b	2018.9.1	YLVs	√	√	√	√
<b>Aggressive</b>	China 6b	2018.9.1	YLVs and Old vehicles	√			

assumes that Guangdong will implement the China 6 (both a and b) LDV emission standards by the announced national timeline on top of the BAU scenario.

- **China 6 early adoption (Early Adoption):** This scenario assumes that Guangdong leapfrogs to the China 6b LDV emission standards directly through an accelerated timeline.
- **China 6/VI early adoption and aggressive scrappage program (Aggressive):** This scenario assumes that old vehicles<sup>3</sup> will be removed beginning in 2022 and that the China 6b emission standard will be adopted early (Early Adoption).

### Modeling results

The following section illustrates the modeling results for LDVs in Guangdong based on the four scenarios defined. In addition to the tailpipe emissions, in this study, we quantified the evaporative emissions. Furthermore, the potential of air quality improvement in 2030 was examined for the Early Adoption scenario based on the change of PM and ground-level O<sub>3</sub> concentrations. We also reported the value of premature mortality and

<sup>3</sup> *Old vehicles* are defined here as vehicles not meeting the China 4 gasoline and diesel LDV standards.

hospital admissions avoided and estimated the costs and benefits of the early implementation of China 6b LDV emission standards in 2030 according to the timeline assumed in the Early Adoption scenario.

### EMISSION IMPACTS

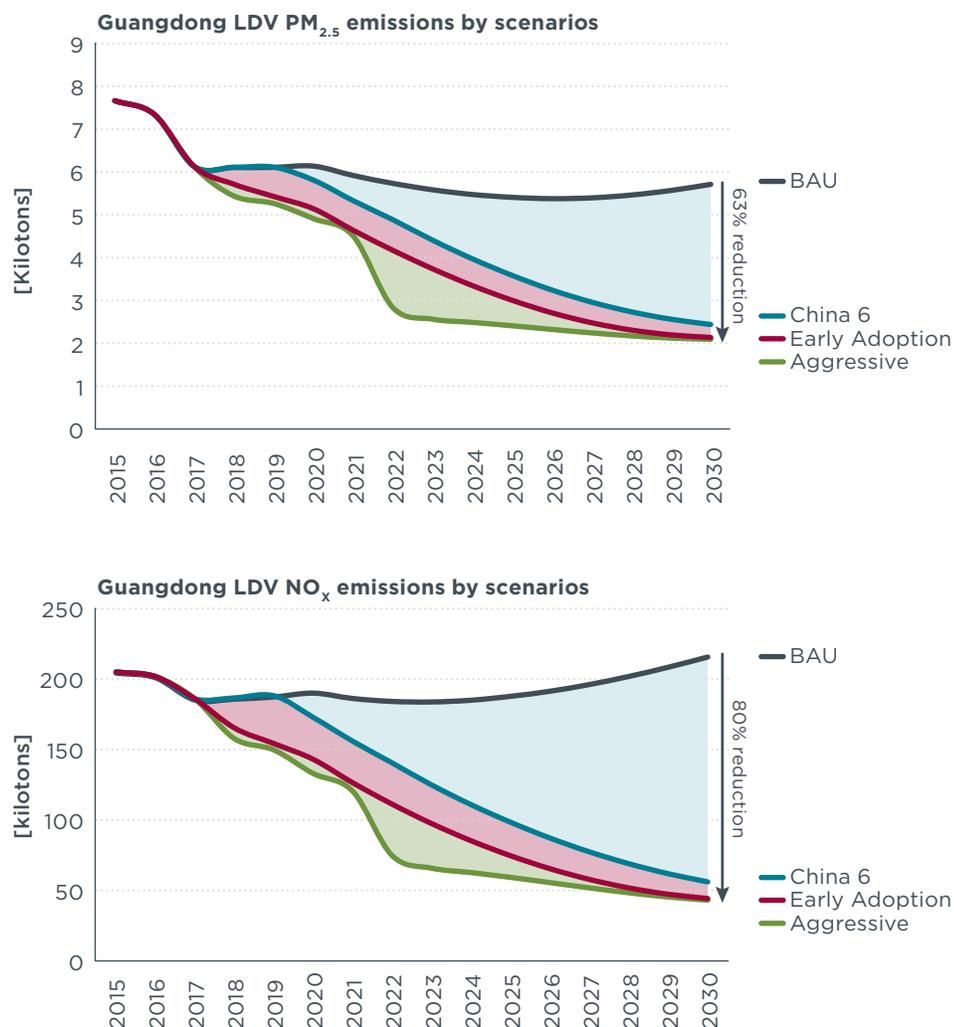
Introducing the China 6 emission standard can effectively control the emissions from LDVs in Guangdong within the timeline observed in this analysis. The China 5 standard fails to prevent the long-term increase in vehicle emissions arising from the rapidly growing vehicle population (Shao et al., 2014). Tightened emission limits and improved in-use compliance in the China 6 LDV standard result in emissions reductions up to 63% for PM and 80% for NO<sub>x</sub> in 2030, as illustrated in Figure 4. The early adoption of China 6b can yield additional benefits compared to just following the national timeline assumed in the China 6 scenario, achieving over 7 kilotons of PM and 307 kilotons of NO<sub>x</sub> savings cumulatively by 2030 (light red areas in Figures 4 and 5). The additional emission savings from adopting China 6b beginning in 2018 continue beyond 2030, although they are not fully shown in the chart.

