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Costs and Benefits of China 5/V and 6/VI Standards in Guangdong Province

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1. Executive Summary

The ICCT conducted a cost-benefit analysis of the introduction of stringent new vehicle emissions and fuel quality standards in Guangdong Province. The analysis estimates future emissions, health and climate impacts, and costs associated with the four scenarios summarized in Table ES-1.[1]

The results show that early implementation of the China 5/V emissions standards and ultralow sulfur fuel standards in Guangdong will yield immediate emissions reductions from the motor vehicle fleet. These emissions reductions will lead to corresponding improvements in public health from reduced air pollution exposure as well as reductions of climate pollutant emissions. Using standard cost-benefit methodologies, we estimate that the overall value of these benefits will outweigh the total costs of the standards by 1.4 billion RMB in 2015 alone. Furthermore, these results should be considered extremely conservative since the health impacts estimates only consider premature mortalities from primary $PM_{2.5}$ emissions and not yet model morbidities or exposure to secondary PM or other pollutants including ozone. Our results strongly support the need for early implementation of the China 5/V standards in Guangdong.

However, our results also demonstrate that due to the expected continued dramatic rise in motor vehicle population in Guangdong, the China 5/V standards will not be sufficient to achieve long-term emissions reductions in the province. Only with the introduction of the world-class China 6/VI standards will emissions from motor vehicles continue to decline through 2030. Furthermore, the China 6/VI standards are extremely cost-effective, consistent with results in other regions implementing advanced tailpipe emission standards around the world. In 2030, a conservative estimate of the benefits of the China 6/VI standards is that they outweigh the costs by a factor of 2.5 to 1 (even higher farther into

Table ES-1: Scenarios for vehicle emissions and fuel quality standards implementation dates

Scenario	Pearl River Delta				Rest of Guangdong Province			
	China 5/V	China 6/VI	10 ppm gasoline	10 ppm diesel	China 5/V	China 6/VI	10 ppm gasoline	10 ppm diesel
China 4/IV (Current)	-	-	-	-	-	-	-	-
Late China 5/V	1/1/2018	-	1/1/2016	1/1/2016	1/1/2018	-	1/1/2016	1/1/2016
Early China 5/V	10/1/2014* 7/1/2015**	-	10/1/2014	7/1/2015	7/1/2015	-	7/1/2015	7/1/2015
China 6/VI	10/1/2014	1/1/2018	10/1/2014	7/1/2014	10/1/2014	1/1/2018	7/1/2015	7/1/2015

* Light-duty gasoline vehicles only
** All other vehicles

1 Note: in this table and throughout this report, Arabic numerals are used to refer to light-duty vehicle emission standards, while Roman numerals are used to refer to heavy-duty vehicle emission standards.

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the future). Under this scenario, premature mortalities from air pollution exposure in Guangdong will be reduced by 45% compared to the 2010 level.

Therefore, while the China 5/V standards are a cost-effective and important near-term policy step for Guangdong, the ICCT strongly recommends that the province consider in parallel the development and implementation of the China 6/VI standards as early as possible.

2. Introduction

China's remarkable recent economic growth has been accompanied by a dramatic rise in motor vehicle population. From 2000 to 2012, the number of cars, trucks, and buses in China grew nearly sevenfold from 16 million to 108 million, far exceeding even aggressive predictions.[2] Along the way, China surpassed the United States to become the world's largest automobile market beginning in 2009. With continued rapid growth in sales, China could be home to the world's largest population of highway vehicles as early as 2020.

The unexpectedly rapid proliferation of vehicles in China has brought enormous environmental pressures, especially urban air pollution. China's Ministry of Environmental Protection (MEP) has estimated that vehicles contribute a quarter to a third of particulate matter air pollution and at least half of urban nitrogen oxide pollution in megacities. China has responded aggressively with efforts to mitigate the negative environmental impacts of these tens of millions of vehicles, including the stepwise implementation of increasingly stringent tailpipe emissions and fuel quality standards. However, air quality remains poor throughout the country, and it is clear that much more must be done.

Although the national government has a critical role to play in developing and implementing nationwide policies, sub-national regions, especially densely populated provinces and megacities, have an opportunity to move even faster and more aggressively. The State Council, China's highest government body, is increasingly prioritizing a regional approach to air quality management. In September 2013, the State Council released a major air quality improvement plan that establishes concrete environmental targets for three selected key regions: the greater Beijing "Jing-Jin-Ji" region, the Yangtze River Delta region, and the Pearl River Delta region (State Council, 2013a).

The analysis in this report focuses specifically on the environmental impacts of motor vehicles in Guangdong, one of the leading provinces in China. Like the rest of China, the vehicle market in Guangdong has grown remarkably fast, with the total motor vehicle population growing from 1.7 million to 11 million from 2000-2012. Cities in Guangdong have suffered deeply from the downsides of these vehicles, including hazy weather and congestion. With both the State Council and the Guangdong provincial government prioritizing air quality improvement, cleaning up the vehicle fleet is critical at this stage.

This report presents the results of modeling and cost-benefit analyses of the accelerated introduction of stringent vehicle emissions standards (i.e. China 5/V and 6/VI), fuel quality standards (i.e. 10 ppm sulfur gasoline and diesel fuels), and aggressive scrappage/replacement programs in Guangdong province, especially the nine cities in the Pearl River Delta region, in advance of national policy timelines. The research reveals the environmental impacts, health benefits, and cost-effectiveness of the early introduction of stringent environmental management of motor vehicles in Guangdong. The profound implications of these results are important not just for Guangdong itself, but also for other regions all over China.

3. Overview of model

3.1 Modes and pollutants

This analysis focuses on the air pollution impacts of on-road vehicles—cars, trucks, buses, and motorcycles—in Guangdong province.[3] The emissions inventory model developed for this analysis is a customized version of the ICCT's peer-reviewed Global Transportation Roadmap Model.[4] The model calculates emissions based on activity, which is estimated by socioeconomic forecasts in population, gross domestic product (GDP), and fuel prices (Façanha et al, 2012). By applying localized input parameters related to vehicle technology, efficiency, and fuel share, the model estimates emissions of numerous conventional pollutant species including particulate matter smaller than 2.5 micrometers ($PM_{2.5}$), NO_X, CO, HC, and others. The model also outputs emissions of climate pollutant species including CO_2, CH_4, OC, and BC. The emission factors adopted in the current version are based on latest COPERT model.

3.2 Regions

This analysis focuses exclusively on Guangdong province. Four sub-regions—Guangzhou, Shenzhen, rest of Pearl River Delta region, and rest of Guangdong province—are

2 For example, Wang et al (2006) predicted China would have just 53 million highway vehicles in 2010 under a "high-growth" scenario; the actual population in 2010 was 77 million.

3 The inclusion of off-road sources including construction, agricultural, and marine equipment, is an important area for future modeling expansion

4 The ICCT's Global Transportation Roadmap model is available online at: http://theicct.org/global-transportation-roadmap-model

modeled independently. We designed our analysis and modeling to address expected action in these sub-regions. Each sub-region uses customized inputs for factors including policy implementation dates, vehicle population, vehicle activity, and more. Province-wide modeling results are the sum of the modeling estimates for the four sub-regions.

3.3 Policies

The objective of the modeling is to generate and compare quantitative results from selected motor vehicle emission control policy scenarios for on-road vehicles in Guangdong province. Particularly, the analysis considers the impacts of early adoption of China 5/V, fuel quality improvements, and aggressive scrappage/replacement programs. These assumptions are consistent with current regulatory proposals by the Guangdong government. We also investigate the impacts of the future introduction of China 6/VI standards. Detailed descriptions of the policies modeled are presented in Chapter 4.

3.4 Benefits and costs

Reducing vehicle pollutant emissions yields corresponding improvements in ambient air quality, which has broad positive effects on public health. This analysis estimates premature mortality in Guangdong province from lung cancer, cardiopulmonary disease, and acute respiratory infection caused by primary $PM_{2.5}$ emissions. Emissions are converted to urban exposure by means of the intake fraction approach.[5] Morbidities and impacts from emissions of other pollutants or secondary PM are not considered. Therefore, the health impacts results presented here should be considered highly conservative estimates.

Vehicle emissions have an effect not only on public health, but also on the environment in a variety of ways. In addition to health impacts, we evaluate the climate impacts from the introduction of advanced vehicle emissions and fuel quality standards by examining the net warming or cooling caused by vehicle tailpipe emissions of non-CO_2 climate pollutants, including black carbon, organic carbon, and methane. The climate impacts are estimated under the assumption of a 100-year time horizon for global warming potential (GWP).

Use of cost-benefit analysis around the world

Cost-benefit analysis is an important framework for evaluating any public policy. Costs are what the government pays to implement a new regulation and what society pays to comply. Benefits include potential economic, environmental, public health, safety, or other advantages of a new regulation. In the United States, the use of cost-benefit analysis is widespread and mature, in large part because regulatory agencies are legally required by the President to assess costs and benefits of significant new actions and to design regulations that maximize net benefits to society.

Most studies around the world that weigh the costs of controlling vehicle emissions and lowering fuel sulfur levels against the value of improved public health have found that the health benefits far surpass the costs of regulations. This implies that motor vehicle emission control is an extremely cost-effective strategy to reduce air pollution and improve public health.

The following table summarizes some international precedent in cost-benefit analysis of motor vehicle emission control:

Table 3.4.1: International precedent in cost-benefit analysis of motor vehicle emission control

Region	Policy	Costs	Benefits	Ratio (Benefits: Costs)	Source
USA	Tier 2	$5.3 billion	$25.2 billion	5:1	EPA, 1999
USA	Tier 3	$1.5 billion	$6.7-$19 billion	4:1 to 13:1	EPA, 2014
Mexico	Tier 2-equivalent	<$1 billion	$7 billion	8:1	INE, 2006
Sub-Saharan Africa	Low sulfur fuel supply	$2.7 billion	$25 billion	9:1	UNEP, 2009
India	Ultralow sulfur fuel supply and world class emission standards	$14.2 billion	$107 billion	8:1	Bansal and Bandivadekar, 2013

5 The intake fraction methodology is described in detail in the ICCT's Global Health Roadmap report (Chambliss et al, 2013).

The health and climate benefits are quantified in terms of economic value from reduced health burdens and climate damages. Estimated social benefits are due to reductions in premature mortality from improved urban air quality, as well as benefits from mitigated global climate change. The economic benefits of reductions in premature mortality are calculated based on a value of statistical life (VSL) approach.[6] The economic benefits from climate mitigation are calculated based on the social cost of carbon.[7] Climate benefits here include only the valuation of the reduction in emissions of short-lived climate pollutants such as black carbon, and do not include CO_2 reductions from fuel efficiency gains. A 2.5 percent annual discount rate is assumed.

As for costs, this study considers both additional technology costs from more stringent standards as well as production costs for refining higher quality fuel. Further details about the specific cost assumptions are presented in Chapter 5.

3.5 Validation of results

Our research represents an independent—but validated—analysis of Guangdong's motor vehicle emission control programs. Independent means we built our own models using peer-reviewed data for many parameters such as emission factors, survival curves, and vehicle activity (VKT) degradation curves. Validated means that throughout the modeling process, we communicated closely with project partners in China to identify missing data, seek feedback on early model runs, verify scenarios, etc. Our goal was to ensure that our resulting conclusions would be credible—and therefore influential—within China. An especially valuable partner was the Vehicle Emission Control Center (VECC), China's national vehicle emission policy and emissions modeling research center under the Ministry of Environmental Protection (MEP), who provided critical data inputs on regional VKT and more. We worked closely with VECC-MEP over the course of late 2013 and early 2014 to review results and calibrate our model.

6 VSL is an economic term to estimate the marginal cost of death prevention. The value covers a wide range of fatality risk including economics, health care, environmental impact assessment, and globalization. In this analysis, VSL is cited from Viscusi's study (Viscusi, 2004), and customized to China's development by using Gross National Income (GNI) Purchasing Power Parity (PPP). All the cost value is converted to 2010 U.S. dollars.

7 Social cost of carbon is a useful term to measure the benefits from CO_2e reductions. According to the EPA, "the social cost of carbon is a comprehensive estimate of climate change damages and includes, but is not limited to changes in net agricultural productivity, human health, and property damages from increased flood risk." Further information can be found at http://www.epa.gov/climatechange/EPAactivities/economics/scc.html.

4. Modeled scenarios for Guangdong province

4.1 Tailpipe emission standards

4.1.1 Historical

Guangdong's modern motor vehicle emission control program has mostly followed China's national pattern. Since 2000, tailpipe emission standards for nearly all categories of vehicles have been issued and periodically tightened. Some selected regions in Guangdong province, particularly the cities of Guangzhou and Shenzhen, have done early adoption of nationwide tailpipe emission standards, starting from China 3/III. Current emission standards throughout Guangdong province for new vehicles are China 4/IV.