The scrappage program targeting old vehicles and YLVs helps to speed up the process of emission reduction in the near term, because vehicles are

scrapped earlier than their original retiring age. The ongoing program successfully scrapped 1.7 million YLVs from 2014 to 2016. The removal of old vehicles in the Aggressive scenario further reaches a cumulative reduction of 6.6 kilotons of PM and 156 kilotons of NO<sub>x</sub> in the next 15 years compared to the Early Adoption scenario (green areas in Figures 4 and 5). As the impacts of the program dissipate over time (Shao & Wagner, 2015), the benefits of emission reduction in the Aggressive scenario eventually phase out around 2030.

The China 6 LDV emission standard will significantly reduce hydrocarbon (HC) emissions (Figure 5) as well—one of the important gaseous precursors of secondary PM<sub>2.5</sub> and O<sub>3</sub>. The cumulative tailpipe HC reduction from China 6 is over 536 kilotons when compared with the BAU scenario within the observed timeline, in which over one third comes from the early implementation of the China 6b standard (Early Adoption scenario). In addition, the China 6b standard immediately decreases the evaporative HC by almost 20 kilotons in 2018 once it is phased in. This saves 341 kilotons in 2030 compared with BAU, and the savings will continue to increase beyond 2030. The evaporation-related control strategies required under the China 6 standards ensure that the tailpipe and evaporative HC emissions are effectively managed.

The timeline of implementing the China 6 standard matters to Guangdong for controlling vehicle emissions. Leapfrogging to the China 6b standard directly in mid-2018 (Early Adoption scenario) leads to an additional 31%–43% emission reduction on top of following the announced national timeline (China 6 scenario), as summarized in Table 2. The savings will be even larger if Guangdong could commit to an earlier timeline (i.e., at the beginning of 2018).



**Figure 4:** Guangdong LDV PM and NO<sub>x</sub> annual emissions by scenarios, 2015–2030.

**Table 2:** Cumulative savings from tailpipe emissions among different scenarios (timeline), 2015–2030.

	PM (kilotons)	NO <sub>x</sub> (kilotons)	HC (kilotons)
<b>China 6 vs. BAU</b>	20	982	375
<b>Early Adoption vs. BAU</b>	27	1,289	536
<b>Additional savings</b>	35%	31%	43%

Our modeling results capture the highlights of the China 6 compliance and enforcement program, which includes the RDE requirement, OBD provision, and compliance test program, although they are not listed separately here. The improved compliance and enforcement program in the China 6 standard ensures that Guangdong will reach

the emission reduction and air quality targets as expected, even with pressure from a rapidly growing fleet. The early adoption of the China 6b standard in 2018 guarantees that vehicles sold between 2018 and 2023 will meet the most stringent emission requirements. Those vehicles will play an important

role in meeting Guangdong's ambitious air quality target in the next decades.

### AIR QUALITY IMPACTS

Based on the emission amounts calculated, we conducted a chemical transport model simulation<sup>4</sup> to estimate annual average PM<sub>2.5</sub> (both primary and secondary formation) concentrations and seasonal (April–September) average daily 1-hour peak O<sub>3</sub> concentrations in 2030 for two scenarios considered—BAU and the Early Adoption scenario.