Figure 4.1.1 shows ICCT estimates of historical on-road vehicle population in Guangdong province by tailpipe emission standard. These modeled estimates are the results of combining vehicle population and sales data with tailpipe standard implementation dates. The figure shows province-level aggregate data only, though the data account for different implementation dates for light-duty and heavy-duty vehicles, as well as separate implementation dates in the Pearl River Delta area as compared with the rest of the province. Note in the figure that, despite the rapid pace of implementation of increasingly stringent standards, there is still a large fraction (over a quarter) of Euro 2 and older vehicles in the fleet even in 2013.

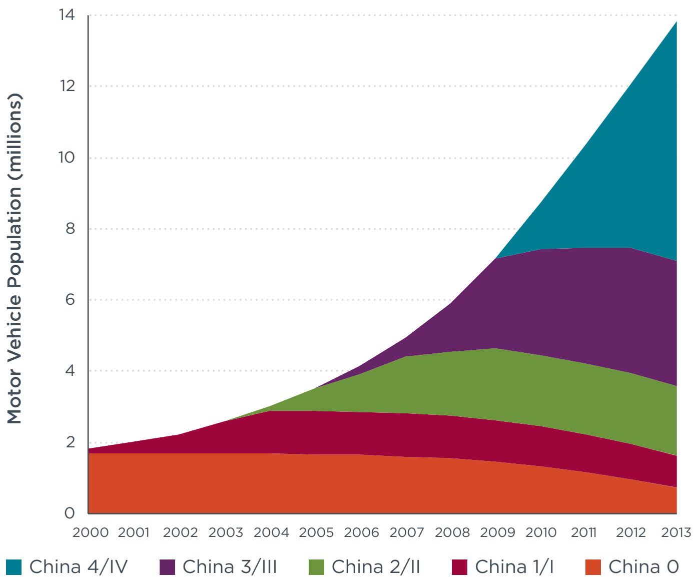

Figure 4.1.1: Guangdong's vehicle stock by tailpipe emission standard, 2000-2013

IMPORTANCE OF STRINGENT STANDARDS

Modern emission control systems are extremely effective at reducing tailpipe emissions to near-zero levels. As shown in the following figure, vehicles meeting the world-class Euro 6/VI tailpipe emission standards emit 99% less $PM_{2.5}$ than conventional (uncontrolled) vehicles. As vehicle populations around the world surge—especially in developing countries—reducing tailpipe emissions to near-zero levels is essential for controlling overall emissions and protecting public health (Chambliss et al, 2013).

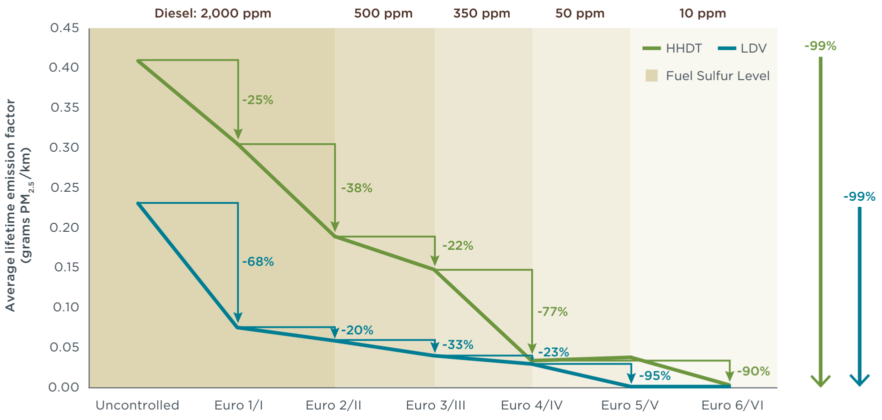

Figure 4.1.2: Fine particulate ($PM_{2.5}$) average lifetime emission factors for diesel vehicles by emission standard and fuel sulfur content

CHINA IV AND V HEAVY-DUTY DIESEL VEHICLE (HDDV) STANDARDS

Released in 2005, the China IV and V heavy-duty diesel vehicle standards were initially scheduled to be implemented nationwide for all vehicle sales and registrations on 1/1/2011 and 1/1/2013, respectively. However, concerns over the nationwide availability of low-sulfur fuel forced the Ministry of Environmental Protection (MEP) to delay the implementation of the China IV standard twice. The standard was finally implemented nationwide on 7/1/2013. The China V standard has been delayed indefinitely, although it is expected that it will be implemented nationwide on 1/1/2018.

China follows the European precedent for tailpipe emission standards, but has occasionally made some important revisions. Most recently, China issued several important supplemental testing standards to revise the China IV and V heavy-duty diesel vehicle standards. These standards, one issued by the national MEP (HJ 689-2014) and two issued by the Beijing Environmental Protection Bureau (DB11/964-2013 and DB11/965-2013), are designed to prevent excess NO_x emissions from heavy-duty diesel vehicles operating in urban environmental. It is critical important for Guangdong to also implement these China IV/V “fix” policies to ensure NO_x emissions expected by the standards are actually achieved.

4.1.2 Future proposed

This analysis investigates the impacts of the future introduction of the China 5/V and 6/VI tailpipe emission standards in Guangdong province. Four scenarios are modeled. In the “Current” scenario, no further progress beyond China 4/IV is assumed. In the “Late China 5/V” scenario, the China 5/V standards are assumed to be implemented throughout Guangdong on January 1, 2018, consistent with national requirements. In the “Early China 5/V” scenario, the China 5/V emission standards are adopted on October 1, 2014, for light-duty gasoline vehicles in the Pearl River Delta, and on July 1, 2015, for all vehicles throughout the province. Finally, we model a “China 6/VI” scenario, which follows the “Early China 5/V” scenario plus the added introduction of China 6/VI standards throughout Guangdong on January 1, 2018.

The following charts summarize Guangdong’s historical progress as well as modeled future policy scenarios for light-duty gasoline and heavy-duty diesel vehicles by sub-region. These standards together cover over 90% of the on-road vehicles, since the majority of heavy-duty vehicles are powered by diesel, while most light-duty vehicles are powered by gasoline. Cities in the Pearl River Delta region, especially Guangzhou and Shenzhen, have pioneered the early introduction of standards, with the early adoption of China 3/III standards in 2006. We expect these cities, along with the rest of the Pearl River Delta region, to continue this leadership with the early introduction of China 5/V.