We assumed that Guangdong will meet the State Council mandates for air pollution control with an emphasis on power and industrial sector emissions even under the BAU scenario in 2030. Then, Guangdong will continue efforts toward the PM<sub>2.5</sub> concentration target of 10 µg/m<sup>3</sup> recommended by WHO (2016).

Introducing the China 6b LDV emission standard ahead of the national schedule (Early Adoption scenario) will help Guangdong improve the concentration of annual average PM<sub>2.5</sub> and average daily 1-hour peak O<sub>3</sub> by 0.4 µg/m<sup>3</sup> and 2.0 ppb<sup>2</sup>, respectively. The improvement represents more than 2.5% in 2030 compared with the BAU scenario, as shown in Table 3. Although Guangdong is already in better compliance with the national air quality standard compared with other provinces (Cui et al., 2017), the province has still not met the WHO recommendation. Implementing the China 6b standard can help Guangdong reduce the contribution from LDVs and move closer to the target with the Early Adoption timeline.

<sup>4</sup> This study used the Community Multi-Scale Air Quality (CMAQ) modeling system (Byun, Ching, Novak, & Young, 1998) for calculation. For details, refer to *Cost-benefit assessment of proposed China 6 emission standard for new light-duty vehicles* (Cui et al., 2017).

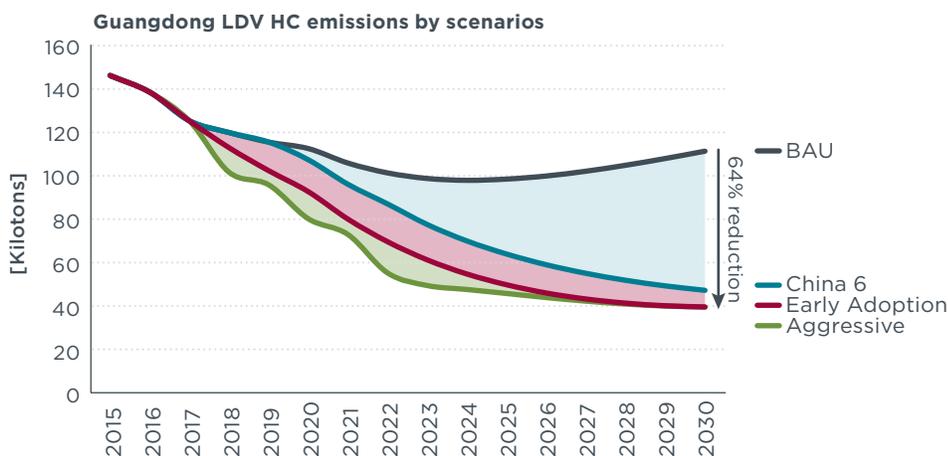


Figure 5: Guangdong LDV tailpipe HC savings by scenarios, 2015–2030.

Table 3: Effect of early adoption of China 6 on PM<sub>2.5</sub> and O<sub>3</sub> concentrations in 2030 in relation to the BAU scenario.<sup>1</sup>

	Annual average PM <sub>2.5</sub> concentration		Seasonal average daily 1-hour peak O <sub>3</sub>	
	Improvement (µg/m <sup>3</sup> )	% Change	Improvement (ppb) <sup>2</sup>	% Change
<b>Guangdong</b>	0.4	-2.5%	2.0	-3.0%

<sup>1</sup> Concentration values are population-weighted.

<sup>2</sup> The scale that relates to ambient ozone concentrations—parts per billion (ppb).

Although the 2%–3% improvement seems minor, it represents a major achievement for Guangdong. Because Guangdong is assumed to have addressed most emission concerns locally by 2030, it will become more challenging to further improve the air quality. Phasing in the China 6b standard beginning in 2018 offers Guangdong an effective approach to further lower the PM concentration and O<sub>3</sub> simultaneously.

### HEALTH IMPACTS

High concentrations of PM and O<sub>3</sub> lead to poor air quality and a series of negative effects on human health. If inhaled into the respiratory tract, PM and O<sub>3</sub> will quickly interact with respiratory cells, fluid, and tissues and cause damage that could further weaken lung function. Children are at greatest risk from exposure to high PM and O<sub>3</sub>

concentrations because their lungs are still developing and they are more likely to be active outdoors when O<sub>3</sub> levels are high, which increases their exposure (U.S. EPA, 2016).