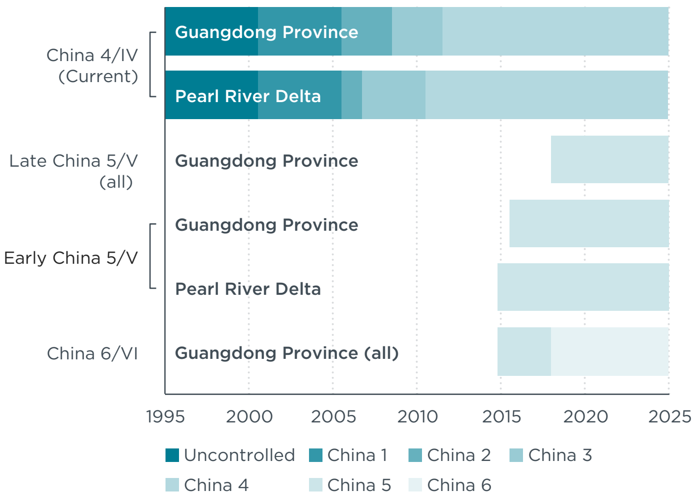

Figure 4.1.3: Light-duty gasoline vehicle emission standard implementation dates

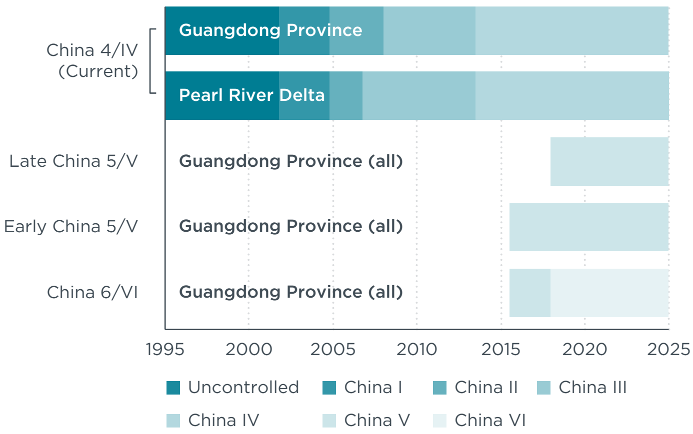

Figure 4.1.4: Heavy-duty diesel vehicle emission standard implementation dates

4.2 Fuel quality standards

Extensive studies have been carried out to investigate the linkages between fuel quality, vehicle technology, and emissions levels.[8] These studies have shown that dramatic reductions in tailpipe emissions can only be achieved if fuel quality and vehicle technologies are considered together in parallel and improved as a system.

Fuel quality impacts motor vehicle emissions in two important ways. First, many fuel properties directly affect the combustion process, including the type and amount of pollutants formed during combustion. Second, more importantly, fuel quality can either restrict or enable the use of certain after-treatment emission control technologies. Many advanced after-treatment devices are sensitive to impurities in fuel, so they can only be used effectively when fuel quality meets certain minimum standards. After lead, sulfur is the most important fuel parameter affecting emissions and the selection and use of emission control technologies.

Fuel quality standards in China have been periodically upgraded over the past two decades. However, China's fuel quality standards, especially sulfur levels, have historically lagged behind equivalent tailpipe emission standards, creating a "mismatch" which has caused delays of emission standard implementation. This mismatch led to the repeated delay of the China IV heavy-duty diesel vehicle (HDDV) tailpipe emissions and other standards, as described in the China IV/V HDDV standards box above.

In early 2013, in response to severe air pollution episodes across China, China's State Council issued a landmark directive calling for the nationwide introduction of ultralow sulfur fuels (10 ppm) by the end of 2017 (State Council, 2013b). The same announcement also called for 10 ppm gasoline and diesel fuel supply in the three key regions by the end of 2015.

Along with new vehicle emissions standards, selected cities in the Pearl River Delta as well as Guangdong province as a whole have a history of moving more aggressively than the national government to improve fuel quality. The current and proposed future timelines for improvement of China's gasoline and diesel fuel quality are shown in Figures 4.2.1 and 4.2.2. Four scenarios are again modeled. In the "Current" scenario, gasoline and diesel fuel sulfur levels throughout the province remain at 50 ppm. In the "Late China V" scenario, fuel sulfur levels throughout Guangdong follow the State Council requirement of 10 ppm by January 1, 2016. In the "Early China V" scenario, gasoline sulfur levels in the Pearl River Delta drop to 10 ppm by October 1, 2014, and both gasoline and diesel fuel sulfur levels throughout the province drop to 10 ppm by July 1, 2015, even earlier than the State Council requirement. The fuel supply timelines in the "China VI" scenario are identical to "Early China V."

The future tailpipe emissions and fuel quality standards scenarios are summarized in Table 4.2.2.

8 For example, http://www.crcao.org/reports/recentstudies2008/E-84/E-84%20Report%20Final,%20Aug%2014.pdf; http://www.epa.gov/otaq/models/moves/documents/420d13003.pdf; http://www.epa.gov/otaq/fuelsmodel.htm

FUEL SENSITIVITIES OF DIFFERENT VEHICLE EMISSION CONTROL TECHNOLOGIES

Table 4.2.1: Sulfur sensitivities of primary pollution control technologies

Emission Control Technology	Vehicles used on	Pollutants controlled	Fuel Sulfur Requirements
Three-way catalyst (TWC)	Euro 1+ gasoline	HC, CO, NO_x	conversion efficiency optimized with <30 ppm; emissions increase with higher sulfur levels but effects are reversible
Diesel oxidation catalyst (DOC)	Euro 3/III+ diesel	HC, CO, PM	<350 ppm viable, <50 ppm preferred
Diesel particulate filter (DPF)	Euro 5+ diesel Euro VI+ diesel	HC, CO, PM	<15 ppm
Exhaust gas recirculation (EGR)	Euro 3/III+ diesel	NO_x	<350 ppm
Selective catalytic reduction (SCR)	Euro 6+ diesel Euro IV + diesel	NO_x	<350 ppm (Vanadium-based) <50 ppm (Zeolite-based)
Lean NO_x traps (LNT)	Euro 6+ diesel	NO_x	<15 ppm

Note: This table is extensively revised from the June 2014 version of this paper.