Exposure to PM<sub>2.5</sub> and O<sub>3</sub> pollution will result in both acute (short-term) and chronic (long-term) health impacts. This study focused on the latter because long-term health impacts are more inclusive and typically account for short-term impacts. We applied the Global Burden of Diseases Study 2010 integrated exposure-response functions developed by Burnett et al. (2014) to estimate the gridded premature deaths of four major diseases attributable to PM<sub>2.5</sub> pollution, including ischemic heart disease, stroke, chronic obstructive pulmonary disease, and lung cancer. We calculated the relative risk of mortality of each disease and the cardiovascular and

respiratory hospitalizations attributable to PM<sub>2.5</sub> exposure, as well as the premature deaths from respiratory diseases and respiratory hospitalizations due to O<sub>3</sub> exposure.

In 2030 alone, the early implementation of the China 6b standard will avoid 880 premature deaths and more than 626 hospitalizations in Guangdong province (Table 4). Most of these avoided health impacts will be attributable to reductions in exposure to ambient PM<sub>2.5</sub> concentrations. Reduction in O<sub>3</sub> exposure will account for approximately one quarter of the avoided deaths and hospitalizations.

## TECHNOLOGY COST ASSESSMENT

We developed estimates of the cost for both gasoline and diesel LDVs to comply with China 6 requirements. Based on our study focusing on the introduction of advanced vehicle control technologies required to meet the more stringent emission standards for LDVs (Posada, Bandivadekar, & German, 2012), we updated the cost of technologies already in the market and added cost items relevant to the requirements specified by the China 6a and 6b, as shown in the Table 5.

The compliance cost for gasoline vehicles is much lower than that for diesel vehicles. For most of the China 6-qualified LDVs (i.e., gasoline powered PVs and LCVs), the incremental cost is less than approximately US\$138 (approximately 950 Renmingbi [RMB]), which is quite inexpensive. Most of the cost for gasoline vehicle compliance comes from the adoption of gasoline particulate filters for direct injected engines<sup>5</sup> required to meet

<sup>5</sup> This study assumes that gasoline direct injection (GDI) technology will cover the entire gasoline passenger car fleet in 2020 and beyond. This may lead to overestimation of the technology cost.

**Table 4:** Avoided health impacts from early adoption of the China 6b standard in 2030 relative to BAU.

	Avoided premature deaths			Avoided hospital admission		
	PM <sub>2.5</sub>	O <sub>3</sub>	Total	PM <sub>2.5</sub>	O <sub>3</sub>	Total
<b>Guangdong</b>	669	211	880	471	155	626

**Table 5:** Incremental cost to comply with the China 6 standard based on an average car (@1.7L engine).<sup>1,2</sup>

	China 5 to 6a		China 5 to 6b	
	PVs	LCVs	PVs	LCVs
<b>Gasoline</b>	\$131	\$123	\$138	\$128
<b>Diesel</b>	\$648	\$678	\$699	\$729

<sup>1</sup> Costs reflect the incremental costs to manufacturers, not the price increment paid by the consumers.

<sup>2</sup> PVs = passenger vehicles, LCVs = light commercial vehicles

the particulate number targets, and from evaporative emission control technology. For diesel vehicles, 67% of the compliance costs (around US\$430) comes from selective catalytic reduction technologies, which are needed to meet the NO<sub>x</sub> standards for diesel vehicles; the remainder is incurred by changes to the air-fuel management system, OBD requirements, and engine calibration.

Moving directly to China 6b (i.e., skipping 6a) benefits car manufacturers as well. The proposed Early Adoption scenario reflects an optimized research and development strategy, which prevents car manufacturers from introducing two generations of new models within a short period of time to meet the China 6a and 6b standards separately. This strategy further saves car manufacturers from investing in two sets of production lines for China 6a and 6b. In addition, early adoption of the China 6b standard better prepares car manufacturers in Guangdong to dominate the domestic market. The car manufacturers will increase their competitiveness in the global market, as the China 6 standard incorporates the best practices from Europe, the state of California, and the United States. Manufacturers could test the waters of a global market as early

as 2018, when the China 6b standard would be required.