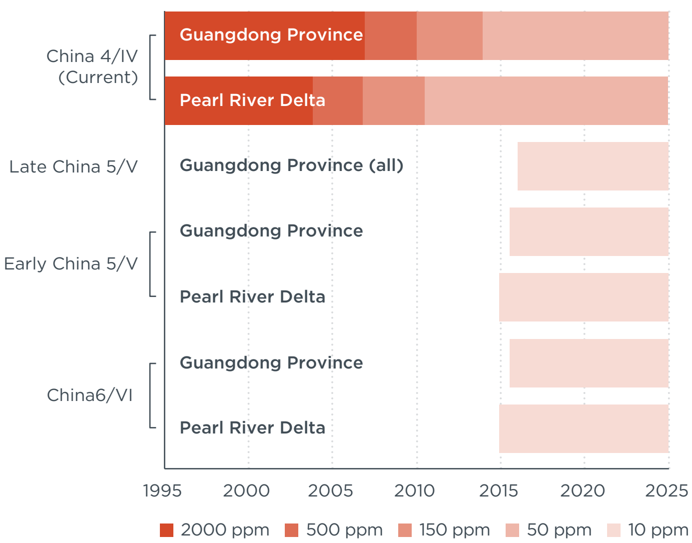

Figure 4.2.1: Gasoline fuel quality improvement timelines

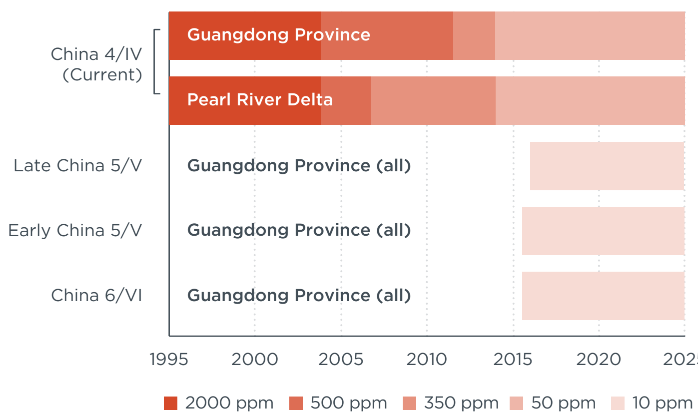

Figure 4.2.2: Diesel fuel quality improvement timelines

Table 4.2.2: Scenarios for vehicle emissions and fuel quality standards implementation dates

	Pearl River Delta				Rest of Guangdong Province			
Scenario	**China 5/V**	**China 6/VI**	**10 ppm gasoline**	**10 ppm diesel**	**China 5/V**	**China 6/VI**	**10 ppm gasoline**	**10 ppm diesel**
China 4/IV (Current)	-	-	-	-	-	-	-	-
Late China 5/V	1/1/2018	-	1/1/2016	1/1/2016	1/1/2018	-	1/1/2016	1/1/2016
Early China 5/V	10/1/2014* 7/1/2015**	-	10/1/2014	7/1/2015	7/1/2015	-	7/1/2015	7/1/2015
China 6/VI	10/1/2014	1/1/2018	10/1/2014	7/1/2014	10/1/2014	1/1/2018	7/1/2015	7/1/2015

* Light-duty gasoline vehicles only
** All other vehicles

4.3 Scrappage programs

The Chinese government has identified scrappage of older, high-emitting vehicles as a key priority to achieve short-term emissions reductions and air quality improvement. At the national level, the State Council has called for scrapping all yellow-label vehicles (YLVs), which are defined as gasoline vehicles not meeting the China 1/I standard and diesel vehicles not meeting the China 3/III standard, nationwide by the end of 2017. The State Council has further called for "basically" scrapping all YLVs in the three key regions by the end of 2015 (State Council, 2013a).

Earlier this year, the Guangdong government released a detailed air quality improvement plan for the period 2014-2017 (Guangdong Provincial Government, 2014). Echoing the State Council targets, the plan emphasizes the determination to scrap YLVs throughout Guangdong province before 2017. More aggressively, all YLVs in Pearl River Delta should be scrapped before 2015. These targets are reflected in all future modeling scenarios ("Late China 5/V," "Early China 5/V," and "China 6/VI"). The "Current" scenario includes no scrappage assumptions.

In addition to scrappage, the provincial and city governments in Guangdong province have implemented numerous other in-use vehicle emission control programs including inspection and maintenance (I/M) programs, low emission zones, as well as limited use of remote sensing, retrofitting, and more. For modeling simplification, only the results of scappage programs are quantified in this analysis, though expansion of the modeling to cover other in-use control programs is noted as an important area for future work.

5. Modeling results

5.1 Guangdong's motor vehicle population projections

Figure 5.1.1 shows ICCT's projections for future motor vehicle population in Guangdong by vehicle type. We project a total population of cars, trucks, and buses in Guangdong of just over 40 million by 2030. These vehicles are overwhelmingly light-duty vehicles, reflecting the continued consumer desire to purchase cars. The future vehicle population is assumed to be identical in all modeled scenarios; only the share of vehicles by emission standard changes over time.

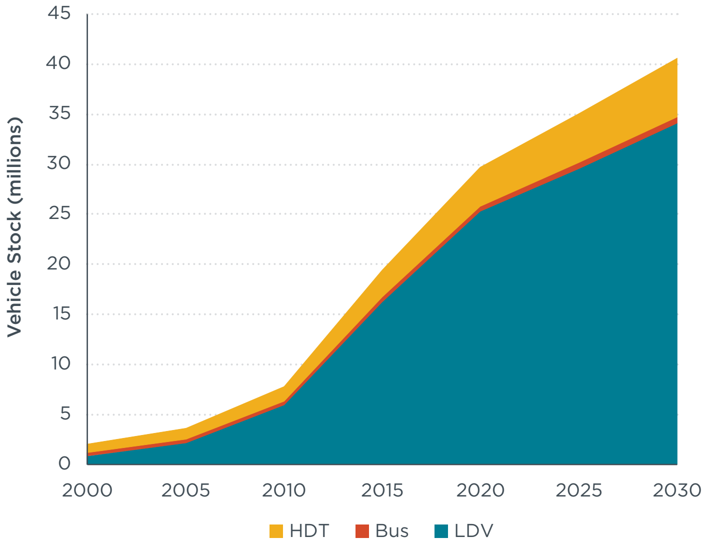

Figure 5.1.1: Vehicle population by mode in Guangdong, 2000-2030

5.2 Emissions projections

The following figures show aggregated province-wide emissions of two main pollutants of concern—NO_x and $PM_{2.5}$ under the four scenarios described in Chapter 4. The scrappage program is included for all scenarios except Current.

The results strongly support the need for early implementation of China 5/V emissions and 10 ppm sulfur fuel quality standards. These standards yield important, immediate emissions reductions in the province. However, the results also indicate that, due to the continued rapid rise of motor vehicle population in Guangdong, only the China 6/VI emissions standards are effective at forcing long-term emissions reductions of both NO_x and $PM_{2.5}$.