## COST-BENEFIT RATIO

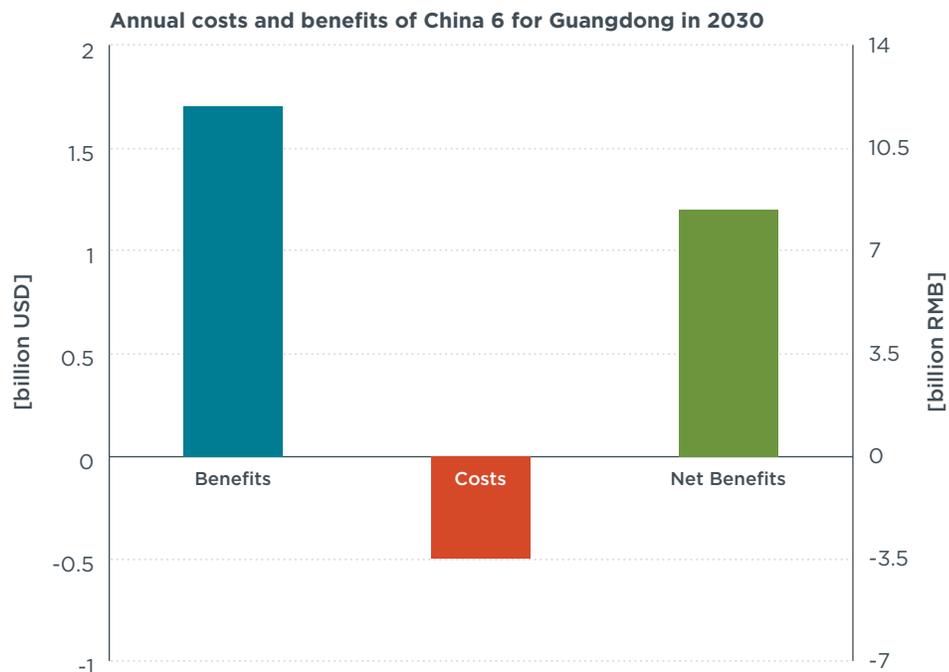
Reducing vehicle pollutant emissions yields corresponding improvements in ambient air quality, which has broad positive effects on the environment and public health. This analysis compares the incremental technology costs of complying with the China 6 standard with the economic value of avoided premature death in a single year (2030).

For cost, we mainly assess the incremental costs from the manufacturers in vehicle technology upgrades for complying with the proposed China 6 vehicle emission standard. The method is to multiply the per-vehicle incremental cost of technology improvement between China 5 and China 6b and the number of vehicles sold in Guangdong in each calendar year. Annual cost reduction resulting from learning technology and increasing production volume is assumed to be 3% from 2015 to 2020, 2% from 2020 to 2025, and 1% from 2025 to 2030 based on California Air Resources Board estimates.

The health benefits stemming from the introduction of advanced vehicle

emissions control standards are quantified in terms of the economic value of avoided premature deaths (not including avoided hospitalization), both from lower exposure to ambient PM<sub>2.5</sub> and O<sub>3</sub> concentrations. The economic benefits of reductions in premature mortality are calculated based on a value of statistical life (VSL), an indicator of willingness to pay to avoid health impacts.<sup>6</sup> The results should be considered as conservative as no benefits of reduced morbidity are monetized. Due to a lack of local empirical studies, we adopted a “benefit transfer” approach (Minjares et al., 2014) to adjust the value from other countries with the per-capita income. The VSL of China used in this analysis is \$1.89 million in 2015, and \$1.95 million in 2030 according to the U.S. central VSL estimates recommended by the U.S. EPA<sup>7</sup> and projected growth in per capital income.

Comparing these quantified benefits with the costs, we examine the cost-effectiveness of the China 6 standard in 2030,<sup>8</sup> approximately 12 years after the standard phase in. As shown in Figure



**Figure 6:** 2030 annual costs and benefits of implementing China 6 LDV emission standards in Guangdong (Early Adoption scenario vs. BAU).

6 VSL is an economic concept. It is used to estimate “how much people are willing to pay for small reductions in their risks of dying from adverse health conditions that may be caused by environmental pollution” (U.S. EPA, 2017). It is used mostly in regulatory impact analysis and scientific research. It summarizes the value society places on preventing death for any particular person. This study begins with a suggested VSL value from the U.S. EPA (derived from economic studies of willingness-to-pay) that is then adjusted for China based on relative differences in gross national income.