5.2.1 NO_x emissions projections

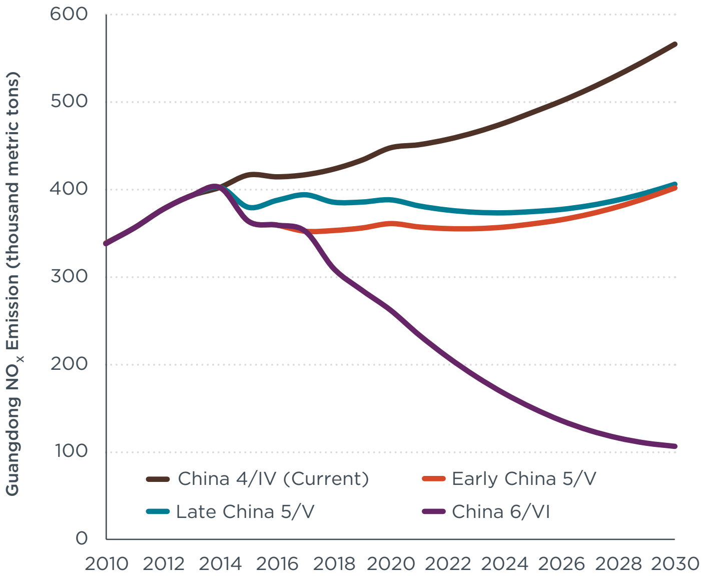

Figure 5.2.1: NO_x emission projections from motor vehicles in Guangdong, 2010-2030

Major observations from Figure 5.2.1 are as follows:

- NO_x emissions from motor vehicles in Guangdong province have been increasing steadily since 2010. Under the Current scenario, these emissions will keep growing as the vehicle market expands. If no future policies beyond China 4/IV are adopted, NO_x emissions in 2030 could be almost as twice as the level in 2010. More stringent tailpipe emission standards are clearly required to slow down and prevent future emissions increases.
- In both the Late and Early China 5/V scenarios, emissions growth is effectively controlled for the next decade, but emissions begin to increase again after around 2025 due to the continued rapid growth of vehicle population in Guangdong.
- The Early China 5/V scenario shows a clear advantage in the near term over Late China V. In particular, by 2017, NO_x emissions in the Early China V scenario are 41,727 tons or 11% lower than the Late China V scenario. The gap between two scenarios will not be eliminated until 2030.
- The graph clearly shows that only the China 6/VI standards are effective at forcing long-term emissions reductions. Although the China 5/V standards are important, the China 6/VI results underscore the importance of introducing world-class emission standards in Guangdong as early as possible.

5.2.2 Particulate matter (PM) emissions projections

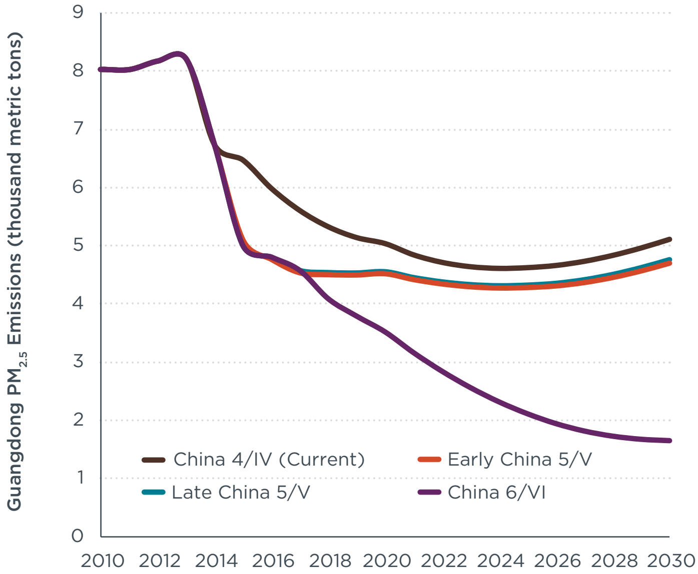

Figure 5.2.2: $PM_{2.5}$ emissions projections from motor vehicles in Guangdong, 2010-2030

The PM results in Figure 5.2.2 show some slight differences to the NO_x results. First, the introduction of 50 ppm sulfur fuels throughout the province at the end of 2013 and beginning of 2014 yields immediate PM reductions from all vehicles in the fleet, even before more stringent tailpipe emission standards take effect. These reductions are even more dramatic for the 10 ppm scenarios. With regards to the tailpipe emission standards, we can make the following observations:

- For PM emissions, the timing of the introduction of China 5/V has minimal importance. This is because most PM emissions come from heavy-duty diesel vehicles, for which the PM emission limit for China IV and V is identical.
- As with the NO_x trends, due to the continued dramatic increase in motor vehicle population in Guangdong, neither the China 4/IV nor China 5/V standards are effective at controlling long-term emissions.
- World-class China 6/VI standards are clearly required to achieve long-term emissions reductions, given continued rise in vehicle population. The projection shows that the China 6/VI standards can reduce over two thirds of the PM emissions by 2030 as compared with the Current scenario.

Table 5.2.3: Emissions reduction comparison for NO_X, $PM_{2.5}$, HC and CO

Pollutant	Annual emissions reductions in 2017 of Early China 5/V vs. Late China 5/V	Annual emissions reductions in 2030 of Early China 5/V vs. Current	Annual emissions reductions in 2030 of China 6/VI vs. Current
NO_x	41,727 tons (-11%)	164,377 tons (-29%)	459,854 tons (-81%)
$PM_{2.5}$	39 tons (-1%)	359 tons (-7%)	3,459 tons (-68%)
HC	3,240 tons (-8%)	13,070 tons (-32%)	17,485 tons (-43%)
CO	1,991 tons (0.32%)	3,901 tons (-1%)	100,256 tons (-15%)

5.2.3 Other pollutant emissions projections

The early implementation of China 5/V yields emissions reductions not just of NO_X and PM, but for all types of conventional pollutants. Table 5.2.3 illustrates the emissions savings for four major pollutants in 2017 as well as 2030. Less than two years after implementation, the reductions are already apparent, with savings up to 11%. This further supports the importance of early standard adoption.

The table also shows the additional benefits from China 6/VI compared to China 5/V. In 2030, for example, the $PM_{2.5}$ emissions reduction can be extended from 7% to 68% compared to the Current scenario, while NO_X, HC, and CO also show large reductions. These results offer strong evidence of the importance of Guangdong continuing to China 6/VI.

5.3 Health impacts

We convert primary vehicular $PM_{2.5}$ emissions into ambient concentrations, from which we estimate human exposure using the intake fraction approach, as introduced in Chapter 3 and documented extensively in previous ICCT publications (especially Chambliss et al, 2013). Human exposure to ambient $PM_{2.5}$ varies according to the different policy scenarios, from which we can estimate differences in health impacts under the various scenarios. We then estimate premature mortalities due to primary $PM_{2.5}$ emissions exposure from lung cancer, cardiopulmonary disease, and acute respiratory infection. The health impacts estimates here should be considered highly conservative, since we do not yet model morbidities or exposure to secondary PM or other pollutants including ozone.

Figure 5.3.1 shows normalized estimates of current and future premature mortalities in Guangdong from vehicular primary $PM_{2.5}$ emissions under the four policy scenarios. The 2010 level is set as the normalization point for comparison. Under the Current scenario (China 4/IV and 50 ppm sulfur fuels), premature mortalities drop slightly until 2020, though still higher than 2010. Without additional policy action, the number of premature mortalities will begin to grow again through 2030, with the 2030 value being 60% higher than that in 2010. Implementing China 5/V and 10 ppm standards could reduce 20% of the premature mortalities in the very near term, but mortalities will soon start to increase again after 2017. Much of this increase is driven by expected surging of urban populations in Guangdong. Parallel to the emissions results, only the introduction of the China 6/VI standards can result in large, long-term human health improvements, with premature mortalities decreasing over 45% in 2030 compared to 2010.

Similar to the PM emissions observation, the timing of the introduction of China 5/V has minimal importance when it comes to our estimates of premature mortalities. The reason is because our methodology for estimating health impacts only captures primary particle emissions from on-road vehicles in urban areas. Morbidities and impacts from emissions of other pollutants or secondary PM are not considered. Accordingly, the health impacts results presented here should be considered highly conservative estimates.

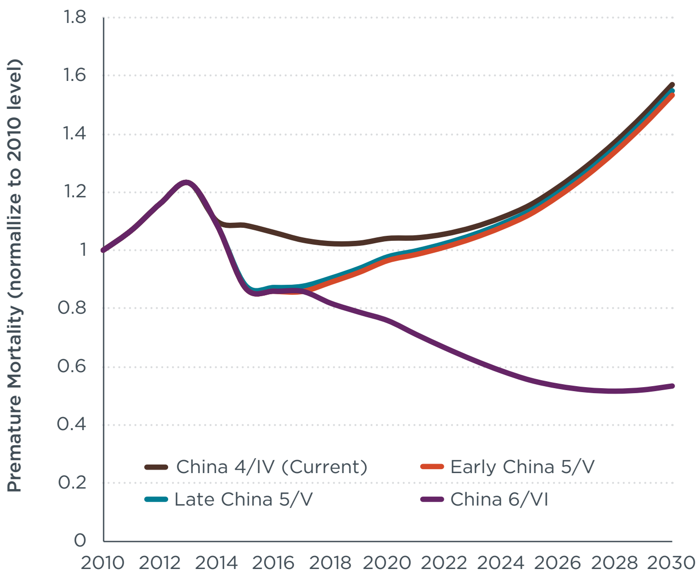

Figure 5.3.1: Premature mortalities from vehicular primary $PM_{2.5}$ emissions in Guangdong, 2010-2030 (normalized to 2010)

Table 5.4.1: Cumulative additional vehicle emission control technology cost over uncontrolled level

	Large Buses	Taxis	Private Cars	Motor-cycles	Light Trucks	Heavy Trucks
Fuel	**Diesel**	**Gasoline**	**Gasoline**	**Gasoline**	**Diesel**	**Diesel**
Euro 1/I*	$158	$142	$142	$29	$150	$174
Euro 2/II*	$210	$204	$204	$35	$200	$232
Euro 3/III*	$683	$326	$326	$51	$650	$752
Euro 4/IV*	$2,727	$351	$351	$51	$2,414	$4,991
Euro 5/V*	$2,958	$361	$361	$54	$2,632	$5,394
Euro 6/VI*	$4,700	$361	$361	$100	$4,190	$9,075

*Costs are summarized as European Standards equivalent.

5.4 Costs

5.4.1 Vehicle technology

We modeled the increased costs associated with the introduction of advanced vehicle emission control technologies required to meet the more stringent emission standards specified in each scenario. Table 5.4.1 summaries the assumed vehicle costs. These numbers are ICCT estimates of cumulative emissions control technology costs over no-control engines across a range of developed and developing countries. The incremental costs associated with additional emissions control technologies vary by fuel type and engine size.

5.4.2 Fuel quality improvement

In addition to vehicle technology costs, we also modeled the increased costs associated with supply of higher quality fuels. Costs include both upfront refinery costs (e.g. capital equipment upgrades) as well as increased operating costs. Considering all costs together on a per-liter basis yields average additional costs of 0.7 U.S cents (0.04 RMB) and 1.7 cents (0.11 RMB) per liter for gasoline and diesel desulfurization, respectively, to reach 10 ppm levels. Further, detailed information about ICCT's desulfurization cost estimates is presented in previous publications (e.g. ICCT, 2012; ICCT, 2014).

5.5 Combined analysis—benefit-cost ratios

In this section, the aforementioned benefits and costs for the various scenarios are compared, in order to evaluate the cost effectiveness of the implementation of more stringent vehicle emissions and fuel quality standards. Here, we examine the cost effectiveness in 2015 of the early introduction of the China 5/V standards, as well as the cost effectiveness in 2030 of the China 6/VI standards.

In this analysis, cost data are customized to better represent Chinese local conditions. For climate benefits, valuation is calculated by using the social cost of carbon. Because carbon dioxide mitigation has global impacts, we adopt the U.S.'s estimation directly in this study (U.S. Government, 2013). For the VSL, which is used for estimating the value of reductions in number of premature mortalities, adjustments were applied by using the 2010 GNIPPP ratio between U.S. and China. Future VSL trend is further adjusted by GDP growth trend.

5.5.1 Early China 5/V standards

The early introduction of the China 5/V standards yields critical near-term emissions reductions and corresponding health and climate benefits. Figure 5.5.1 compares the costs and benefits in 2015 of the Early China V standards scenario vs. the Current (China 4/IV scenario). The total value of the benefits reaches almost 5 billion RMB. For this case, the costs are also significant, though the benefits still outweigh the cost. The net value of the standards in 2015 is estimated at over 1.4 billion RMB.