7 For analyses of environmental policies in the United States, the U.S. EPA recommends using a central VSL estimate of \$7.4 million (2006 USD) adjusted to the year of analysis. The corresponding value in 2015 USD is \$8.75 million.

8 We focus on 2030 impact considering the timetable of China’s ambient air quality standard and clean air action plans developed accordingly. The cost-effectiveness of the standard will continue to scale up in the longer run as China 6 vehicles account for a greater share of vehicle activity.

6, the economic value of total PM<sub>2.5</sub>- and O<sub>3</sub>-related health benefits from implementing China 6 are more than 3 times the cost of implementation. The early adoption of the China 6 standard yields tremendous benefits over the midterm (in 2030).

### Conclusion and Recommendations

Based on the following observations and findings, we highly recommend that Guangdong adopt the China 6 standard and an aggressive high-emitting-vehicle retirement program by mid-2018.

- O<sub>3</sub>, PM, and NO<sub>2</sub> emissions are the most concerning air quality pollutants in the region of Guangdong—all are highly related to vehicle emissions.
- The China 6 standard, especially China 6b, can significantly reduce emissions of PM, NO<sub>x</sub>, and other O<sub>3</sub> precursors.

- Current vehicle emission control measures have achieved major progress in stabilizing emissions in the near to mid-term.
- Only by adopting the China 6 standard will Guangdong achieve long-term emissions reduction and air quality benefits. Improved compliance and enforcement, enhanced OBD provisions, adoption of the RDE test, and an improved in-use testing program would enable better compliance with emissions standards for vehicles in real-world driving conditions.
- Early adoption of the China 6 standard would lead to more than a third of additional savings from LDVs, and the benefits last beyond 2030.
- A more aggressive high-emitter-retirement program would significantly advance the health benefits (i.e., avoided premature deaths and avoided hospital admissions) in the short term.

- The health benefits outweigh the technology cost by a factor of 3 in 2030. This number will grow even higher beyond 2030.

To meet the challenge of reaching a sustainable Guangdong Blue (sky), Guangdong needs more aggressive strategies to control emissions from LDVs. Demonstrated by the modeling results, adopting China 5 LDV emission standards cannot prevent long-term increases in vehicle emissions in Guangdong. Only the China 6 standard—especially the stringent China 6b emission standard—can effectively reduce the air pollution burden in Guangdong Province.

Early adoption of the China 6b standard would reduce an additional cumulative 27 kilotons of PM emission from 2015 to 2030 compared with the BAU scenario. It also reduces two major O<sub>3</sub> precursors—NO<sub>x</sub> and HC—which was demonstrated by the air quality modeling analysis to effectively alleviate the O<sub>3</sub> concentration levels in Guangdong. Over the next 15 years,

adoption of the China 6 standard would reduce tailpipe emissions by a cumulative 1,289 kilotons of NO<sub>x</sub> and 536 kilotons of HC. Among those, over 30% of the emission reduction comes from implementing China 6b ahead of the national timeline (Early Adoption scenario). Furthermore, introducing China 6b effectively reduces the evaporative emissions by 90% in 2030.

The China 6 LDV standard would improve air quality and public health. The PM<sub>2.5</sub> concentration and ground-level O<sub>3</sub> (1-hour peak) are expected to decrease by 2.5% and 3% in 2030, respectively. Early adoption of the China 6b standard in Guangdong is highly cost-effective, with the annual benefits outweighing the cost by a ratio of 3 to 1 in 2030. Combined with the aggressive scrappage program, early adoption of China 6 vehicle standards will improve policy effectiveness in the near term. The aggressive scrappage program will accelerate the replacement of higher emitters with cleaner vehicles in the fleet and maximize the

impacts of the China 6 standard on air quality in Guangdong.

Meanwhile, early implementation of the China 6b standard would be a win-win strategy for Guangdong and local car manufacturers. The car manufacturers can save significantly from avoiding preparing two sets of models to qualify for the China 6a and 6b standards in a short period. The manufacturers will be better prepared to expand the domestic and global market in advance, thanks to the state-of-the-art technology required by the China 6b, as early as mid-2018. Not to mention that the incremental cost for most of the LDVs (gasoline-powered LDVs) is less than 1,000 RMB, even with the most expansive emission-control package.

We strongly support the early adoption of the China 6b standard in Guangdong province. The China 6b standard will help Guangdong address its most prominent air quality and human health concerns cost-effectively, in both the short and long term.

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