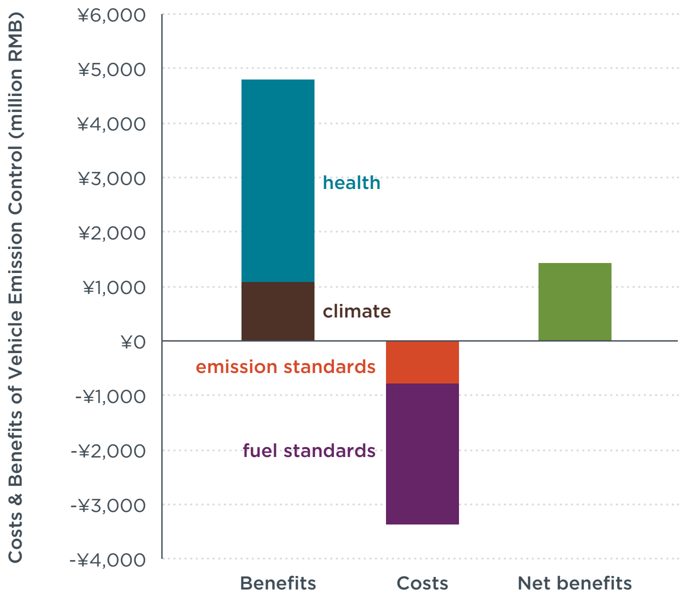

Figure 5.5.1: 2015 costs and benefits of the Early China 5/V scenario in Guangdong (as compared with the Current scenario)

Regarding Figure 5.5.1, it is important to note that the health impacts analysis is very conservative, since it only considers health impacts from primary $PM_{2.5}$ emissions. Most of these emissions come from heavy-duty diesel vehicles, for which the China V PM emission limit is identical to that of China IV. Therefore, the health impacts here appear smaller than perhaps expected. The China 5/V standards will yield multiple other health benefits—include reductions in morbidities as well as health benefits of reductions of secondary PM, NO_2, toxics, ozone, and other pollutants—which are not reflected here.

5.5.3 Early China 6/VI standards

The following charts show the cost-benefit analysis for the China 6/VI standards in 2030. The results show that the introduction of the China 6/VI standards is highly cost-effective, yielding a return within five years of implementation. Dramatic results can be found in Figures 5.5.2 and 5.5.3. The adoption of stringent vehicle emission standards and ultralow sulfur fuels will result in increased costs, but eventually these costs stop growing considerably. In contrast, the benefits, especially the health benefits, continue to grow significantly in the long-term, quickly overtaking the investment. The charts also reflect the fact that the return from China 6/VI standards is rapid and substantial. These enormous benefits dwarf the costs, outweighing them by a factor of about 2.5 to 1 in 2030. If evaluating at even later years beyond 2030, the ratio would grow even higher. Plus, again, due to the limitation of the methodology on health impacts, our estimation on the benefits should be considered very conservative.

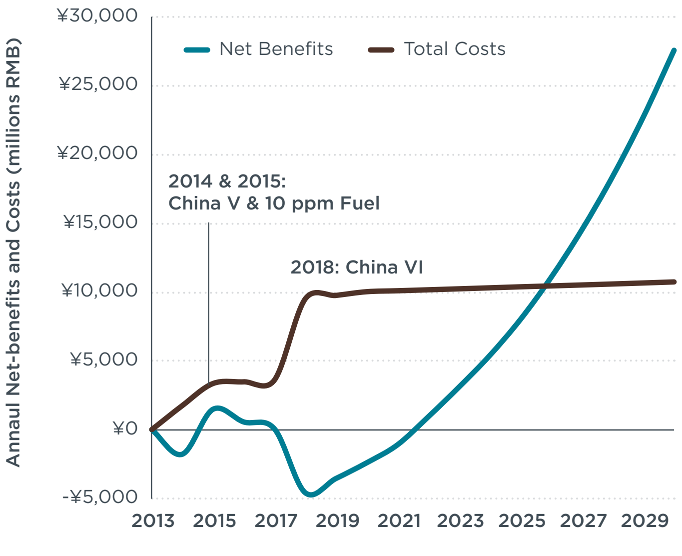

Figure 5.5.2: Annual costs and benefits of the China 6/VI scenario in Guangdong (as compared with Current scenario)

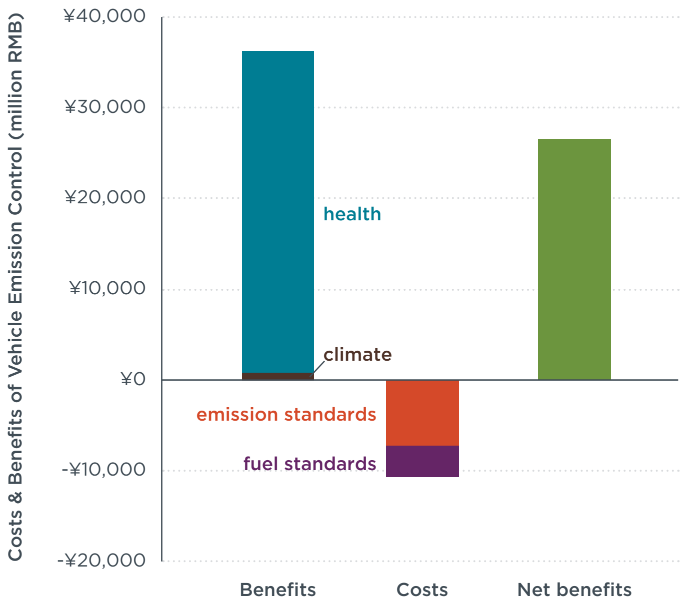

Figure 5.5.3: Total costs and benefits of the China 6/VI scenario in Guangdong (as compared with the Current scenario)

Conclusions and Recommendations

Adopting the China 5/V vehicle standards and lowering fuel sulfur levels are recognized and proven effective approaches for reducing the air pollution burden in Guangdong province. Combined with the scrappage program, which is powerful but transient in reducing emissions, air quality deterioration can be avoided. Improving air quality benefits public health by reducing risk of cardiopulmonary disease, stroke, cancer, and other illnesses and problems. Because the overall cost of these health problems—as valued in terms of premature mortalities, cost of medical treatment, cost of lower productivity, and more—can be significant, improving air quality can deliver enormous value and benefits to a society. Early implementation of China 5/V can guarantee that cost-effective benefits can be achieved much more rapidly.

However, China 5/V cannot prevent long-term increases in vehicle emissions arising from the rapidly growing vehicle population. Only future China 6/VI standards can help Guangdong reduce pollutant emissions in the long-term. The results strongly support the introduction of China 6/VI to greatly improve local air quality. Public health will be concurrently dramatically improved, since the early death rate and the risk of illnesses are reduced. In other words, the average life years for people in Guangdong can be extended. Those impacts will be reflected soon after the introduction of China 6/VI. Furthermore, the introduction of China 6/VI standards are highly cost-effective, with the benefits estimated to outweigh the costs by a ratio of 2.5 to 1.

An investment return will be realized within five years of implementation.

The ICCT strongly supports the early adoption of China 5/V in Guangdong province. The importance has been well demonstrated by the benefits from both air quality and human health. It is also critical for Guangdong to continue moving towards even more stringent tailpipe standards. Only China 6/VI standards can help Guangdong prevent long-term emission growth, and more importantly, human health condition will be significantly improved.

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